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Stark broadening and hfs of Mn II

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Abstract

Large differences between previous calculations of the Mn II spectral line Stark widths [Popović, L.Č., Dimitrijević, M.S., 1997a. A&AS 128, 203; Popović, L.Č., Dimitrijević, M.S., 1997b. SAJ 156, 173] and a recent experiment by [Djeniže, S., Bukvić, S., Srećković, A., Nikolić, Z., 2006. NewA 11, 256] are considered. In order to do so, new semiclassical perturbation calculations of the Stark broadening parameters of three spectral lines within Mn II $3d^54s\ a^7S–3d^54p\ z^7P^o$ and three within Mn II $3d^54s\ a^5S–3d^54p\ z^5P^o$ multiplets, are performed. The influence of hfs on the Stark broadening parameters determination as a possible reason of disagreement is also discussed, on the example of Mn II 260.6455 nm and 259.4497 nm lines. Namely, measured and calculated values taking into account the hfs effect are compared. We found that this effect cannot explain the large discrepancy between experiment and theory. Other possible reasons for disagreement like the configuration interaction are discussed as well. The new semiclassical perturbation calculations, more sophisticated than previous ones, performed by using the modified semiempirical theory, are in better agreement with experiment, but a large difference up to a factor 2.39 for the width, still exist.
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Keywords: Plasma; Line; Profiles

1. Introduction

Ionized manganese lines are of interest for the analysis and modelling of stellar spectra as for example for HgMn stars (see e.g. Wahlgren and Hurbig, 2004; Smith and Dworetsky, 1993). For plasma conditions in such star atmospheres, hydrogen is mainly ionized and Stark broadening is the main pressure broadening mechanism, influencing spectral line shapes. It is shown as well (see e.g. Popović and Dimitrijević, 1996; Popović et al., 2001) that in atmospheres of A stars exist conditions where Stark widths are comparable and even larger than the corresponding thermal Doppler widths. Theoretical data for Stark broadening parameters, spectral line full width at half intensity maximum (FWHM) – W, and shift – d for 16 Mn II multiplets, obtained within the modified semiempirical approach (Dimitrijević and Konjević, 1980; Dimitrijević and Kršljanin, 1986) are given in Popović and Dimitrijević (1997a); Popović and Dimitrijević, 1997b. Stark widths for Mn II $a^5D–z^5P^o$ multiplet, obtained by Dimitrijević (1982) by using the semiclassical theory (Jones et al., 1971; Griem, 1974), the modified semiempirical theory (Dimitrijević and Konjević, 1980) and Griem's semiempirical theory (Griem, 1968) are also given in Popović and Dimitrijević (1997a). Moreover, for Mn II $a^7S– z^7P^o$ multiplet, width and shift, estimated on the basis of Stark broadening parameter dependence on ionized potential from the lower level of the corresponding transition are given in Lakićević (1983).

Recently, Stark broadening widths and shifts for 11 Mn II lines are determined experimentally by Djeniže

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et al. (2006). They found a large disagreement (up to a factor of 5.7) between their experimental and theoretical results of Popović and Dimitrijević (1997a). As possible reasons for such discrepancy they give: (i) "It should be pointed out that the calculations (Popović and Dimitrijević, 1997a) are performed using the modified semiempirical approximation which gives, generally, lower W values than the more sophisticated semiclassical approximation." (ii) "Inclusion of the helium ions, as perturbers, in the sophisticated semiclassical theory may lead to increase of the theoretical Mn II and Mn III Stark width values in helium plasma. Future calculations in this way would be helpful".

An additional problem in the experiment of Djeniže et al. (2006) was the hfs splitting and the authors emphasize that due to large Doppler broadening they had no possibility to monitor Stark broadening of particular hfs component, but only "equivalent light intensity distribution caused by Doppler broadening".

The aim of this paper is to analyze the reasons of disagreement of experimental (Djeniže et al., 2006) and theoretical results (Popović and Dimitrijević, 1997a), assumed in Djeniže et al. (2006). In order to do so, we performed more sophisticated than in Popović and Dimitrijević (1997a), calculations for six Mn II lines, by using the semiclassical perturbation theory (Sahal-Bréchot, 1969a) see also a review of updatings and innovations in (Dimitrijević, 1996). Calculations were also performed for ionized helium impact broadening in order to check the assumption of Djeniže et al. (2006) that this contribution may improve the agreement between experiment and theory. Additionally, we made a detailed analysis of the influence of hfs splitting on the experimental results of Djeniže et al. (2006).

2. The Stark broadening parameter calculation

Calculations have been performed within the semiclassical perturbation formalism, developed and discussed in detail in Sahal-Bréchot (1969a,b). This formalism, as well as the corresponding computer code, have been optimized and updated several times (see e.g. Sahal-Bréchot, 1974; Dimitrijević and Sahal-Bréchot, 1996). A brief review of the calculation procedure, with discussion of updatings and validity criteria is given by Dimitrijević (1996).

Within this formalism, the full width of an ionized emitter isolated spectral line broadened by electron impacts can be expressed in terms of cross sections for elastic and inelastic processes as

$$W_{if} = 2\frac{\lambda_{if}^2}{2\pi c} n_e \int v f(v) \mathrm{d}v \left(\sum_{i' \neq i} \sigma_{ii'}(v) + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_{el} \right) + W_R, \quad (1)$$

and the corresponding line shift as

$$d_{if} = \frac{\lambda_{if}^2}{2\pi c} n_e \int v f(v) \mathrm{d}v \int_{R_3}^{R_D} 2\pi \rho d\rho \sin 2\phi_p. \quad (2)$$

Here λ_{if} is the wavelength of the line originating from the transition with the initial atomic energy level i and the final level f, c is the velocity of light, n_e is the electron density, $f(v)$ is the Maxwellian velocity distribution function for electrons, m is the electron mass, k is the Boltzmann constant, T is the temperature, and ρ denotes the impact parameter of the incoming electron. The inelastic cross-section $\sigma_{jj'}(v)$ is determined according to Chapter 3 in Sahal-Bréchot (1969b), elastic cross-section σ_{el} according to Sahal-Bréchot (1969a), and the contribution of the Feshbach resonances according to Fleurier et al. (1977). The cut-off due to Debye screening – R_D, and the cut-off R_3, included (together with R_1 and R_2 needed for the calculations of the inelastic and elastic cross-sections in Eq. (1)) in order to maintain the unitarity of the $\widehat{S}$-matrix, are described in Section 1 of Chapter 3 in Sahal-Bréchot (1969b). The formulae for the ion-impact broadening parameters are analogous to the formulae for the electron-impact broadening.

The atomic energy levels needed for the calculations were taken from Bashkin and Stoner (1982). Reliable data for Mn II oscillator strengths are scarce (see e.g. http://physics.nist.gov/PhysRefData/ASD/lines_form.html; Toner and Hibbert, 2005; Kling and Griesmann, 2000) and the references therein; (Kling et al., 2001) so that it is not possible to find a sufficiently complete atomic data set (oscillator strengths for all significant perturbing (virtual) transitions). Consequently, in order to obtain a self consistent data set, the oscillator strengths were calculated within the Coulomb approximation (Bates and Damgaard, 1949, and the tables of Oertel and Shomo, 1968), since it is not sure that inclusion of several values from different sources would improve the final results. For higher levels, the method of van Regemorter et al. (1979) was used.

In Table 1, electron-impact broadening parameters (full width at half maximum W and shift d) for 6 Mn II lines for perturber density of 10^{17} cm^{-3} and temperatures from 5000 to 100,000 K, are shown. In order to check the possible influence of configuration interactions on found disagreement between the experiment and theory, the first set of values is calculated with the included estimated maximal contribution of forbidden transitions registered in Bashkin and Stoner (1982). The second set of values, denoted by ($'$), is calculated taking into account only dipoly allowed transitions, as in Popović and Dimitrijević (1997a,b) (also see Dimitrijević and Konjević, 1980).

The ratio of both semiclassical linewidths (W_e and W'_e) and the modified semiempirical Stark width in Popović and Dimitrijević (1997a,b) (Wpd) as a function of temperature is shown in Fig. 1 for Mn II $\lambda = 260.65$ nm line from a ^{7}S–z ^{7}P^o multiplet.

One can see that at the temperature of experiment (49,000 K), the configuration interaction has the influence but can not explain the established difference between experiment and theory. We analyzed also the difference between semiclassical and modified semiempirical results. At low temperatures ($T = 5000$ K), the agreement is within

Table 1
Electron-impact broadening parameters (full width at half maximum W and shift d in [Å]) for 6 Mn II lines for perturber density of 10^{17} cm^{-3} and temperatures from 5000 to 100,000 K

Transition	T (K)	W_e (Å)	d_e (Å)	W'_e (Å)	d'_e (Å)
a ^{7}S–z ^{7}P^o 2606.5 Å	5000	0.125	−0.777E−02	0.142	0.913E−04
	10000	0.967E−01	−0.631E−02	0.103	−0.816E−03
	20000	0.739E−01	−0.528E−02	0.746E−01	−0.917E−03
	30000	0.638E−01	−0.450E−02	0.626E−01	−0.773E−03
	50000	0.552E−01	−0.431E−02	0.520E−01	−0.992E−03
	100000	0.483E−01	−0.389E−02	0.436E−01	−0.983E−03
a ^{7}S–z ^{7}P^o 2594.5 Å	5000	0.128	0.236E−03	0.141	0.924E−04
	10000	0.948E−01	−0.996E−03	0.102	−0.756E−03
	20000	0.702E−01	−0.116E−02	0.740E−01	−0.858E−03
	30000	0.598E−01	−0.956E−03	0.621E−01	−0.726E−03
	50000	0.507E−01	−0.128E−02	0.516E−01	−0.924E−03
	100000	0.435E−01	−0.118E−02	0.433E−01	−0.921E−03
a ^{5}S–z ^{5}P^o 2576.9 Å	5000	0.130	0.719E−03	0.139	0.943E−04
	10000	0.937E−01	−0.401E−03	0.101	−0.669E−03
	20000	0.680E−01	−0.446E−03	0.732E−01	−0.771E−03
	30000	0.571E−01	−0.310E−03	0.614E−01	−0.658E−03
	50000	0.475E−01	−0.492E−03	0.511E−01	−0.824E−03
	100000	0.398E−01	−0.422E−03	0.429E−01	−0.830E−03
a ^{5}S–z ^{5}P^o 2933.9 Å	5000	0.184	0.626E−03	0.174	−0.574E−03
	10000	0.136	−0.169E−02	0.129	−0.238E−02
	20000	0.101	−0.202E−02	0.959E−01	−0.244E−02
	30000	0.863E−01	−0.159E−02	0.822E−01	−0.198E−02
	50000	0.740E−01	−0.233E−02	0.706E−01	−0.268E−02
	100000	0.642E−01	−0.192E−02	0.613E−01	−0.245E−02
a ^{5}S–z ^{5}P^o 2940.2 Å	5000	0.185	0.617E−03	0.175	−0.604E−03
	10000	0.136	−0.174E−02	0.129	−0.244E−02
	20000	0.101	−0.207E−02	0.963E−01	−0.250E−02
	30000	0.866E−01	−0.162E−02	0.825E−01	−0.202E−02
	50000	0.743E−01	−0.238E−02	0.709E−01	−0.274E−02
	100000	0.644E−01	−0.197E−02	0.615E−01	−0.250E−02
a ^{5}S–z ^{5}P^o 2950.1 Å	5000	0.226	−0.394E−01	0.176	−0.653E−03
	10000	0.165	−0.302E−01	0.130	−0.253E−02
	20000	0.121	−0.234E−01	0.969E−01	−0.258E−02
	30000	0.102	−0.193E−01	0.830E−01	−0.209E−02
	50000	0.884E−01	−0.168E−01	0.713E−01	−0.282E−02
	100000	0.800E−01	−0.137E−01	0.619E−01	−0.257E−02

The first set of values is calculated with the included estimated maximal contribution of forbidden transitions registered in Bashkin and Stoner (1982). The second set of values, denoted by ′, is calculated taking into account only dipole allowed transitions.

the error limit of both theories and is better when the configuration interaction is not included (see also Table 5 in Popović and Dimitrijević, 1997a). At the temperature of 50,000 K, close to the experimental one, the ratio of semiclassical and modified semiempirical results is around two and the disagreement between experimental and theoretical values is smaller but still very large. We note here that for simple emitters like He I or Li II, the accuracy of semiclassical results is ±20%, while for complex spectra like the Mn II one errors are much larger. For the modified semiempirical approach an average accuracy for simpler spectra is ±50%, but for particular transitions and for complex spectra these uncertainties might be much larger.

In Table 2, full width at half maximum (W) and shift (d) due to collisions with protons (p) and helium ions (He II) for perturber density of 10^{17} cm^{-3} and temperatures from 5000 to 100,000 K, are shown. The validity of the impact approximation was estimated for data shown in Tables 1 and 2, by checking if the collision volume (V) multiplied by the perturber density (N) is much less than one (Sahal-Bréchot, 1969a,b), and for all shown values, even for He II collisions the product $N \times V$ is less than 0.1 and the impact approximation is valid not only for electrons but also for ions. When the impact approximation is not valid, the ion broadening contribution may be estimated by using the quasistatic approach (Sahal-Bréchot, 1991, or Griem, 1974). We calculated also the quasistatic ion broadening parameter A defined in Griem (1974) but the obtained values are, as expected, too small and out of limits of validity for quasistatic approach. One can see in Tables 1 and 2, that proton-impact contribution to the width is one order of magnitude smaller than electron-impact one and its inclusion cannot explain the difference between experiment and theory.

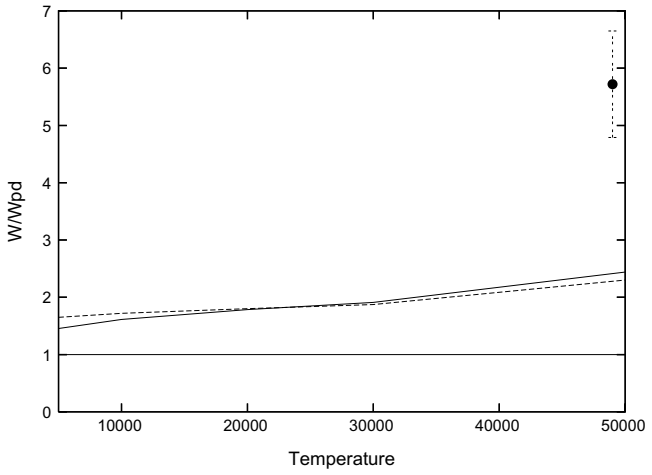

Fig. 1. The semiclassical perturbation (W_e/Wpd-solid line and W'_e/Wpd-dashed line) Stark widths with and without configuration interaction scaled to the modified semiempirical Stark width in Popović and Dimitrijević (1997a,b) (Wpd-solid horizontal line) as a function of temperature, for Mn II $\lambda = 260.65$ nm line from the a ^{7}S–z ^{7}P^o multiplet. The ratio between the experimental width and Wpd is presented as a full circle with denoted error bars.

In Table 3, our calculations are compared with experimental results in Djeniže et al. (2006). One can see that one part of disagreement may be explained by more sophisticated, semiclassical perturbation calculations, inclusion of configuration mixing and proton-impact broadening, but the disagreement of up to a factor of 2.39 for the width is still large.

As one can see from Table 3, also large differences between experimental and theoretical Stark shifts exist. Note here that the theoretical determination of shifts may be more complicated. Namely, while particular contribution to the width are positive, they are with different signs for the shifts and due to mutual cancellations of principal contributions, much smaller final result may be of lower accuracy than for width. So the error bars of width result are also valid for the shift. Here we have just the case where shift values are one order of magnitude lower than width ones and theoretical determinations of such small shifts are uncertain.

3. The influence of the hyperfine structure-hfs

Due to the hfs splitting of lines in Mn II spectra, one can expect complex line profiles (Booth and Blackwell, 1983; Holt et al., 1999; Blackwell-Whitehead et al., 2005; Djeniže et al., 2006). In Djeniže et al. (2006) was noted that they could not measure the hfs components, but only the whole line profile due to Doppler width. Here, we will consider how much the hfs splitting can affect the measured Doppler and Lorentz line widths. Note here, that all hfs components of a line should be with the same Lorentz and Doppler widths which are caused by the conditions in the plasma.

First we simulated numerically the case where the Lorentzian (W_L) and Doppler (W_D) widths are the same, but taking different ratios between the widths and hfs splitting ($W_{L,D}/D_{hfs}$), assuming only two components in hfs. We calculated the sum of the two components and after that fit the total profile with Voigt function. As one can see in Fig. 2, this effect can lead to significant differences in the estimation of widths, but only in the case where $W_{L,D}/D_{hfs} < 3$. In the case where $W_{L,D}/D_{hfs} > 3$ this effect is negligible (the differences between measured widths of components and composite profiles are a few percentage). It is interesting that in the first case, the Doppler width can be overestimated in difference with the Lorentz width that is underestimated.

Furthermore we performed a test where we fitted the composite line profile assuming that $W_D^{fit} = W_D/2$ is fixed, i.e. underestimating Doppler width. We found that for $W/D_{hfs} < 2.5$ the line cannot be well fitted, but for $W/D_{hfs} > 2.5$, one can obtain a relatively good fit (see Fig. 3, where $W/D_{hfs} = 3$), however in this case the Lorentz width is overestimated. In the case shown in Fig. 3, from the best fit we obtained that W_L is larger around 25% than one included in each component.

To demonstrate the previous test on the real cases, we will consider here Mn II 260.6459 nm and 259.4497 nm lines, where the hfs components are measured and given in Blackwell-Whitehead et al. (2005). Blackwell-Whitehead et al. (2005) found 14 hfs components of Mn II 260.6459 nm and 16 hfs components of Mn II 259.4497 nm (see Table 6 in their paper). First we simulate the sum of these two hfs components and after that, using χ^2 minimization, we found the Doppler and Lorentz width from the line obtained after summation of these components.

The Stark width of the line is measured by Djeniže et al. (2006) and also has been calculated by Popović and Dimitrijević (1997a). As was mentioned in Djeniže et al. (2006) there is a big disagreement between the measured and calculated values ($W_m/W_{th} = 5.72$ and 5.44, respectively). In order to simulate the influence of the hfs to the line profile, in this case we adopted the Doppler width given by Djeniže et al. (2006) and Stark widths (W_{st}) given by Popović and Dimitrijević (1997a). First, we assume that all of the profiles have the same widths (W_L and W_D), and after summation of the hfs components we obtained a composite profile (see Fig. 4). After that we fitted the composite profile with a Voigt one. From the best fit we obtain W_L and W_D. We found that the Doppler width is slightly larger (around 5%) and Lorentz one is slightly smaller (around 2%) than originally included in each component. Note, here that the influence of hfs can affect the line shifts. In the considered cases for Mn II 260.6459 nm it is negligible, but for Mn II 259.4497 nm we found $d_{hfs} = +1.6$ pm, which is an order of magnitude of measured and calculated Stark shift for this line (see Fig. 5).

In order to explain such big difference we analyzed also Doppler widths from Table 1 given in Djeniže et al. (2006) and found that they are very close (slightly smaller) than those expected for thermal broadening at $T = 49{,}000$ K, which can be calculated as (see Konjević, 1999)

Table 2
Full width at half maximum (W) and shift (d) in [Å] due to collisions with protons (p) and helium ions (He II) for perturber density of 10^{17} cm^{-3} and temperatures from 5000 K to 100,000 K

Transition	T (K)	W_{p+} (Å)	d_{p+} (Å)	W_{HeII} (Å)	d_{HeII} (Å)
a ^{7}S–z ^{7}P^o 2606.5 Å	5000	0.207E−02	−0.398E−03	0.309E−02	−0.392E−03
	10000	0.383E−02	−0.829E−03	0.481E−02	−0.768E−03
	20000	0.554E−02	−0.140E−02	0.634E−02	−0.121E−02
	30000	0.636E−02	−0.170E−02	0.686E−02	−0.148E−02
	50000	0.702E−02	−0.215E−02	0.748E−02	−0.175E−02
	100000	0.790E−02	−0.258E−02	0.821E−02	−0.211E−02
a ^{7}S–z ^{7}P^o 2594.5 Å	5000	0.205E−02	−0.169E−03	0.308E−02	−0.169E−03
	10000	0.379E−02	−0.368E−03	0.478E−02	−0.355E−03
	20000	0.547E−02	−0.669E−03	0.629E−02	−0.614E−03
	30000	0.625E−02	−0.868E−03	0.678E−02	−0.744E−03
	50000	0.688E−02	−0.111E−02	0.738E−02	−0.953E−03
	100000	0.770E−02	−0.139E−02	0.807E−02	−0.115E−02
a ^{5}S–z ^{5}P^o 2576.9 Å	5000	0.205E−02	−0.710E−04	0.307E−02	−0.709E−04
	10000	0.377E−02	−0.157E−03	0.475E−02	−0.155E−03
	20000	0.543E−02	−0.308E−03	0.624E−02	−0.287E−03
	30000	0.620E−02	−0.415E−03	0.673E−02	−0.376E−03
	50000	0.682E−02	−0.552E−03	0.732E−02	−0.485E−03
	100000	0.761E−02	−0.755E−03	0.801E−02	−0.615E−03
a ^{5}S–z ^{5}P^o 2933.9 Å	5000	0.328E−02	−0.324E−03	0.482E−02	−0.321E−03
	10000	0.585E−02	−0.691E−03	0.730E−02	−0.657E−03
	20000	0.829E−02	−0.123E−02	0.931E−02	−0.109E−02
	30000	0.929E−02	−0.151E−02	0.101E−01	−0.133E−02
	50000	0.102E−01	−0.195E−02	0.109E−01	−0.163E−02
	100000	0.114E−01	−0.239E−02	0.119E−01	−0.195E−02
a ^{5}S–z ^{5}P^o 2940.2 Å	5000	0.329E−02	−0.331E−03	0.482E−02	−0.328E−03
	10000	0.586E−02	−0.705E−03	0.732E−02	−0.670E−03
	20000	0.830E−02	−0.125E−02	0.933E−02	−0.111E−02
	30000	0.931E−02	−0.154E−02	0.101E−01	−0.135E−02
	50000	0.102E−01	−0.198E−02	0.110E−01	−0.166E−02
	100000	0.114E−01	−0.243E−02	0.119E−01	−0.199E−02
a ^{5}S–z ^{5}P^o 2950.1 Å	5000	0.335E−02	−0.108E−02	0.488E−02	−0.104E−02
	10000	0.601E−02	−0.209E−02	0.743E−02	−0.192E−02
	20000	0.860E−02	−0.325E−02	0.953E−02	−0.285E−02
	30000	0.971E−02	−0.400E−02	0.103E−01	−0.335E−02
	50000	0.108E−01	−0.468E−02	0.113E−01	−0.387E−02
	100000	0.123E−01	−0.567E−02	0.124E−01	−0.462E−02

Table 3
The comparison of experimental (Djeniže et al., 2006) Stark widths W_m and shifts d_m with theoretical ones (W_{PD}, d_{PD} – Popović and Dimitrijević, 1996)

Transition	W_m (Å)	d_m (Å)	$\frac{W_m}{W_{PD}}$	$\frac{d_m}{d_{PD}}$	$\frac{W_m}{W_e}$	$\frac{d_m}{d_e}$	$\frac{W_m}{W_e+W_i}$	$\frac{d_m}{d_e+d_i}$
3d^5(^{6}S)4s–3d^5(^{6}S)4p a ^{7}S–z ^{7}P^o 2606.5 Å	0.192	−0.012	5.72	1.50	2.67	2.00	2.34	1.50
3d^5(^{6}S)4s–3d^5(^{6}S)4p a ^{7}S–z ^{7}P^o 2594.5 Å	0.182	−0.008	5.44	1.00	2.76	4.00	2.39	2.67
3d^5(^{6}S)4s–3d^5(^{6}S)4p a ^{5}S–z ^{5}P^o 2933.9 Å	0.212	−0.030	4.36	2.68	2.19	10.00	1.91	6.00
3d^5(^{6}S)4s–3d^5(^{6}S)4p a ^{5}S–z ^{5}P^o 2940.2 Å	0.158	−0.020	3.28	1.80	1.63	6.67	1.42	4.00
3d^5(^{6}S)4s–3d^5(^{6}S)4p a ^{5}S–z ^{5}P^o 2950.1 Å	0.208	−0.026	4.28	2.32	1.80	1.18	1.60	0.96

W_e, d_e-present calculations, electron-impact broadening; W_{e+i}, d_{e+i}-present calculations, electron + ion impact broadening.

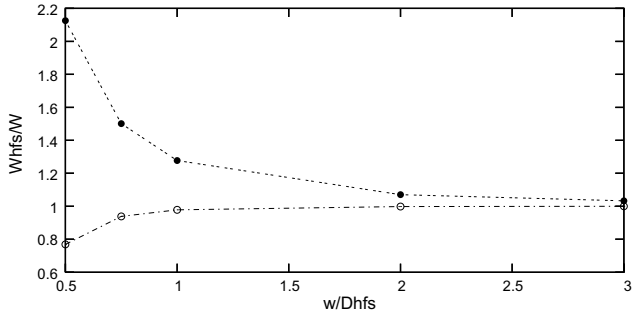

Fig. 2. The ratio between the real widths of the hfs components W_{hfs} and determined ones fitting the composite profile (W_{D} is denoted with full, and W_{L} with open circles) from the composite profile, for different ratios of $W_{\mathrm{L,D}}/D_{\mathrm{hfs}}$ (where D_{hfs} is hfs splitting between two hfs components). The Lorentz and Doppler widths are taken to be the same for each component.

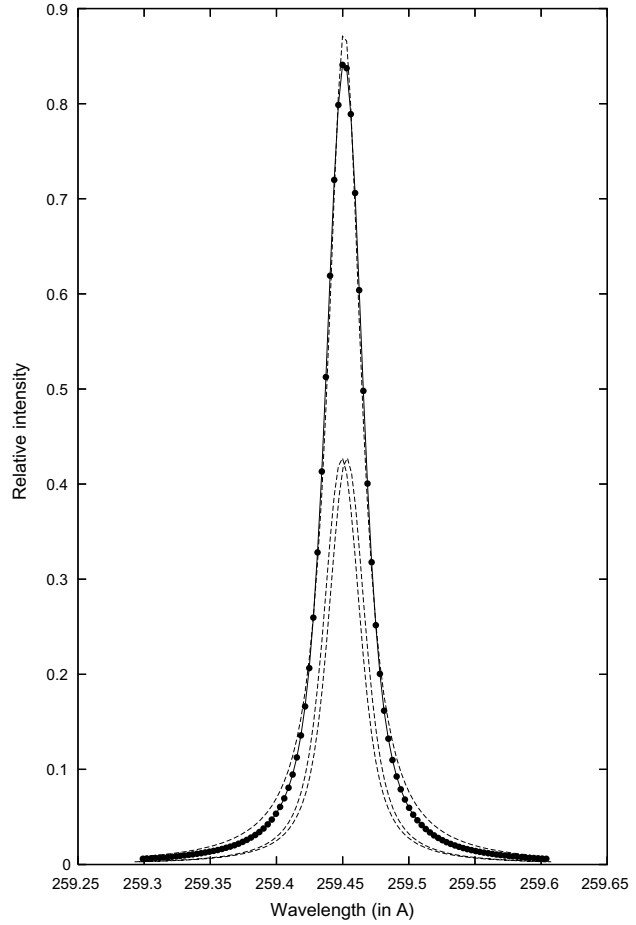

Fig. 3. The composite profile (dots) of two hfs components (dashed lines within composite profile) where $W/D_{\mathrm{hfs}} = 3$. Solid line presents the best fit where W_{L} and W_{D} are taken as a free parameter and dashed line the fit where the Doppler width is underestimate and fixed to $W_{\mathrm{D}}/2$, that leads to the larger Lorentz width measurements around 25% than it is originally taken in each component.

$$W_{\mathrm{d}} = 7.16 \cdot 10^{-7} \cdot \lambda_0 \sqrt{\frac{T}{M(\mathrm{au})}}$$

where M is the atomic mass of Mn ($M = 54.938$ au).

On the other hand, the instrumental width should be additionally present and it might be that the Doppler width in the fitting procedure of experimental lines is underestimated. Consequently, we performed a test to fit the composite line profile of Mn II 259.4497 nm fixing Doppler width. We took that in composite profile the Doppler width is $0.7 \cdot W_{\mathrm{D}}$ and $0.9 \cdot W_{\mathrm{D}}$ (where W_{D} is the width of each component). Note here that these values are close to the ratio between expected (see Section 3 in Djeniže et al., 2006) of 7.6 pm and obtained from fit (presented in Table 1) of 6.3 pm. As one can see in Fig. 6, one can obtain a relatively good fit with underestimated value of the Doppler width, but in this case we obtained that W_{L} is overestimated around 50% and 30% for $0.7 \cdot W_{\mathrm{D}}$ and $0.9 \cdot W_{\mathrm{D}}$, respectively.

At the end, an additional test have been performed, assuming that in the case of Mn II 259.4497 nm line, each component has the Doppler width (FWHM) of 9.7 pm and Stark of 2.8 pm. Then we fixed Doppler FWHM as 5.5 pm (around 1.7 times smaller than taken in each component) and fit the composed line profile. From the fit, we obtained that Stark width is overestimated around 2.4 times. But as can be seen in Fig. 6, there is disagreement between the best fit (solid line in the Fig. 6) and composite profile (dots in the figure) only in the wings, i.e. the part of profile with intensity smaller than 10% of maximal intensity (dashed horizontal line in the figure, solid horizontal line represents 5% of maximal intensity). Therefore, one can conclude that in the case where the line wings in experiment are not well defined/measured (e.g. a big noise in line wings), it may significantly affect the measured Stark widths.

As it can be seen from tests performed above, there is possibility that the Lorentz contribution (as well as Doppler) to the composite line profile in the case of hfs can be overestimated (underestimated). The effects of hfs on measured value of Stark width in the experiment of Djeniže et al. (2006) might be present. Consequently, a part of disagreement between theoretical and measured Stark broadening parameters might be due to this effect, but the question of such big differences between measured (Djeniže et al., 2006) and calculated values of Stark width (~2.4 in the case of semiclassical approach – this paper and 5.72 – previous MSE calculation Popović and Dimitrijević, 1997a) stay open.

4. Conclusion

In order to discuss a big disagreement between measured Stark widths given in Djeniže et al. (2006) and MSE calculations by Popović and Dimitrijević (1997a,b), here we recalculated the Stark widths and shifts for 6 Mn II lines with more sophisticated semiclassical approach. Also, we tested the influence of hfs structure on the Stark width measurement. From our investigation one can conclude:

(i) The SC theory gives larger widths than MSE, and consequently the calculated values of Stark widths

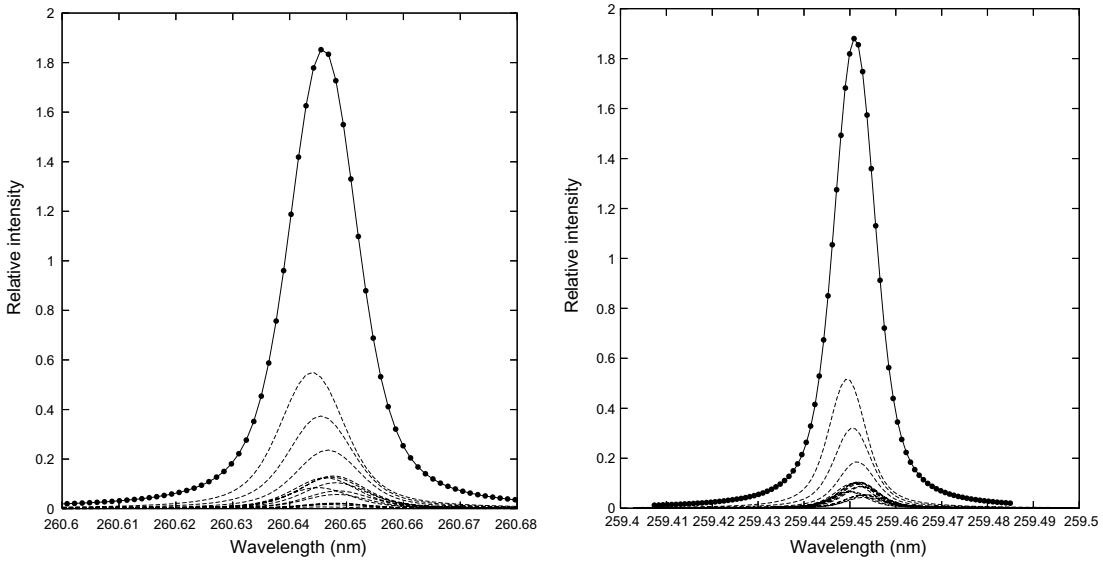

Fig. 4. The hfs components (dashed line, below), their sum (full circles) and the best fit with the common Voigt profile (solid line) for Mn II 260.6459 nm (left) and 259.4497 nm (right). The intensity ratio of components is taken from Table 6 given in Blackwell-Whitehead et al. (2005).

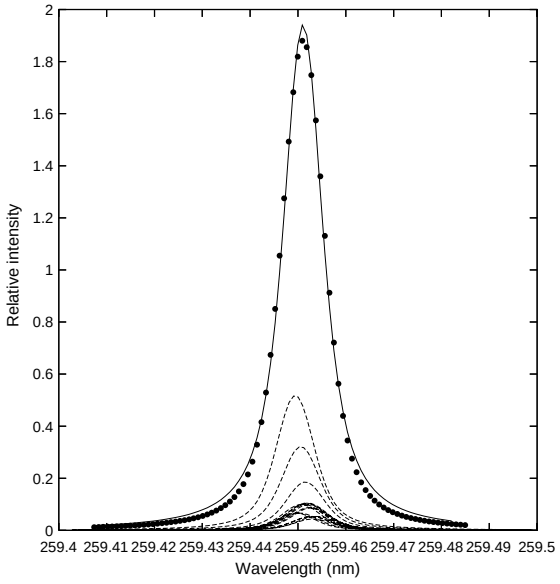

Fig. 5. The best fit for Mn II 259.4497 nm line where the Doppler width was fixed as 70% of the value included in the each hfs component (bottom).

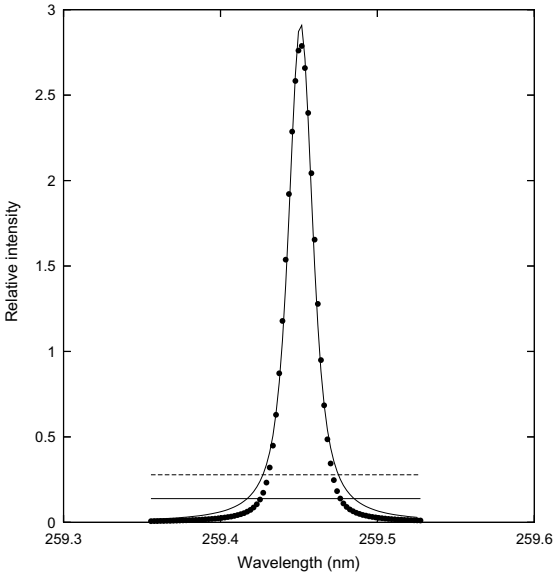

Fig. 6. The best fit of composite line profile of Mn II 259.4497 nm where the Stark width is obtained as 2.4 times larger than was taken in each component. The horizontal lines represent the intensity at 10% (dashed line) and 5% (solid line) of maximal intensity.

are in better agreement with experimental ones given in Djeniže et al. (2006), but agreement between experiment and theory ($W_{exp}/W_{th} \approx 1.63$–$2.76$) is still not good.

(ii) The inclusion of proton-impact contribution, and configuration interaction effects could not explain the difference between experiment and theory ($W_{exp}/W_{th} \approx 1.42$–$2.39$).

(iii) The hfs effects can affect measured value of Stark widths, especially if the Doppler contribution is underestimated in fitting procedure of the composite line profile. In this case the Stark width can be significantly overestimated (e.g. Mn II 259.4497 nm), especially if the wings of measured line are with big noise.

At the end, let us stress that new measurements of Stark broadening parameters for Mn II lines are needed, especially in the plasma with lower temperature in order to explain such big differences between the experimental and theoretical values. Especially, taking into account that there are a few cases where such large differences between

theory and experiment are present (see e.g. Konjević et al., 2002).

Acknowledgements

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References

Bashkin, S., Stoner, J.O., 1982. Atomic energy levels and Grotrian diagrams, Vol. IV, Manganese, I–XXV, North Holland, Amsterdam.
Bates, D.R., Damgaard, A., 1949. PTRSL 242, 101.
Blackwell-Whitehead, R.J., Toner, A., Hibbert, A., Webb, J., Ivarsson, S., 2005. MNRAS 364, 705.
Booth, A.J., Blackwell, D.E., 1983. MNRAS 204, 777.
Dimitrijević, M.S., 1982. In: Fricke, W., Teleki, G. (Eds.), Sun and Planetary System. D. Reidel P.C., p. 101.
Dimitrijević, M.S., 1996. Zh. Priklad. Spektrosk. 63, 810.
Dimitrijević, M.S., Konjević, N., 1980. JQSRT 24, 451.
Dimitrijević, M.S., Kršljanin, V., 1986. A&A 165, 269.
Dimitrijević, M.S., Sahal-Bréchot, S., 1996. PhyS 54, 50.
Djeniže, S., Bukvić, S., Srećković, A., Nikolić, Z., 2006. NewA 11, 256.
Fleurier, C., Sahal-Bréchot, S., Chapelle, J., 1977. JQSRT 17, 595.
Griem, H.R., 1968. Phys. Rev. 165, 258.
Griem, H.R., 1974. Spectral Line Broadening by Plasmas. McGraw-Hill, New York.
Holt, R.A., Scholl, T.J., Rosner, S.D., 1999. MNRAS 306, 107.
Jones, W.W., Benett, S.M., Griem, H.R., 1971. Univ. of Maryland, Techn. Rep. No. 1971-128, College Park, MD.
Konjević, N., 1999. PhR 316, 339.
Kling, R., Griesmann, U., 2000. ApJ 531, 1178.
Kling, R., Schnabel, R., Griesmann, U., 2001. ApJS 134, 173.
Konjević, N., Lesage, A., Fuhr, J.R., Wiese, W.L., 2002. J. Phys. Chem. Ref. Data 31, 820.
Lakićević, I.S., 1983. A&A 127, 37.
Oertel, G.K., Shomo, L.P., 1968. ApJ 136, 906.
Popović, L.Č., Dimitrijević, M.S., 1996. A&AS 120, 373.
Popović, L.Č., Dimitrijević, M.S., 1997a. A&AS 128, 203.
Popović, L.Č., Dimitrijević, M.S., 1997b. SAJ 156, 173.
Popović, L.Č., Simić, S., Dimitrijević, M.S., Milovanović, N., 2001. A&AS 135, 109.
Sahal-Bréchot, S., 1969a. A&A 1, 91.
Sahal-Bréchot, S., 1969b. A&A 2, 322a.
Sahal-Bréchot, S., 1974. A&A 35, 321.
Sahal-Bréchot, S., 1991. A&A 245, 322.
Smith, K.C., Dworetsky, M.M., 1993. A&A 274, 335.
Toner, A., Hibbert, A., 2005. MNRAS 361, 673.
van Regemorter, H., Hoang Binh Dy, Prud'homme, M., 1979. J. Phys. B 12, 1073.
Wahlgren, G.M., Hurbig, S., 2004. A&A 418, 1073.

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Kinematics of the broad absorption line region in QSOs: Rotation and random motion

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ABSTRACT

Assuming that the Broad Absorption Line Region – BALR (originated in a disk wind) is composed of a number of successive independent absorbing density layers, which have apparent rotational and radial velocities and where ions have random velocities, we applied a model in order to obtain the kinematical parameters of BALR, by fitting the broad absorption lines. The model can be easily used in fitting the observed absorption lines, providing us with basic kinematical parameters of BALR (random, rotational and radial velocities). Fitting broad absorption lines of several BALQSOs observed with the HST we discuss the fraction of the rotation and random motion in the BALR. Moreover, using the obtained parameters from the best fit we discuss the general characteristics of the BALR which are in support of the disk wind origin of the region.

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1. Introduction

Approximately about 10% of all quasars are with broad, blue-shifted absorption lines. The outflow velocity can reach up to 0.1–0.2 c. Usually, in their spectra the high ionization species as C IV λ1549, Si IV λ1397, N V λ1240 and Lyα lines have been observed. Rarely some low ionization lines, such as Mg II λ2798 and Al III λ1857, also exhibit broad absorption lines (see e.g. Hamann et al., 1993; Crenshaw et al., 2003). Broad absorption lines can have different shapes. Also different types of these objects may have differences in their continua (Reichard et al., 2003).

A fundamental issue in the study of the BALR is to determine their geometry and origin. No compelling evidence in favor of a specific picture exists, and the uncertainty in these issues is hampering our attempts to obtain a complete physical model for the flows. One of the wide accepted models is that of a disk wind creating the BALR (see e.g. de Kool and Begelman, 1995; Murray and Chiang, 1995; Proga, 2003; Proga and Kallman, 2004). The natural origin of the ejected material is a disk wind that can explain the prevalence of detached and multi absorption components seen in the BALRs. The disk wind model for BALQSOs has been proposed (see Murray and Chiang, 1998; Elvis, 2000; Proga et al., 2000; Proga, 2003; Proga and Kallman, 2004 and references therein), considering that a wind from an accretion disk is shielded from highly ionized gas ($U \sim 10$) which has a high column density ($\sim 10^{23}$ cm^{-2}) in soft X-rays.

The spectrum of a Broad Absorption Line Quasar (BALQSO) is usually interpreted as a combination of (i) a broadband continuum arising from the central engine, (ii) the broad emission lines coming from the Broad Emission Line Region (BELR), emerging near the center of the QSO and (iii) the broad absorption lines that are superposed, originating in a separate outlying region – Broad Absorption Line Region (BALR). But, it is also possible, that line emission and absorption occur in the same line-forming region (Branch et al., 2002). An important question is: Which are the physical connections between the BLR and BALR? This is also important, since at least a part of the BLR seems to be originated from wind of accretion disk (see Murray and Chiang, 1998; Popović et al., 2004). Additionally, one question is: Where is placed the BALR with respect to the center of a BALQSO and the Broad Line Region? To answer this question, one should investigate the kinematical properties of the emission and absorption lines.

The aim of this paper is to investigate kinematical properties of the BALR using a relatively simple model (see Danezis et al., 2007, this issue) that is able to calculate all expected velocities of the absorbing gas and may indicate the location of the BALR. In Sec-

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tion 2 we shortly present the model, in Section 3 we apply the model to the UV spectral lines of several BALQSOs observed with the HST and discuss obtained results and finally in Section 4 the conclusions are given.

2. Theoretical models of BALR

The scattering of resonance-line photons can provide the radiative acceleration that at least partially drives BAL outflows (Arav et al., 2001). The difficulty arises in accelerating the gas to quite large velocities without completely stripping the resonance-line absorbing ions of their electrons. The disk wind model of Murray and Chiang (1998) and references therein has been very successful in explaining this and other properties of BAL quasars. In this model, a wind from an accretion disk is shielded from soft X-rays by a high column density ($N_H \sim 10^{23}$ cm^{-}2) of highly ionized gas ($U \approx 10$).

The quasar structure proposed by Elvis (2000) also assumed a disk wind, but from a narrow range of radii, such that BAL quasars are only observed when the line-of-sight is directly aligned with the wind (Crenshaw et al., 2003). A recent summary of theoretical and computational modeling of disk winds can be found in Proga et al. (2000). Some BAL quasars, particularly LoBALs, may be quasars cocooned by dust and gas rather than quasars with disk winds (Becker et al., 2000), but the only serious modeling relevant to this alternative has been the work of Williams et al. (1999).

It is clear that BAL quasars remain an active area of research. Disk wind models explain many properties of BAL quasars, but it is unclear if they can explain the full range of BAL trough profiles and column densities.

2.1. GR model – Stellar vs. quasar complex absorption lines

Hot stars with emission lines (Oe and Be) show similar phenomena in their spectra (see Fig. 1). Beside the P-Cyg profile that indicates stellar wind, *there are also the so called Discrete Absorption Components – DACs (*Bates and Halliwell, 1986*) or Satellite Absorption Components – SACs (see* Danezis et al. (2003) *and* Danezis et al. (2007, this issue)*). These components indicate some combination of stellar wind with (apparent) spherical density regions that may lie in the disc around the stars.These density regions may have the form of shells, blobs or puffs.* As a result in spectra of Oe and Be stars a number of lines, also detected in spectra of BALQSO, have very complex line profiles. In some cases the line shapes of quasars and hot emission stars are very similar (see e.g. Danezis et al., 2006). As one can see in Fig. 1, the C IV UV doublet of PG 0946+301 (up) and star HD 45910 (down) show similar phenomena, i.e in both objects there is a blue-shifted component that indicates ejection of matter. *It seems that the absorbing regions in hot emission stars and quasar present very similar spectroscopic phenomena*, but with different velocity scales, i.e. in the case of a star the velocity of the wind is around several hundreds kilometers/seconds, but in the case of a quasar it is one order magnitude higher. This motivated us to apply a model developed to investigate kinematics of regions creating DACs and SACs in hot stars (in more details see Danezis et al., 2007) to BAL of quasars *in order to study the kinematical parameters of BALR.*

Based on this idea, we assumed that the BALR and BELR are composed of a number of successive independent absorbing/emitting density layers of matter (that are originated in a disk wind), which have apparent rotational and radial velocities and where ions have random velocities.

Here we will start from the point that absorbing region has three apparent velocities (projected on the line-of-sight of an observer); (i) velocity of outflow, (ii) random velocity in the BALR and (iii) possible rotational velocity, since BALR should be affected by super-massive black hole.

Note here that random motion can be related to the motion of ions, but also, as it is often considered in the case of BELR, it can be related to clouds of gas moving in orbits with different inclinations and eccentricities. In principle, in BELR it can be considered, since we expect that the BELR is composed from a number of emitting clouds, but in the case of BALR, we expect that we have ejected stream of matter that absorbs in a line (which is shifted to the blue) and this effect of randomly distributed clouds should be significantly smaller than in the case of BELR. But such effects probably exist, at least as the differential rotational velocity projected to the line-of-sight of a stream of ejected matter. Since we extract the kinematical parameters from line profile, taking into account this effect, we are able only to give estimates for rotation and random velocities (i.e. maximal and minimal values of the velocities).

2.2. BAL profile simulations using the model

Using the GR model (Lyratzi and Danezis, 2004; Danezis et al., 2007, this issue), first we simulate different line profiles. As one can see in Figs. 2 and 3, the model can very well reproduce the complex line shapes observed in BALQSOs. As it was mentioned above, the aim of the paper is to investigate contribution of the rotational component to broad absorption lines and location of this region with respect to the BELR. In order to simulate different position of the BALR and BELR, using the model, we simulated four cases taking (see Fig. 2):

(a) The BELR is covered by BALR and the random velocity in the BALR is dominant ($V_{rand}/V_{rot} = 10$, Fig. 2a).
(b) The BALR is covered by BELR and the random velocity is the same as in the case (a), see Fig. 2b.
(c) The BELR is covered by BALR and the rotational velocity in the BALR is dominant, see Fig. 2c.
(d) The BALR is covered by BELR and the rotational velocity in the BALR is dominant, see Fig. 2d.

In Fig. 2, we simulated a composed line profile, where we assume that we have one emitting region (with only random motion FWHM = 2000 km/s) and two absorbing regions with $V_{rad1} = -2000$ km/s and $V_{rad2} = -1000$ km/s, and different values of $V_{rand} = 2000$ km/s and $V_{rot} = 200$ km/s (Fig. 2a and b) and $V_{rand} = 200$ km/s and $V_{rot} = 2000$ km/s (Fig. 3a and b). Also we assume that BELR is covered by BALR (Fig. 2a and c) and vice versa (Fig. 2b and d).

As one can see from Fig. 2, even if one uses the same kinematical parameters for the BALR and BELR, the profiles can be significantly different for different cases mentioned above. But we can note some similarities, e.g. in the case where BALR is covered by BELR, the emission component of the line is more intensive (in both cases where V_{rot} or V_{rand} is dominant) than in the case when BELR is covered by BALR.

On the other hand, in the case where random motion is dominant ($V_{rand}/V_{rot} = 10$), the whole absorption profile is more symmetric than in the case where the rotation is dominant. Comparing by eye the line shapes obtained from model with ones registered in the spectra of BALQSOs one can conclude that all of the mentioned cases may be present.

We note here, that the proposed model is relatively simple, aiming to describe the regions where the spectral lines are originated. The model allow us to assume dominant rotation or random motion, and find which of them is predominant. Also, we are able

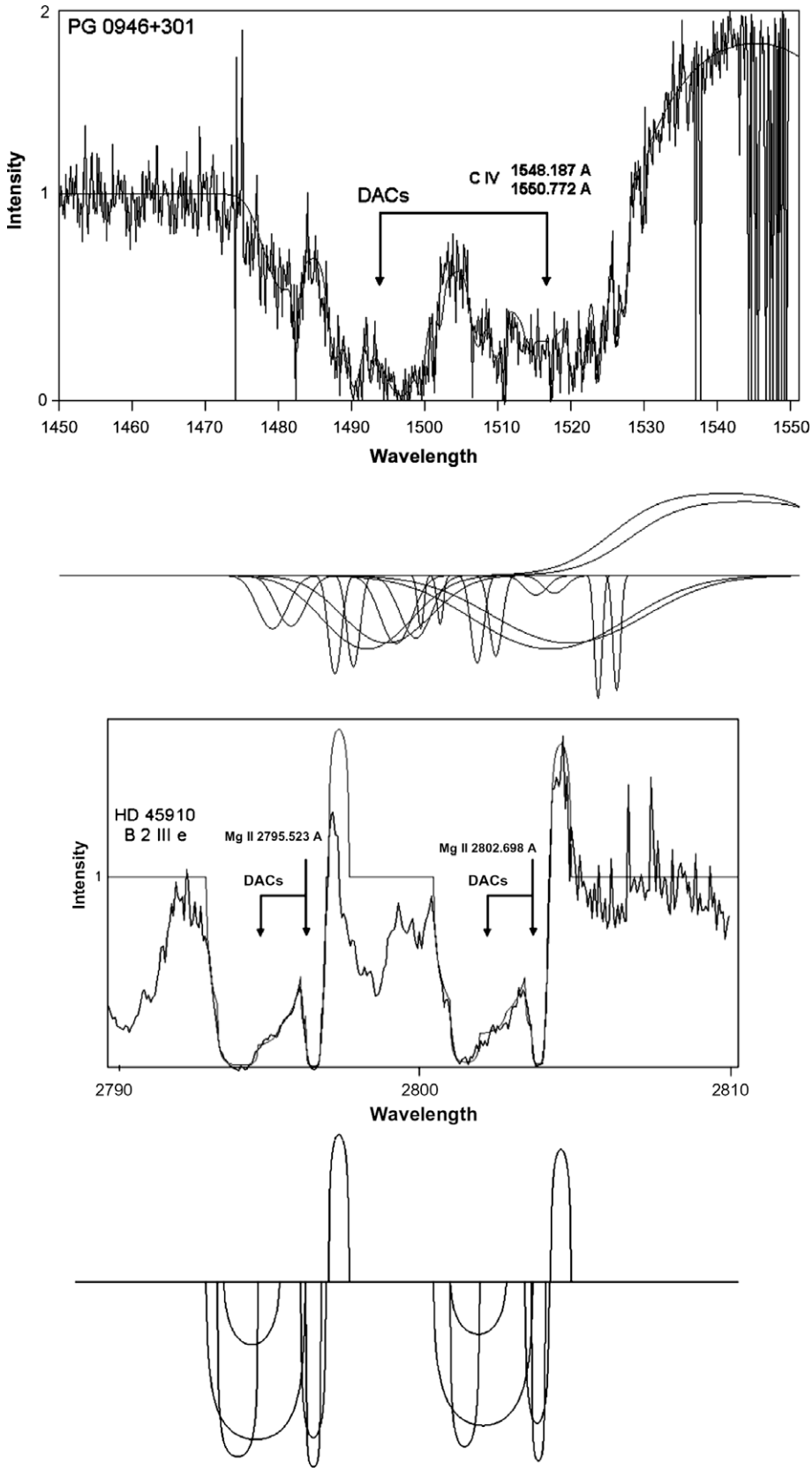

Fig. 1. The C IV UV doublet line profiles of quasar PG 0946+301 (up) and HD 45910 star (down).

to discuss the relationship between emission and absorption components for a line, considering possible connection between broad emission and absorption line regions in sense of which of them is closer to the central black hole.

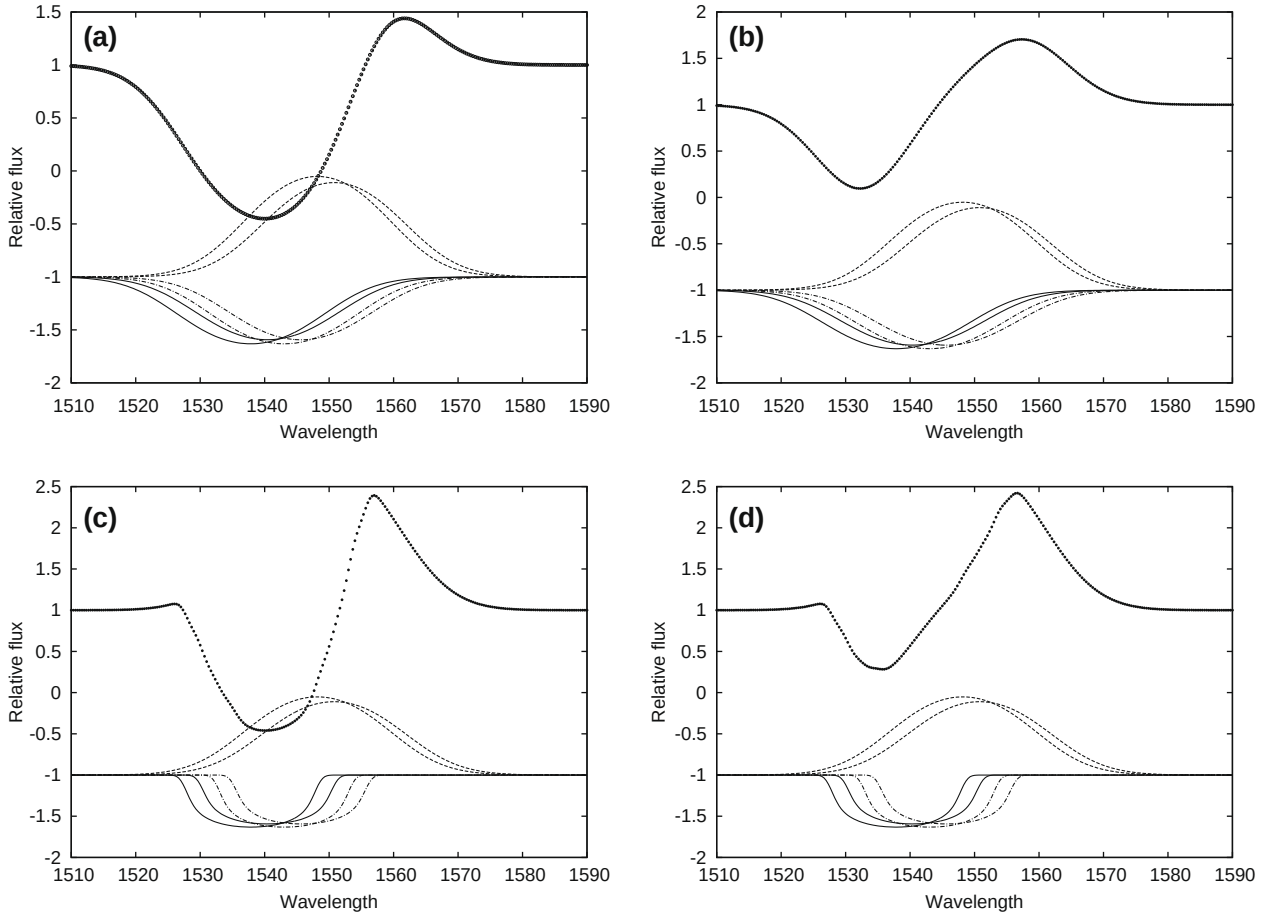

Fig. 2. The modeled CIV doublet, where an emission ($V_{rad} = 0$ km/s) and two absorption regions ($V_{rad1} = -1000$ km/s, $V_{rad2} = -2000$ km/s) were assumed: (a) dominant random velocity ($V_{rand} = 2000$ km/s, $V_{rot} = 200$ km/s for both absorption regions) and assumption that emission region is located before absorption one; (b) the same as (a) but assumption that absorption region is located before emission; (c) the same as (a) the rotational component is dominant ($V_{rot} = 2000$ km/s, $V_{rand} = 200$ km/s for both absorption regions); (d) the same as (b) but the rotational component is dominant and has value as in (c). The composed profile is present with dots and components of the profile are shown below.

3. Model application

3.1. Observations and fitting procedure

We apply the model described above to the spectra of several BALQSOs observed with the HST given in Table 1. In the Table 1, the name of the QSOs, the dates of observations and Instrument/gratings are given, as well as the lines which were fitted. The obtained spectra have resolution from 1.2 and 3.2 Å which is relatively good for application of the model. In order to scale to rest wavelength we use DIPSO software to elaborate the spectra.

A problem is that in the case of BALR, one can expect contribution of the random motion, and the line shapes are complex (i.e. rotation can be hidden by some additional narrow components which are frequently registered in the spectra of BALQSOs). To avoid this problem, we fitted the observed line using two approaches when we start with fit; (a) taking that random velocity is maximal and rotational component is minimal (in this case we will say that it is GR approach), (b) taking that rotational component is dominant (so called RG approach). After that we used *F*-test to conclude which approach of the model is more appropriate to explain the complex absorption lines.

As it is well known the relevant broadening mechanisms in the case of BAL is random motion of absorbing gas, but also, a part of rotation caused by massive black hole can be present. To find limits for rotational and random velocities, we fitted the lines assuming first that random motion is dominant (here we call it GR model) and second that rotation is dominant (RG model).

3.2. Results from the best fit

Here, we are looking for the rotational component only in the broad absorption lines, while the narrow components were fitted assuming that there is not rotational component. This assumption was checked for several lines and it was clear that the rotational component in the narrow lines is not present. In Fig. 3 we present as an example, the fits for H 1413+1143 and PG 1700+518. As one can see from Fig. 3 the model is able to fit lines assuming one or more absorbing components. Here we fitted the broad Lyα and C IV components of BALQSOs listed in Table 1.

The results of the best fit are presented in Table 2. In Table 2, the estimations (minimal and maximal value respectively) for random and rotational velocities as well as radial (outflow) velocity are given. It is clear that in both cases, where we applied RG or GR approach, the outflow velocity remains the same.

As one can see from Table 2, the rotational velocity in the BALR has lower limit of $\sim$100 km/s, that is corresponding to the low rotation (as e.g. the stars in the galactic disc). But in the case of the broad absorption lines (with large FWHM), the maximal value of the rotation reaches the value of several 1000 km/s. We found that the maximal value corresponds to the case of the C IV line of PG 1700+518, where a maximal rotation of 6500 km/s may be present. As one can

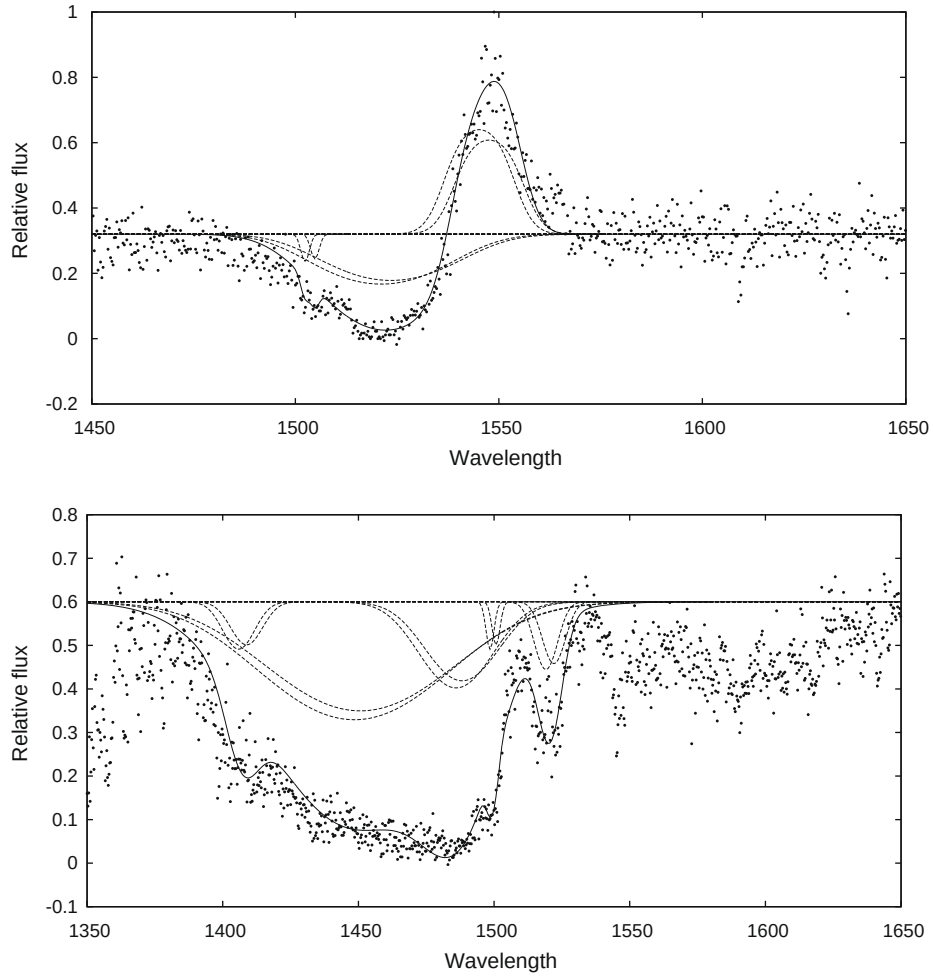

Fig. 3. The C IV line (dots) fitted with the model (solid line) for H1413+1143 and PG 1700+518 quasar. The components of the best fit are shown below.

Table 1
The list of selected BAL QSOs with basic observational data.

Name	Z	Class	Obs. date	Ins./grat.	Lines
PG 0946+301	1.216	BAL QSO	February 16, 1992	FOS/G400,G570	Ly, Si IV, C IV
PG 1700+518	0.292	BAL QSO	September 12, 2000	STIS/G430L,G750L	Si IV, C IV
UM 425	1.462	BAL QSO	November 8, 1994	FOS/G270H	O VI, Ly
HS 1216+5032B	1.45	BAL QSO	June 11,1996	FOS/G270H	Ly
H 1413+1143	2.551	BAL QSO	June 23, 1993, December 23, 1994	FOS/G400H,G570H	Ly, Si IV, C IV
PG1254+047	1.024	BAL QSO	February 17,1993	FOS/G160L,G270H	OV, O VI, Ly, Si IV, C IV
QSO 0957+561	1.41	BAL QSO	October 20,1995	FOS/G270H	Ly

see in Fig. 4, the C IV lines of this BALQSO have no emission component. Also, it is interesting, that maximal value of the rotational velocity decreases when the emission is present in the line.

Additionally, one can speculate that the rotation measured in lines, is caused by gravitational field of massive black hole in the center of BALQSOs than one can estimate distance of BALR using a simple relation $R[R_g] \approx (c/V_{rot})^2$, where R is given in gravitational radii ($R_g = GM_{bh}/c^2$, where G is the gravitational constant, M_{bh} is the mass of central black hole and c is the velocity of light).

As e.g. in the case of PG 1700+518, the C IV absorbing region can be located at $\sim 2000R_g$ that may be closer than the place of the Broad Emission Line Region. It can explain why the emission in PG 1700+518 C IV lines is not present.

On the other hand, taking an average value of the rotational velocity only of broad absorption lines and calculating the location of the BALR using the rotational velocity, we can conclude that it is located around several times of 10^4 R_g. The distance is not so far from the central massive black hole and it should be considered that the model of resonance scattering, where the UV line emission and absorption occur in the same line-forming region (Branch et al., 2002), is relevant to explain BALR.

It is interesting to see some connection between kinematical parameters obtained from the best fit. We discuss, so called averaged random and rotational velocities obtained as $\langle V\rangle = (V_{max}+V_{min})/2$. In Fig. 5 we plot the $|V_r/\mathrm{FWHM}|$ against the averaged rotation (crosses) and random (squares) velocities. *As one can see in Fig. 5, for smaller* $|V_r/\mathrm{FWHM}|$, *the differences between averaged rotational and random velocity are larger. On the other hand, when* $|V_r/\mathrm{FWHM}| > 5$, *there are small averaged random and rotational velocities and the difference between them is small. For* $|V_r/\mathrm{FWHM}| < 5$ *the random velocity is dominant and has a trend to increase as the* $|V_r/\mathrm{FWHM}|$ *decreases. This can be expected, as, in*

Table 2
The parameters of broad absorption line components. The limits for the random and rotational components in the BAL $\left(V_{rand}^{min}, V_{rand}^{max}, V_{rot}^{min}, V_{rot}^{max}\right)$ are given. Assuming that rotational component coming from the gravitation of the central black hole, the limits for the place of origin of the BAL is given.

Object	Line	V_{rand}^{min} (km/s)	V_{rand}^{max} (km/s)	V_{rad} (km/s)	FWHM (km/s)	V_{rot}^{min} (km/s)	V_{rot}^{max} (km/s)
PG0946+301	Lyα	960	1480	−5060	3882	500	1800
		1120	1450	−12,947	3119	100	1000
	C IV	615	2143	−5998	4672	600	3000
		615	1208	−10,833	2704	600	1800
		230	456	−10,061	982	100	600
		2	342	−6385	706	100	700
PG1700+518	C IV	5700	6953	−19,348	15,352	150	6500
		2280	2850	−12,092	6094	100	3000
		1140	1277	−27,474	2650	200	1000
		456	912	−5611	1924	125	1000
		114	319	−9674	671	100	800
UM425	Lyα	291	872	−8804	1826	100	1000
HS1216+5032B	Lyα	116	291	−17,953	801	300	500
H1413+1143	Lyα	440	784	−5919	2282	100	1200
		580	1162	−8557	2708	100	1200
	C IV	2280	3191	−5224	7103	100	3600
PG1254+047	Lyα	1600	1860	−14,303	4720	100	1500
		1600	1976	−19,235	4811	100	1500
	C IV	1595	1938	−5804	3977	100	1000
QSO0957+561	Lyα	350	581	−2219	1740	100	700

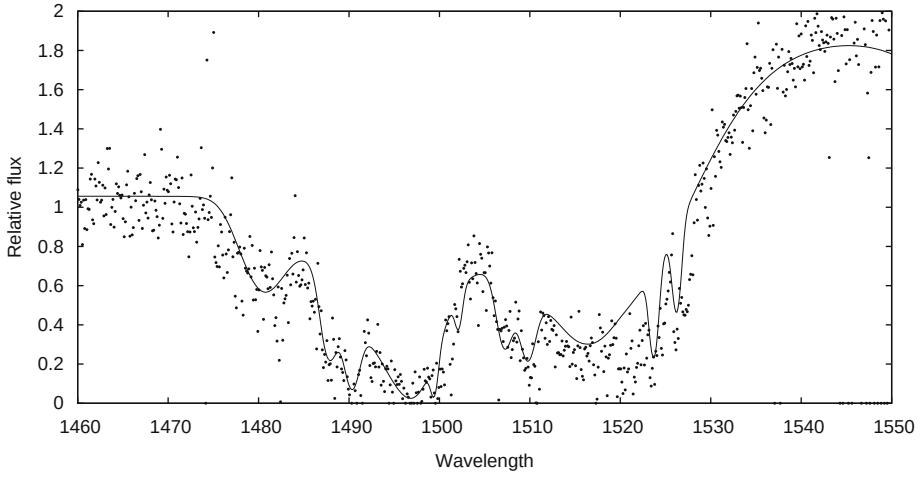

Fig. 4. The C IV line (dots) fitted with the model (solid line) for PG 0946+30 quasar.

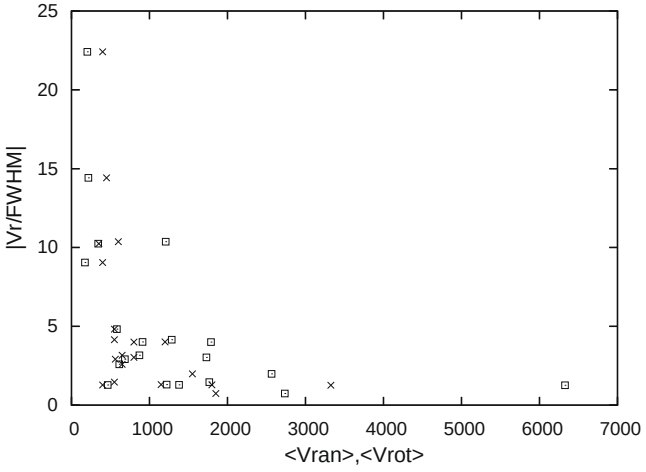

Fig. 5. Normalized radial velocity to FWHM ($|V_r/\text{FWHM}|$) against the averaged rotation (crosses) and random (squares) velocities.

the case of small outflow velocity, the wind of some AGNs may have the form of clouds or blobs. In that case the random velocity is more dominant.

4. Conclusion

Assuming that BALR is composed of a number of successive independent absorbing density layers, which have constant rotational and radial velocity we applied the model, developed to explain hot emission stars' spectra by Danezis et al. (2007, this issue), to BAL and we can outline that:

1. The model can simulate BALs taking into account a high velocity outflow.
2. The model can well fit the observed broad absorption line profiles (absorption as well as emission) and give us estimates of the random, rotational and radial velocities in the BALR.

To estimate kinematical parameters of BALR we fitted BALs, Lyα and C IV, of several BALQSOs (see Table 1) and found that:

1. The BALR is very often composed of several subregions which have different kinematical parameters, where all three kinematical component can be detected (see Table 2).
2. There is indication of a rotation component, that is at least of the order of several hundreds kilometers. If one speculates that it is connected with rotation of absorbing gas around super-massive black hole, the position of BALR is $\sim$ several 10^4 R_g, what is comparable with the position of the BLR.
3. In some objects, as e.g. in PG 1700+518 and PG 0946+30, a strong absorption (without emission) component indicates higher rotational velocities and consequently closer BALR than BLR to super-massive black hole.

Finally, we can conclude that the BALs seem to be produced at the same place (or even closer) as BELs and that this result is in the favor of the models that assume the forming line region as the region which emits broad emission and absorption lines, as e.g. resonance scattering model (Branch et al., 2002).

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References

Arav, N., De Kool, M., Korista, K.T., et al., 2001. ApJ 561, 118.
Bates, B., Halliwell, D.R., 1986. MNRAS 223, 673.
Becker, R.H., White, R.L., Gregg, M.D., Brotherton, M.S., Laurent-Muehleisen, S.A., Arav, N., 2000. ApJ 538, 72.
Branch, D., Leighly, K.M., Thomas, R.C., Baron, E., 2002. ApJL 578, L37.
Crenshaw, M.D., Kraemer, S.B., George, I.M., 2003. ARAA 41, 117.
Danezis, E., Nikolaidis, D., Lyratzi, V., Stathopoulou, M., Theodossiou, E., Kosionidis, A., Drakopoulos, C., Christou, G., Koutsouris, P., 2003. AP&SS 284, 1119.
Danezis, E., Popović, L.Č., Lyratzi, E., Dimitrijević, M.S., 2006. AIP Conf. Proc. 876, 373.
Danezis, E., Nikolaidis, D., Lyratzi, E., Popović, L.Č., Dimitrijević, M.S., Antoniou, A., Theodosiou, E., 2007. PASJ 59, 827.
Danezis, E., Lyratzi, E., Popović, L.Č., Dimitrijević, M.S., Antoniou, A., this issue, NewAR.
de Kool, M., Begelman, M.C., 1995. ApJ 455, 448.
Elvis, M., 2000. ApJ 545, 63.
Hamann, F., Korista, K.T., Morris, S.L., 1993. ApJ 415, 541.
Lyratzi, E., Danezis, E., 2004. AIP Conf. Proc. 740, 458–473.
Murray, N., Chiang, J., 1995. ApJ 451, 498.
Murray, N., Chiang, J., 1998. ApJ 494, 125.
Popović, L.Č., Mediavilla, E., Bon, E., Ilić, D., 2004. A&A 423, 909.
Proga, D., 2003. ApJ 592, 9.
Proga, D., Kallman, T.R., 2004. ApJ 616, 688.
Proga, D., Stone, J.M., Kallman, T.R., 2000. ApJ 543, 686.
Reichard, T.A., Richards, G.T., Hall, P.B., Schneider, D.P., Vanden Berk, D.E., Fan, X., York, Donald G., Knapp, G.R., Brinkmann, J., 2003. AJ 126, 2594.
Williams, R.J.R., Baker, A.C., Perry, J.J., 1999. MNRAS 310, 913.

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Interpreting the complex line profiles in the stellar spectra

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ABSTRACT

In this review we present our recent investigation of the complex absorption lines in spectra of hot emission stars. The lines are created in a material ejected from stars (here we call it density regions around the objects). Particularly we present a model (GR model) which is developed to study satellite or discrete absorption components (SACs or DACs). Using the model we are able to extract kinematical parameters (rotational, radial and random velocity) and some physical parameters (full width at half maximum, optical depth in the center of the line, column density and absorbed or emitted energy) of the density regions.
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1. Introduction

The definition of hot emission stars is that they present emission lines of the Balmer series, which, superposed with the respective absorption lines, construct PCygni profiles. Besides that, they may also present PCygni profiles in the UV region (such as in the case of the resonance lines of Si IV, C IV, N V, Mg II, and the N IV spectral line) and IR excess in their spectra. Additionally, another characteristic of hot emission stars, which also distinguish them from the classical hot stars, is the violent mass ejection, like flares, from active regions. Specifically, hot emission stars are rapid rotators and when the rotational velocity takes a critical value, the star ejects plasma violently from a zone around the equator (Underhill and Doazan, 1982, Part II, Chapter 10). The ejected plasma maybe evolves to a thin spherical shell around the star (Meilland et al., 2006). Some times we have repeated ejection of mater (Danezis, 1984). This means that we can detect not one, but many successive thin and independent spherical shells around the star. These spherical shells rotate rapidly because they lie near the rapidly rotating star and they are the origin of the very broad spectral lines that present rotational velocities with values about the critical. The mass ejection may last for quite long time and results to the fact that near the stars the ejected plasma could form spiral streams due to turbulence and the stellar rotation. These structures form density regions such as shells, blobs or puffs (Underhill, 1975; Henrichs, 1984; Underhill and Fahey, 1984; Bates and Halliwell, 1986; Grady et al., 1987; Lamers et al., 1988; Waldron et al., 1992; Waldron et al., 1994; Cranmer and Owocki, 1996; Rivinius et al., 1997; Kaper et al., 1996; Kaper et al., 1997; Markova, 2000). These spherical blobs, arising from spiral streams or turbulences, are the origin of a group of satellite spectral lines with intermediate or low broadening. The thin spherical shells evolve to an equatorial disk (Meilland et al., 2006) that far away from the star becomes a classical stellar wind. As a result, the material that comes from the star, has not the form of a classical stellar wind near the star. Consequently, the stellar wind models may be used for the outer regions of the equatorial disk, but not for the inner layers.

Additionally, near hot emission stars we can detect density regions that have the characteristics of chromospheres, corona and post-coronal regions (Franco and Stalio, 1983, Part II, Chapter 13; Franco et al., 1983; Underhill and Doazan, 1982). Besides, we detect the corona of hot emission stars in X-rays and in UV we detect the post-coronal regions (Si IV, C IV, N IV, N V lines etc.). Investigations of line profiles of UV lines, can give us more information about these regions, as e.g. the velocity of outflow, rotation of sub-regions, etc.

Here, we give an overview of our recent investigations of complex UV lines in hot emission stars. We study the density regions which are formed due to violent mass ejection from the star, lie near the star and cannot be considered as regions of a classical stellar wind. These density regions are the ones that create the observed complex profiles of the spectral lines.

This paper is organized as follows: In Section 2 we discuss observational facts and problems connected with peculiar and complex spectral line profiles of hot emission stars; in Section 3 we describe GR model, in Section 4 we give some results of our recent investigation and in Section 5 we outline our conclusions.

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2. Peculiar and complex spectral line profiles – observations and problems

Almost all the stars of the same spectral type and luminosity class present the same absorption lines in their spectra. However, in the UV spectral region, some hot emission stars (Oe and Be stars) present some absorption components that should not appear in their spectra, according to the classical physical theory (Fig. 1).

In the case of hot emission stars we call the absorption spectral lines, not corresponding to any known absorption line of the same spectral type stars, discrete absorption components (DACs) (Bates and Halliwell, 1986).

However, DACs are not unknown absorption spectral lines, but spectral lines of the same ion and the same wavelength as a main spectral line, shifted at different $\Delta\lambda$, as they are created in different density regions which rotate and move radially with different velocities (Danezis, 1984; Danezis, 1987; Danezis et al., 1991; Danezis et al., 2003; Lyratzi and Danezis, 2004).

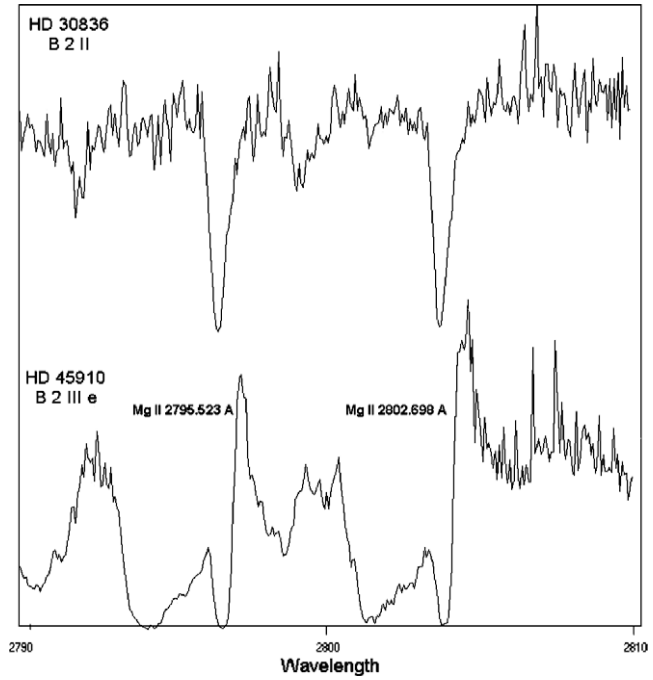

Fig. 1. Comparison of Mg II resonance lines between the spectrum of a normal B star and the spectrum of an active Be star that presents complex and peculiar spectral lines. As we can observe the Be star presents some absorption components that do not appear in the spectrum of the classical B star.

The origin of DACs is an important problem that has been studied by many researchers. Some of them have suggested mechanisms that allow the existence of structures which cover all or a significant part of the stellar disk, such as shells, blobs or puffs (Underhill, 1975; Henrichs, 1984; Underhill and Fahey, 1984; Bates and Halliwell, 1986; Grady et al., 1987; Lamers et al., 1988; Waldron et al., 1992; Waldron et al., 1994; Cranmer and Owocki, 1996; Rivinius et al., 1997; Kaper et al., 1996; Kaper et al., 1997; Markova, 2000), interaction of fast and slow wind components, co-rotation interaction regions (CIRs), structures due to magnetic fields or spiral streams as a result of the stellar rotation (Underhill and Fahey, 1984; Cranmer and Owocki, 1996; Kaper et al., 1996; Kaper et al., 1997; Kaper et al., 1999; Mullan, 1984a,b; Mullan, 1986; Prinja and Howarth, 1988; Fullerton et al., 1997; Cranmer et al., 2000). According to these ideas, DACs result from independent high density regions in the stellar environment, which have different rotational and radial velocities.

Our proposition is that since hot emission stars are surrounded by thin spherical envelopes which evolve to a disk in the equatorial plane, the density regions which create the observed DACs in the stellar spectra may be either the thin spherical shells around the star or apparent spherical density regions that lie in the disc around the star (Fig. 2).

Another problem of this group of hot emission stars is the presence of very complex profile of the spectral lines that we cannot produce theoretically. This means that we could not know the physical conditions that exist in the high density regions that construct these spectral lines. In order to explain this complex line profile our scientific group proposed the SACs phenomenon (satellite absorption components). If the regions that construct the DACs rotate with large velocities and move radially with small velocities, the produced lines have large widths and small shifts. As a result, they are blended among themselves as well as with the main spectral line and thus they are not discrete. In such a case the name discrete absorption components is inappropriate and we use the name: satellite absorption components (SACs) (Danezis, 1984; Danezis, 1987; Lyratzi and Danezis, 2004; Danezis et al., 2006; Sahade et al., 1984; Sahade and Brandi, 1985). The existence of SACs results to the formation of the complex structure of the observed spectral feature.

As we can deduce from the above, the DACs and SACs are two aspects of the same phenomenon. In Fig. 3 it is clear that the Mg II line profiles of the star AX Mon (HD 45910), which presents DACs and the star HD 41335, which presents SACs are produced in the same way. The only difference between them is that the components of HD 41335 are much less shifted and thus they are blended among themselves.

Similar phenomena can also be detected as an effect of the ejected plasma around peculiar stars. Around the Wolf-Rayet star

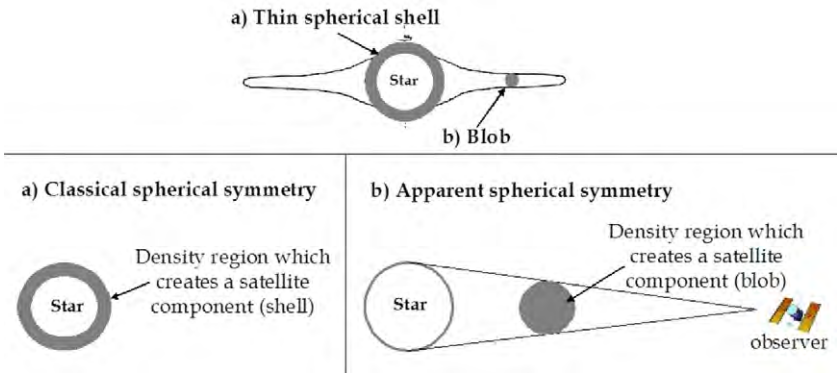

Fig. 2. DACs arise from (a) the thin spherical envelope around hot emission stars or (b) (apparent) spherical density regions in the disc around the stars.

WR 104 we can detect density regions of matter, quite away from the stellar object, able to produce peculiar profiles (Fig. 4).

It is very important to point out that we can detect the same phenomenon in the spectra of some active galactic nuclei (AGN). In Fig. 5 (down) we can see the C IV UV doublet of an AGN (PG

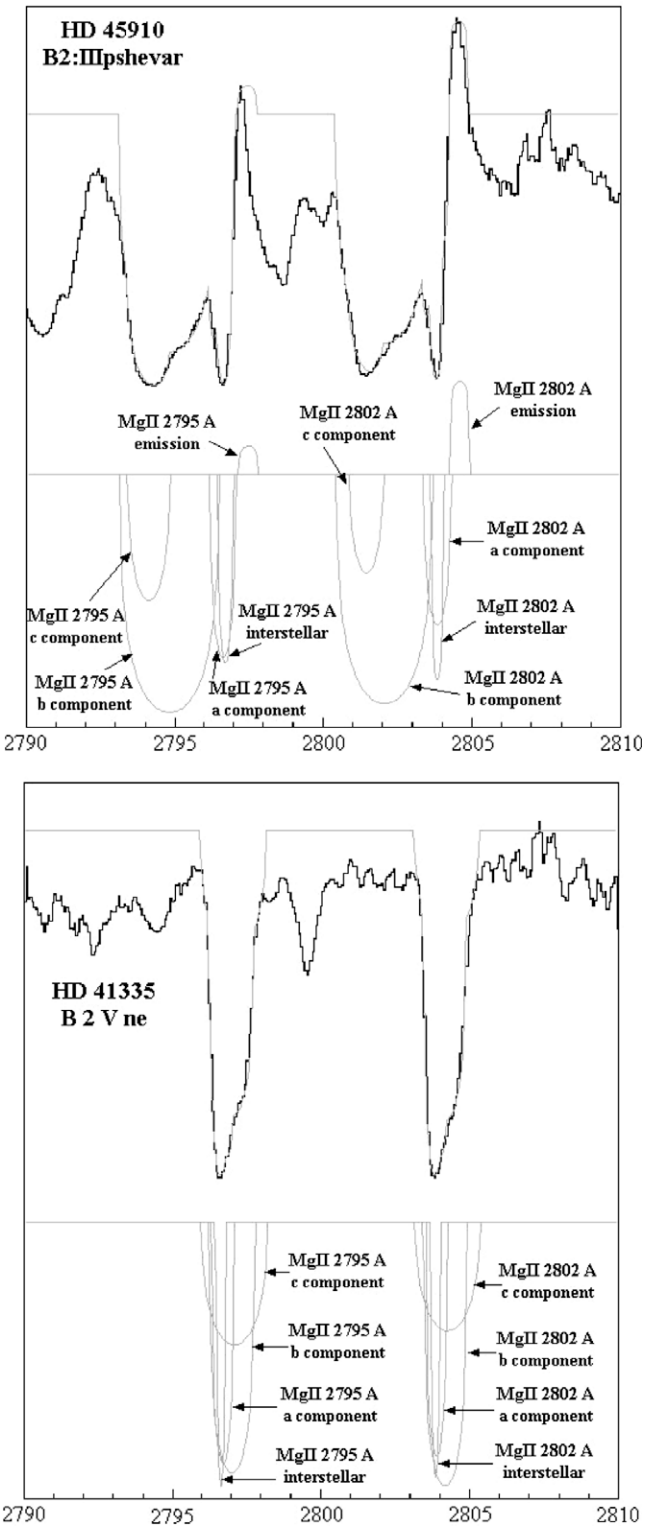

Fig. 3. DACs of the Mg II line profiles of the star AX Mon (HD 45910) and SACs of the star HD 41335 are produced in the same way. The black line presents the observed spectral line's profile and the grey one the model's fit. All the components which contribute to the observed features are shown separately.

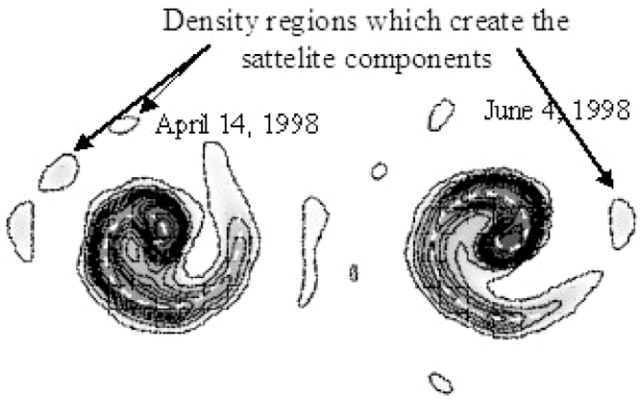

Fig. 4. Density regions of matter, able to produce peculiar profiles can be detected around the Wolf-Rayet star WR 104. (This figure is taken from (Tuthill et al., 1999)).

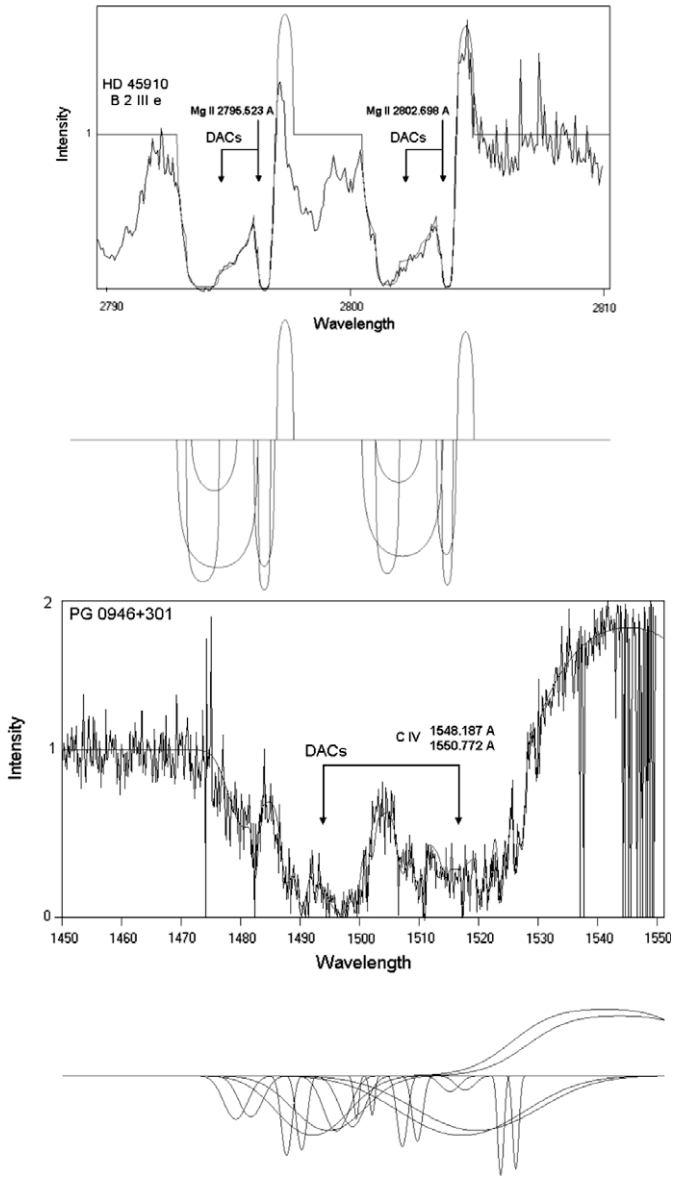

Fig. 5. DACs phenomena in AGNs spectra: similarity of DACs phenomenon in Be star's HD 45910 spectrum (Mg II doublet) with AGNs PG 0946+301spectrum (C IV doublet).

0946+301). The values of radial displacements and the ratio of the line intensities indicate that the two observed C IV shapes present DACs phenomenon similar with the DACs phenomenon that we detect in the spectra of hot emission stars (HD 45910, up).

Since the DACs phenomenon is present in AGNs spectra, we also expect the presence of SACs phenomenon which is able to explain the observed absorption lines complex profiles (Fig. 6). In the case of AGNs, accretion, wind (jets, ejection of matter etc.), BLR (broad line regions) and NLR (narrow line regions) are the density regions that construct peculiar profiles of the spectral lines.

In order to study and explain the spectral lines that have complex profiles due to the existence of DACs or SACs and the atmospherical regions where these lines originate, we have to calculate a line function that will be able to reproduce theoretically the observed spectral line profiles. The term line function corresponds to the function that relates the intensity with the wavelength. This function includes as parameters all the physical conditions that construct the line profile. By giving values to these parameters we try to find the right ones in order to have the best theoretical fit of the observed line profile. If we accomplish the best fit, we accept that the theoretical values of the physical parameters are the actual ones that describe the physical conditions in the region that produces the specific spectral line. However, the calculation of a line function is not simple and includes many problems, such as the following. A line function able to reproduce theoretically any spectral line of any ion should include all the atomic parameters. As a result the line function would be very complex. Also, if we wanted a time dependent line function, we should include as parameter the time. The existence of many parameters makes the solution of the radiation transfer equations problematic. Another problem is to choose the correct values of so many parameters.

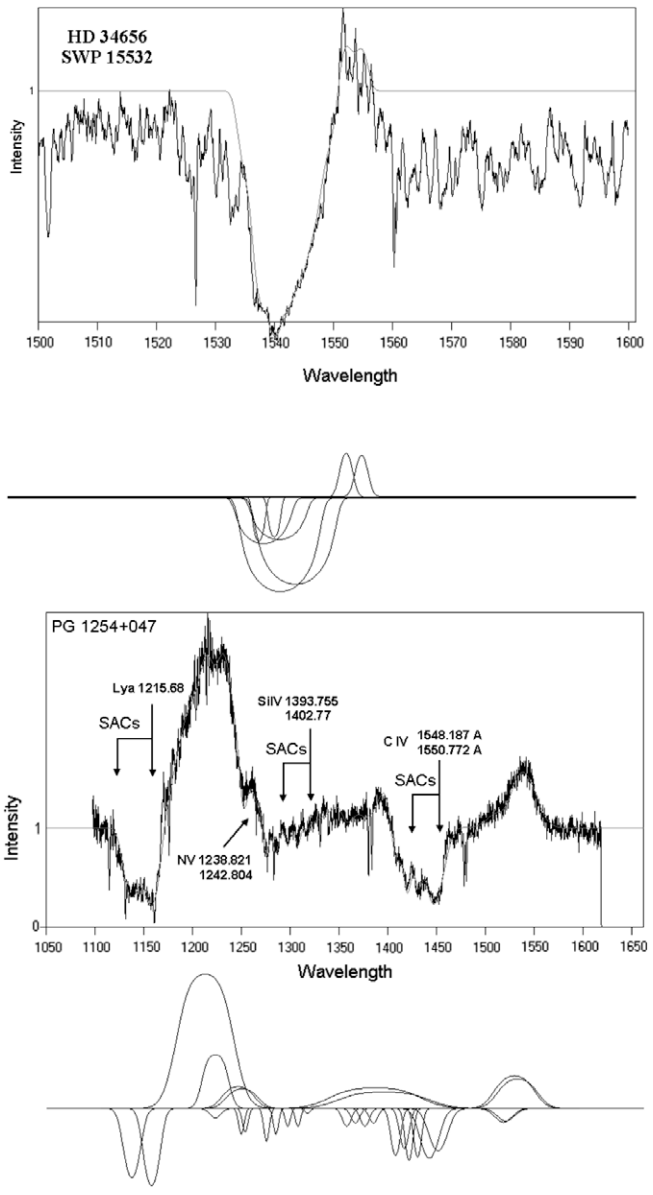

Fig. 6. SACs phenomena in AGNs spectra: similarity of SACs phenomenon in Oe star's HD 34656 spectrum (C IV doublet) with AGNs PG 1254+047 spectrum (Lya and Si IV and C IV doublets).

In order to eliminate some of these problems we considered that in the calculation of a line function we should not include variation with time, as our purpose was to describe the structure of the regions where the SACs are created at the specific moment when a spectrum is taken. In order to study the time-variation of the calculated physical parameters, we should study many spectra of the same star, taken at different moments. Additionally, we needed a line function with which we could study a specific spectral line of a specific ion. This means that we did not need to include the atomic parameters, as in such a case the atomic parameters remain constant. In this way, we were able to solve the radiation transfer equations and to find the correct group of parameters that give the best fit of the observed spectral line.

3. GR (Gauss-rotation) model – the line function

We considered that in the stellar atmosphere the radiation passes through a number of successive independent absorbing and/or emitting density regions of matter until it arrives at the observer. By solving the radiation transfer equations through such a complex structure we obtain a line function (Eq. (1)) for the line profile, able to give the best fit for the main spectral line and its DACs/SACs at the same time (see Danezis et al. (2003), and Danezis et al. (2007a)).

$$I_\lambda = \left[I_{\lambda 0} \prod_i \exp\{-L_i \xi_i\} + \sum_j S_{\lambda ej} (1 - \exp\{-L_{ej} \xi_{ej}\}) \right] \times \prod_g \exp\{-L_g \xi_g\} \quad (1)$$

where, $I_{\lambda 0}$ is the initial radiation intensity, L_i, L_{ej}, L_g are the distribution functions of the absorption coefficients $k_{\lambda i}, k_{\lambda ej}, k_{\lambda g}$, ξ is the optical depth in the center of the spectral line, $S_{\lambda ej}$ is the source function that is constant during one observation.

The geometry and the physical conditions of the region that produces the spectral line are included in the factors L_i, L_{ej}, L_g and not in the calculation of I_λ. So, the decision on the geometry and the physical conditions is essential for the calculation of the distribution function that we use for each component. Specifically, the physical conditions indicate the exact distribution that we must use. This means that for a different geometry and different physical conditions we have a different analytical form of L_i, L_{ej}, L_g and thus a different shape for the spectral line profile of each SAC.

In the case of rapidly rotating hot emission stars, it is very important to insert in the line function the rotational and the radial of the regions that produce each one of the satellite components, as well as the random velocities of the ions. In this case we must define the geometry for the corresponding regions.

3.0.1. Geometry

In our model we considered the spherical geometry. In order to decide on the appropriate geometry we took into consideration

that the spectral line profile is reproduced in the best way when we consider spherical symmetry for the independent density regions. Such symmetry has been proposed by many researchers (Waldron et al., 1992; Rivinius et al., 1997; Kaper et al., 1996; Kaper et al., 1997; Kaper et al., 1999; Markova, 2000; Lamers et al., 1982; Bates and Gilheany, 1990; Gilheany et al., 1990; Cidale, 1998). However, the independent layers of matter, where a spectral line and its SACs are created, could lie either (i) around the star, in which case spherical symmetry is justified, or (ii) at a greater distance from the star, where the spherical symmetry can not be justified (see also Lyratzi et al., 2007).

(i) Independent density regions of matter that lie around the star (see Fig. 2a): In this case we consider the existence of a classical spherical symmetry of the thin spherical envelope around hot emission stars.
(ii) Independent density regions of matter that lie at a greater distance from the photosphere (see Fig. 2b): we consider the existence of independent density regions such as blobs, which cover all or a substantial fraction of the stellar disk, which exist in the disc around hot emission stars. These regions, do not present spherical symmetry around the star, but they may present local spherical symmetry around their own center and they form spectral line profiles which are identical with those deriving from a spherically symmetric structure. So, even if the density regions are not spherically symmetric, through their effects on the line profiles, they appear as spherically symmetric structures to the observer.

The way the density regions of the second case are formed is shown in Fig. 4. The star ejects mass with a specific radial velocity. The stream of matter is twisted, forming density regions such as co-rotating interaction regions (CIRs), structures due to magnetic fields or spiral streams as a result of the stellar rotation (Underhill and Fahey, 1984; Cranmer and Owocki, 1996; Kaper et al., 1996; Kaper et al., 1997; Kaper et al., 1999; Mullan, 1984a,b; Mullan, 1986; Prinja and Howarth, 1988; Cranmer et al., 2000). This means that hydrodynamic and magnetic forces take effect as centripetal forces, resulting to the outward moving matter twisting and moving around the star. Some parts of these streams cut off and form the observed high density regions (shells, blobs, puffs, spiral streams).

3.0.2. Physical conditions

Depending on the physical conditions that we consider for the calculations of the factors L_i, L_{ej}, L_g, the functions $e^{-L_i\xi_i}$ and $S_{\lambda ej}(1-e^{-L_{ej}\xi_{ej}})$ that correspond to the absorption and the emission satellite component, respectively, may take the form of different distribution functions, such as Gauss, Lorentz or Voigt distribution function. However, a very important point is that in this case we do not use the pure mathematical distributions that do not include any physical parameter, but the physical expression of these distributions that are the following.

1. If L_i has the form $L_\lambda = e^{-\alpha(\lambda-\lambda_0)^2}$, where $\alpha = \frac{1}{2(\Delta\lambda_{width})^2}$, the line function $e^{-L_i\xi_i}$ that defines well an absorption line, has the form of a Gauss distribution.
2. If L_i has the form $L_\lambda = \frac{1}{1+\beta(\lambda-\lambda_0)^2}$, where $\beta = \frac{1}{2(\Delta\lambda_{width})^2}$, the line function $e^{-L_i\xi_i}$ that defines well an absorption line, has the form of a Lorentz distribution.
3. If L_i has the form $L_\lambda = \frac{\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} f(x,(\lambda-\lambda_0)\sqrt{a},K)\,dx}{V_0}$, where $\alpha = \frac{1}{2(\Delta\lambda_{width})^2}$, $V_0 = \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} f(x,0,K)\,dx$ and $0 \leqslant K$, the line function $e^{-L_i\xi_i}$ that defines well an absorption line, has the form of a Voigt distribution. Similarly, if we put the above expressions of L_i (cases 1–3) in the emission line function $S_{\lambda ej}(1-e^{-L_{ej}\xi_{ej}})$, it will take the form of a Gauss, Lorentz or Voigt distribution.

Besides the above distribution functions, we had to consider the fact that hot emission stars are rapid rotators and present violent mass ejection, producing density regions that create the observed DACs or SACs and which also rotate quickly around their own center. According to this, we should accept that the rapid rotation of the density regions is one of the main broadening factors of the spectral lines originating from them. This means that the rotation of the density regions should be included in the calculations of our model, in order to be able to reproduce the observed spectral lines.

As a first step, our scientific group constructed a distribution function L that considers as the only reason of the line broadening the rotation of the regions that produce the spectral lines. We called it rotation distribution (see Danezis et al., 2003; Lyratzi et al., 2007). However, it is known that in a gaseous region we always detect random motions, which must be taken into consideration as a second reason of line broadening (Doppler broadening). The distribution function that expresses these random motions is the Gaussian. This means that in order to have a spectral line that has as broadening factors the rotation of the regions and the random motions of the ions, we should construct a new distribution function L that would include both of these reasons (rotation and random motions). Our scientific group constructed this distribution function L (Eq. (2)) and named it Gaussian-rotation distribution (GR distribution).

$$L_{final}(\lambda) = \frac{\sqrt{\pi}}{2\lambda_0 z}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\left[erf\left(\frac{\lambda-\lambda_0}{\sigma\sqrt{2}}+\frac{\lambda_0 z}{\sigma\sqrt{2}\cos\theta}\right) - erf\left(\frac{\lambda-\lambda_0}{\sigma\sqrt{2}}-\frac{\lambda_0 z}{\sigma\sqrt{2}\cos\theta}\right)\right]\cos\theta\,d\theta \quad (2)$$

where, λ is the wavelength of each point of the spectral line profile, $\lambda_0 = \lambda_{lab} \pm \Delta\lambda_{rad}$, where λ_0 is the wavelength of the center of the observed spectral line which is shifted from the laboratory wavelength λ_{lab} of the spectral line at $\Delta\lambda_{rad}$, from which we calculate the radial velocity V_{rad} of the density region, $z = \frac{V_{rot}}{c}$, from which we calculate the rotational velocity V_{rot} of the density region, σ is the Gaussian typical deviation from which we calculate the random velocity V_{rand} of the ions as $V_{rand} = \frac{\sigma c\sqrt{2\ln 2}}{\lambda_0}$ and $erf(x) = \frac{2}{\pi}\int_0^x e^{-u^2}du$, is the known error function (see also Danezis et al., 2007a).

The analytical form and the calculations of the GR distribution function can be found in Danezis et al. (2007a).

Using the GR model, we can calculate some important parameters of the density region that construct the DACs/SACs. Directly, we can calculate the apparent rotational velocities of absorbing or emitting density layers (V_{rot}), the apparent radial velocities of absorbing or emitting density layers (V_{rad}), the Gaussian typical deviation of the ion random motions (σ) and the optical depth in the center of the absorption or emission components (ξ). Indirectly, we calculate the random velocities of the ions (V_{rand}), the full width at half maximum (FWHM), the absorbed or emitted energy (Ea, Ee) and the column density (CD) (see also Danezis et al., 2005).

3.1. Main aspects of the GR model

First of all, we should point out that with GR model we can study and reproduce specific spectral lines. This means that we can study specific density regions in the plasma surrounding the studied object. These density regions lie near the star and are formed by the plasma which is violently ejected from the stellar active regions. This means that the material that comes from the

star has not the form of a classical stellar wind. In order to construct a general model we need to study with the proposed model many density regions that produce spectral lines of different ionization potential, meaning different temperature and thus different distance from the studied object.

3.1.1. The simple case of only one component (simple spectral lines)

The line function of the GR model (Eq. (1)) is able to reproduce any spectral line profile, regardless of the number of the line's components (DACs or SACs). This means that it can be used for any number of absorbing or emitting regions. As a result it may also be used in the simple case that $i = 1$ and $j = 0$ or $i = 0$ and $j = 1$, meaning when we deal with simple, classical absorption or emission spectral lines, respectively. This means that we can calculate all the important physical parameters, such as the rotational, the radial and the random velocities, the optical depth, the column density and the absorbed or emitted energy, for all the simple and classical spectral lines in all the spectral ranges.

3.1.2. The case of many absorption or emission components

In the GR line function (Eq. (1)) the final profile that is produced by a group of absorption lines is given by the product of the line functions of each SAC. On the other hand, the final profile that is produced by a group of emission lines is given by the addition of the line functions of each SAC. The addition of a group of functions is completely different than the multiplication of functions. The spectral line profile that results from the addition of a group of functions is exactly the same with the profile that results from a composition of the same functions. On the contrary, the product of a group of functions is completely different from the composition of the same functions. As a result, we can use the composition of functions for the emission lines, but not for a group of absorption components. This means that in such a case we can not refer to the law of reversion of the spectral lines.

The function $I_{\lambda i} = e^{-L_i \xi_i}$ reproduces the spectral line profile formed by the i density region (profile of one component). In the case of the GR distribution function (Eq. (2)), for each quadruplet of the parameters $V_{rot(i)}, V_{rad(i)}, V_{rand(i)}$ and $\xi_{(i)}$ we have a different profile. This results to the existence of only one quadruplet able to give the best fit of the i component.

3.1.3. Fitting criteria

In order to accept as best fit of the observed spectral line, what is given by the quadruplet $(V_{rot(i)}, V_{rad(i)}, V_{rand(i)}, \xi_{(i)})$ of all the calculated SACs, we must adhere to all the physical criteria and techniques.

First of all, it is necessary to have the superposition of the spectral region that we study with the same region of a classical star of the same spectral type and luminosity class, in order to identify the existence of spectral lines that blend with the studied ones and the existence of SACs.

The resonance lines, as well as those that form in regions close to each other (small difference in ionization potential), must have the same number of SACs and the same values for V_{rot}, V_{rad} and V_{rand}. Besides, in the cases of resonance lines and of lines of the same ion and the same multiplet, the ratio of the values of ξ must be the same as the ratio of the respective intensities.

The final criterion to accept or reject a best fit is that the calculated values of the physical parameters should not go against the classical physical theory.

3.1.4. Method for the fitting of a spectral line

In order to conclude to the group of the parameters which give us the best fit, we use the model by the following two methods:

- In the first method we consider that the main reason of the line broadening of the main line and the satellite components is the rotation of the region which creates the components of the observed feature and a secondary reason is the thermal Doppler broadening. This means that we start fitting the line using the maximum V_{rot}. Then, we include Doppler broadening, in order to accomplish the best fit (rotation case).
- In the second method, we consider the opposite. This means that in this case the main reason of the line broadening of the main line and the satellite components is supposed to be the thermal Doppler broadening and the secondary reason is the rotation of the region which creates the components of the observed feature. This means that we start fitting the line using the maximum Doppler broadening. Then we include the rotation of the region, by increasing V_{rot}, in order to accomplish the best fit (Doppler case).

In both of the above cases (rotation case and Doppler case) we check the correct number of satellite components that construct the whole line profile. First we try to fit with one component. We add another one only when we see that we cannot fit with only one component. We keep adding components until we accomplish the best fit. Finally, we fit using the number of the components that give the best difference graph between the fit and the real spectral line (step by step, component by component). Then we fit using one component less than in the previous fit. The F-test between them allows us to take the correct number of satellite components that construct in the best way the whole line profile.

The F-test between these two cases indicates the best way to fit the spectral lines. When the F-test cannot give definite conclusion on which case we should use, we still could obtain information about the limits of V_{rot} and σ. If the F-test gives similar values, then the rotation case defines the maximal V_{rot} and the minimal σ and the Doppler case defines the minimal V_{rot} and the maximal σ.

The profile of every main spectral line and its SACs is fitted by the function $e^{-L_i \xi_i}$, in the case of an absorption component or by $S_{\lambda ej}(1 - e^{-\tau_{ej}})$, in the case of an emission component. These functions produce symmetrical line profiles. However, we know that most of the spectral lines that we have to reproduce are asymmetric. This fact is interpreted as a systematical variation of the apparent radial velocities of the density regions where the main spectral line and its SACs are created. In order to approximate those asymmetric profiles we have chosen a classical method. This is the separation of the region, which produces the asymmetric profiles of the spectral line, in a small number of sub-regions, each of which is treated as an independent absorbing shell. In this way we can study the variation of the density, the radial shift and the apparent rotation as a function of the depth in every region which produces a spectral line with an asymmetric profile. All the above must be taken into account during the evaluation of our results and one should not consider that the evaluated parameters of those sub-regions correspond to independent regions of matter, which form the main spectral line or its SACs. In this case we could use asymmetric

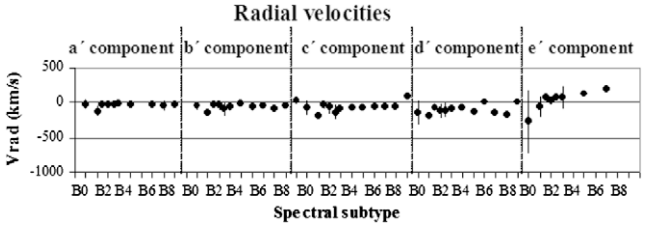

Fig. 7. Radial velocities of the regions that create the Si IV resonance lines as a function of the spectral subtype, in a sample of 68 Be stars (Lyratzi et al., 2007).

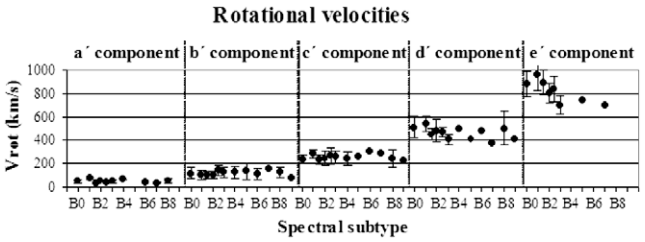

Fig. 8. Rotational velocities of the regions that create the Si IV resonance lines as a function of the spectral subtype, in a sample of 68 Be stars (Lyratzi et al., 2007).

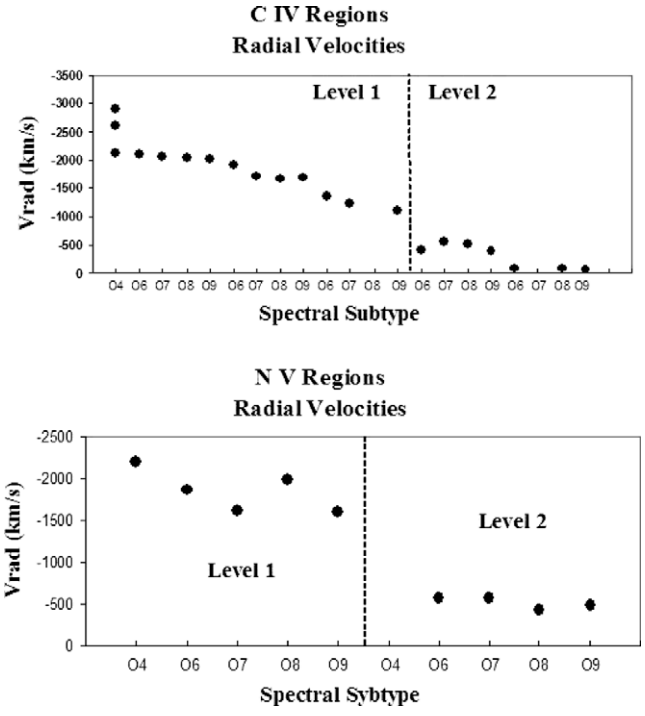

Fig. 9. Radial velocities V_{rad}) in the C IV region (left) and in the N V region (right) as a function of the spectral subtype. We detect two levels of radial velocities in both regions. The first level has high values (between −3000 and −1500 km s^{-1} in the C IV region and between −2300 and −1500 km s^{-1} in the N V region) and the second level has low values (between −500 and −20 km s^{-1} in the C IV region and between −500 and −100 km s^{-1} in the N V region) (Antoniou et al., 2008).

distributions (e.g. Maxwell). This means that we could fit the observed profile with an asymmetric mathematical distribution. However, until now we do not have an expression of the distribution function L_i that would correspond to a Maxwell distribution and which would include physical parameters. As a result, even if we could fit the observed profile with a mathematical asymmetric distribution, we would not be able to calculate any physical parameter. In order to be able to calculate some physical parameters, we use the above mentioned way.

4. Some results from our studies with Gauss-rotational model

As we have already mentioned, with GR model, we can calculate many parameters of the regions where the studied spectral lines are created. Such parameters are the apparent rotational and radial velocities, the random velocities of the ions, as well as the full width at half maximum, the optical depth in the center of the line, the column density and the absorbed or emitted energy of the independent density regions of matter which produce the SACs/DACs of the studied spectral lines. Here we present some results of our studies on hot emission stars (see also Lyratzi et al., 2005; Lyratzi et al., 2007; Danezis et al., 2007b; Antoniou et al., 2008). In Figs. 7 and 8 we give the results of our study of 68 Be stars (Lyratzi et al., 2007). Specifically, Figs. 7 and 8 show the radial and the rotational velocities of the regions that create the Si IV resonance lines as a function of the spectral subtype, respectively. From the calculation of the above mentioned parameters we can study the relations between them. In a study of 20 Oe stars, we calculated

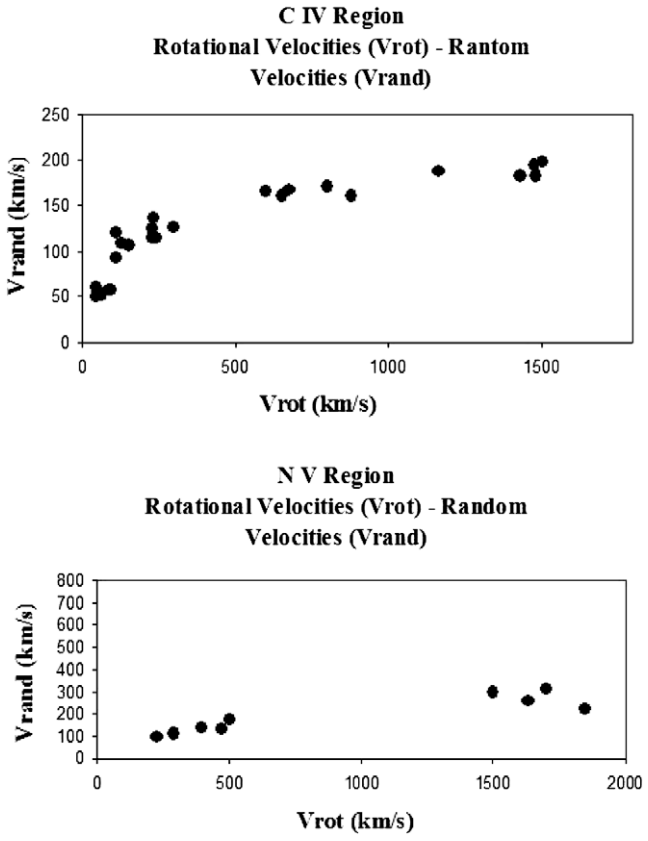

Fig. 10. The random velocities of the CIV and NV density regions, as a function of the apparent rotational velocities, in a sample of 20 Oe stars.

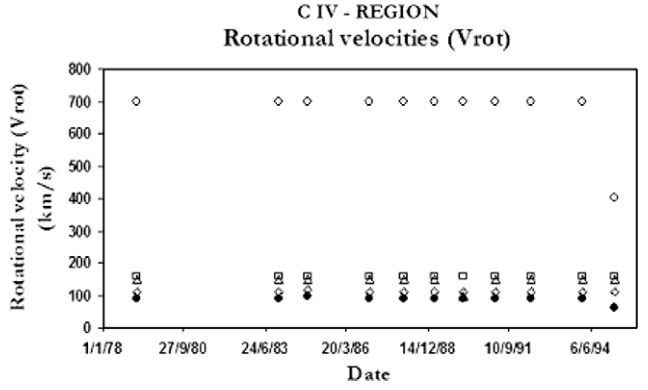

Fig. 11. Timescale changes of the apparent rotational velocities (V_{rot}) (km/s) of the C IV resonance lines ($\lambda\lambda$1548.155, 1550.774 Å) for the independent density regions of matter which create the five satellite components in the spectra of the Oe star HD 93521. The low value (about 400 km/s) in the first component has been tested carefully (Danezis et al., 2007b).

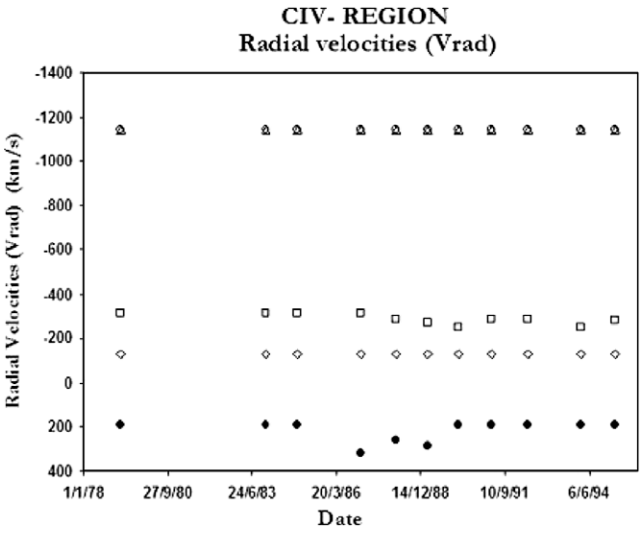

Fig. 12. Timescale changes of the radial velocities (V_{rad}) (km/s) of the $\lambda\lambda$ 1548.155, 1550.774 Å C IV resonance lines for the independent density regions of matter which create the five satellite components in the spectra of the Oe star HD 93521 (Danezis et al., 2007b).

the kinematical parameters of the density regions that create the SACs/DACs (Fig. 9) and the relation among these parameters (Fig. 10). Fig. 9 shows the radial velocities (V_{rad}) in the C IV region (up) and in the N V region (down) as a function of the spectral subtype. We detect two levels of radial velocities in both regions (Antoniou et al., 2008). In Fig. 10 we present the relation between the rotational and random velocities of the density regions that create the C IV (a) and the N V (b) spectral lines, in the studied 20 Oe stars. Finally, in a statistical study of the Oe star HD 93521 (Danezis et al., 2007b) we calculated the timescale changes of the kinematical parameters of the density regions that create the C IV resonance lines (Figs. 11 and 12).

5. Conclusions

In this review we discuss the complex absorption lines in spectra of hot emission stars and quasars. We propose the GR model that can describe such complex spectral line taking into account the ejection of material (radial velocity) as well as rotational and micro-turbulent velocity in the density region around the objects. In brief, the results of our study are as follows:

1. We applied successfully the GR model to a great number of spectral lines of hot emission stars and quasars.
2. We were able to explain the origin of DACs phenomenon and to propose the SACs phenomenon in order to explain the complex structure of the observed profiles of many spectral lines that are created in the environment of hot emission stars. Especially, we were able to reproduce and explain the complex profiles of the spectral lines that are created in the plasma condensations formed in the density regions of hot emission stars (such as the post-coronal regions). These regions lie near the star and are formed by the plasma which is violently ejected from the stellar active regions. This means that the material that comes from the star has not the form of a classical stellar wind.

By the calculation of a number of parameters for the first time, we are able to study the physical laws that exist in the regions where the spectral lines that present DACs and SACs are created.

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References

Antoniou, A., Danezis, E., Lyratzi, E., Nikolaidis, D., Popović, L.Č., Dimitrievć, M.S., 2008. JPhCS 133a, 2028.
Bates, B., Gilheany, S., 1990. MNRAS 243, 320.
Bates, B., Halliwell, D.R., 1986. MNRAS 223, 673.
Cidale, L.S., 1998. ApJ 502, 824.
Cranmer, S.R., Owocki, S.P., 1996. ApJ 462, 469.
Cranmer, S.R., Smith, M.A., Robinson, R.D., 2000. ApJ 537, 433.
Danezis, E. 1984. The Nature of Be Stars, Ph.D. Thesis, University of Athens.
Danezis, E. 1987. IAU, Colloq. No. 92, Physics of Be Stars, Cambridge University Press.
Danezis, E., Theodossiou, E., Laskarides, P.G., 1991. Ap&SS 179, 111.
Danezis, E., Nikolaidis, D., Lyratzi, V., Stathopoulou, M., Theodossiou, E., Kosionidis, A., Drakopoulos, C., Christou, G., Koutsouris, P., 2003. Ap&SS 284, 1119.
Danezis, E., Nikolaidis, D., Lyratzi, V., Popović, L.Č., Dimitrijević, M.S., Theodossiou, E., Antoniou, A., 2005. Mem. Soc. It. Suppl. 7, 107.
Danezis, E., Popović, L.Č., Lyratzi, E., Dimitrijević, M.S., 2006. AIP Conf. Proc. 876, 373.
Danezis, E., Nikolaidis, D., Lyratzi, E., Popović, L.Č., Dimitrijević, M.S., Antoniou, A., Theodossiou, E., 2007a. PASJ 59, 827.
Danezis, E., Antoniou, A., Lyratzi, E., Nikolaidis, D., Popović, L.Č., Dimitrievć, M.S., Theodossiou, E. 2007. Long term variability of the coronal and post-coronal C IV region of the Oe star HD 93521" in UV astronomy: stars from birth to death. In: Gómez de Castro, Ana I., Barstow, Martin A. (Eds.), Proceedings of the Joint Discussion No. 4 During the IAU General Assembly of 2006, Editorial Complutense, Madrid, p. 113.
Franco, M.L., Stalio, R., 1983. MmSAL 54, 537.
Franco, M.L., Stalio, R., Kontizas, E., Kontizas, M., 1983. A&A 122, 97.
Fullerton, A.W., Massa, D.L., Prinja, R.K., Owocki, S.P., Cranmer, S.R., 1997. A&A 327, 699.
Gilheany, S., Bates, B., Catney, M.G., Dufton, P.L., 1990. Ap&SS 169, 85.
Grady, C.A., Sonneborn, G., Chi-chao, Wu., Henrichs, H.F., 1987. ApJ Suppl. 65, 673.
Henrichs, H.F. 1984. In: Rolfe, E., Battrick, B. (Eds.), Proceedings of the Fourth European IUE Conference, ESA SSSP-218, p. 43.
Kaper, L., Henrichs, H.F., Nichols, J.S., Snoek, L.C., Volten, H., Zwarthoed, G.A.A., 1996. A&A Suppl. 116, 257.
Kaper, L., Henrichs, H.G., Fullerton, A.W., Ando, H., Bjorkman, K.S., Gies, D.R., Hirata, R., Dambe, E., McDavid, D., Nichols, J.S., 1997. A&A 327, 281.
Kaper, L., Henrichs, H.F., Nichols, J.S., Telting, J.H., 1999. A&A 344, 231.
Lamers, H.J.G.L.M., Gathier, R., Snow, T.P., 1982. ApJ 258, 186.
Lamers, H.J.G.L.M., Snow, T.P., de Jager, C., Langerwerf, A., 1988. ApJ 325, 342.
Lyratzi, E., Danezis, E., 2004. AIP Conf. Proc. 740, 458.
Lyratzi, E., Danezis, E., Nikolaidis, D., Popović, L.Č., Dimitrievć, M.S., Theodossiou, E., Antoniou, A., 2005. Mem. Soc. It. Suppl. 7, 114.
Lyratzi, E., Danezis, E., Antoniou, A., Nikolaidis, D., Popović, L.Č., Dimitrievć, M.S. 2007. The complex structure of the Si IV 1393.755, 1402.77 Å regions of 68 Be-type stars in UV astronomy: stars from birth to death. In: Gómez de Castro, Ana I., Barstow, Martin A. (Eds.), Proceedings of the Joint Discussion No. 4 During the IAU General Assembly of 2006, Editorial Complutense, Madrid, p. 137.
Lyratzi, E., Danezis, E., Popović, L.Č., Dimitrijević, M.S., Nikolaidis, D., Antoniou, A., 2007. PASJ 59, 357.
Markova, N., 2000. A&A Suppl. 144, 391.
Meilland, A., Stee, Ph., Zorec, J., Kanaan, S., 2006. A&A 455, 953.
Mullan, D.J., 1984a. ApJ 283, 303.
Mullan, D.J., 1984b. ApJ 284, 769.
Mullan, D.J., 1986. A&A 165, 157.
Prinja, R.K., Howarth, I.D., 1988. MNRAS 233, 123.
Rivinius, Th., Stahl, O., Wolf, B., Kaufer, A., Gang, Th., Gummersbach, C.A., Jankovics, I., Kovacs, J., Mandel, H., Peitz, J., Szeifert, Th., Lamers, H.J.G.L.M., 1997. A&A 318, 819.
Sahade, J., Brandi, E., 1985. Rev. Mex. Astron. Astrofis. 10, 229.
Sahade, J., Brandi, E., Fontela, J.M., 1984. A&A Suppl. 56, 17.
Tuthill, P., Monnier, J., Danchi, W., 1999. Nature 398, 487.
Underhill, A.B., 1975. ApJ 199, 691.
Underhill, A.B., Doazan, V. 1982. B Stars With and Without Emission Lines, NASA SP–456, Part II, Chapters 10, 13.
Underhill, A.B., Fahey, R.P., 1984. ApJ 280, 712.
Waldron, W.L., Klein, L., Altner, B., 1992. ASP Conf. Series 22, 181.
Waldron, W.L., Klein, L., Altner, B., 1994. ApJ 426, 725.

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The project of Serbian Virtual Observatory and data for stellar atmosphere modeling

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ABSTRACT

We review recent developments in Serbian Virtual Observatory (SerVO) as well as developments surrounding Virtual Atomic and Molecular Data Center. Main components of SerVO are going to be the archive of photographic plates, database of Stark broadening parameters and stellar evolution database. Photographic plates were obtained at Belgrade Observatory from 1936 to 1996. Data for Stark broadening were obtained using semiclassical perturbation and modified semiempirical theories. Stellar evolution database is a mirror of Darthmouth evolution database with improvement and VO compatible outputs.
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1. Introduction

Astronomy is very well positioned to exploit advances in the information technology. It comes from its early commitment to formatting standards, i.e. flexible image transport system (FITS) came about in mid-80s of the last century. Also, today astronomers universally use digital detectors which allow much quicker acquisition of data. And, from the early days, astronomers were committed to data preservation and data reuse.

Virtual observatories are fairly new concept in astronomy as international, community based initiative. Their origin can be traced to the NASA centers for mission oriented datasets in early 1990s. Also, in the mid-90s two large all sky surveys appeared (i.e. 2MASS and SDSS), so large quantity of data became available for the general use. Originally main aim of virtual observatories was to find, retrieve and analyze astronomical data from ground and space based telescopes worldwide.

Virtual observatories today combine research in different areas of astrophysics (some of which are fairly new): multi-wavelength astrophysics archival research survey astronomy temporal astronomy theory and simulations (comparisons with observations) and information technology such as Moore's law (amount of information that can be processed doubles approximately every two years) digital detectors massive data storage the Internet data representation standards.

Virtual observatories are not only facilities for accessing data, but also provide data analysis techniques, common standards, wide network bandwidth and state of the art analysis tools. We can briefly compare the 'normal' and virtual observatories as follows. The 'normal' observatories have telescopes for gathering electromagnetic radiation or particles, instruments for analyzing and recording as well as different facilities for support of operation. The virtual observatories consist of data centers, loads of astronomical data, software systems and processing capabilities.

1.1. Organization of virtual observatories

International Virtual Observatory Alliance (IVOA, www.ivoa.net) is organization which was formed in June of 2002. Its mission is to facilitate the international coordination and collaboration necessary for the development and deployment of the tools, systems and organizational structures necessary to enable the international utilization of astronomical archives as an integrated and interoperating virtual observatory. So the work of the IVOA mainly focuses on the development of standards.

European Virtual Observatory – Euro-VO is an organization which aims at deploying VO in Europe. Its main objectives are: technology take-up, VO compliant resource provision, building the technical infrastructure, support its utilization by the scientific community.

Euro-VO is organized in three main parts:

Facility center (VOFC) is an organization that provides the EURO-VO with a centralized registry for resources, standards and

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certification mechanisms as well as community support for VO technology take-up and dissemination and scientific program support using VO technologies and resources.

Technology center (VOTC) is a distributed organization that coordinates a set of research and development projects on the advancement of VO technology, systems and tools in response to scientific and community requirements.

Data Center Alliance (DCA) is an alliance of European data centers who will populate the EURO-VO with data, provide the physical storage and computational fabric and who will publish data, metadata and services to the EURO-VO using VO technologies. Many types of contribution are possible in DCA: data archives, with a particular emphasis put on 'science ready' data; added-value data bases, services; tools, software suites and algorithms, for instance for data visualization, data analysis and data mining; thematic services to help solving a well-defined science question; full data analysis or research environments. New types of services are emerging, with in particular theoretical services, providing modeling results, or matching models with observations.

2. Serbian Virtual Observatory

Serbian Virtual Observatory is a new project whose funding was approved through a grant TR13022 from Ministry of Science and Technological Development of Republic of Serbia. Duration of the project is 33 months from April 1st 2008 till December 31st 2010. The project objectives are:

- establishing SerVO and join the Euro-VO and IVOA;
- establishing SerVO data Center for digitizing and archiving astronomical data obtained at Belgrade Astronomical Observatory;
- development of tools for visualization of data.

Main aim is to publish data obtained by Serbian astronomers as well as to provide astronomers in Serbia with VO tools for their research (see Fig. 1). In the first three years of the project the main goals are:

- digitization and publishing in VO photo-plates from the archive of AOB;
- publishing, together with Observatoire de Paris, STARK-B – Stark broadening data base containing as the first step Stark broadening parameters obtained within the semiclassical-perturbation approach by two of us (MSD-SSB) in VO compatible format;
- make a mirror site for DSED (Darthmouth Stellar Evolution Database – Dotter et al. (2007, 2008)) in the context of VO.

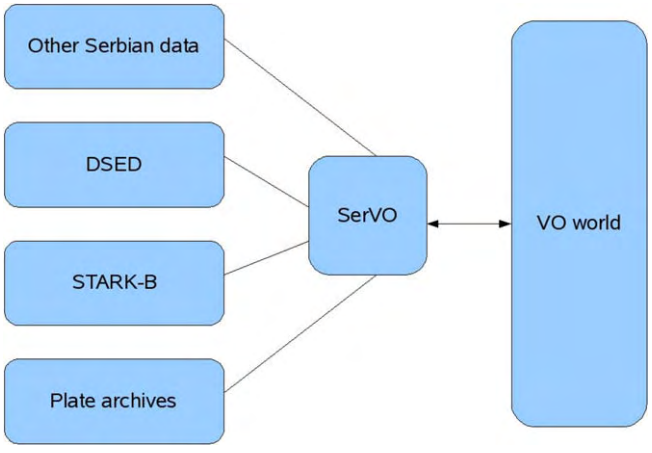

Fig. 1. Content of Serbian Virtual Observatory.

The digitization and publication in VO of around 14,500 photoplates archived on Belgrade Astronomical observatory, as well as stellar catalogues produced in Serbia, and digitization of astronomical publications, is in progress. Also, together with French colleagues, in progress is the development of the database STARK-B with Stark broadening data of interest for stellar spectra analysis and modeling, produced during 30 years of French–Serbian collaboration. It will enter in VAMDC – Virtual Atomic and Molecular Data Center, MOLAT and SerVO.

2.1. Archives of photographic plates

The archives of photographic plates of Belgrade Astronomical Observatory contain 14,500 wide field plates, obtained between 1936 and 1996, and our objective is that they become accessible by astronomical community through Serbian Virtual Observatory. The plates are preparing to enter in SerVO in collaboration with the Milcho Tsvetkov, Katya Tsvetkova and their team (Tsvetkova et al., 2009) who created Wide-Field Plate Database (http://www.skyarchive.org) in the Institute of Astronomy of Bulgarian Academy of Sciences.

Informal collaboration in the wide-field plate archiving between Astronomical Observatory of Belgrade and the team of the WFPDB has existed since 1999. In 2004 a project entitled "Development and Application of Astronomical Databases" within the frame of the bilateral academic cooperation between Astronomical Observatory of Belgrade and Space Research Institute of Bulgarian Academy of Sciences (in that time a base institution of the WFPDB project) was signed for the period 2004–2006. Now within the frame of the new project between Astronomical Observatory of Belgrade and Institute of Astronomy of Bulgarian Academy of Sciences, running for a period 2007–2009, continues the work on the Belgrade observatory plates. The plates have been accumulated within the frames of the observational programs: Minor planets tracking, search for new objects (33 new minor planets), observations of comets, observations of the Moon, major planets and their satellites, transit of Mercury, lunar occultations, variable stars, double stars, stellar clusters. The working programme of the current bilateral project includes:

Cataloguing of the Belgrade wide-field plate archives, i.e. preparation of computer-readable versions in the WFPDB standard format and inclusion in the SerVO and WFPDB with online access to the descriptive plate information.

Plate digitization with estimation of the quality of the digitization data, linkage of the scanned plate images (plate previews – with minimal resolution for quick plate visualisation and quick online access in TIFF format and compressed 2000×2000 pxl JPEG format, and real scans – for photometric or astrometric tasks with optimal big resolution in the VO required accepted FITS format) to SerVO and WFPDB and online access. The standards and metadata for digitized photographic plates in order to provide indexing, accessing, preserving, and searching for plate images are similar to the developed ones in AIP for the Potsdam Carte du Ciel plates included in the German Astrophysical Virtual Observatory (GAVO, http://vo.aip.de/plates/). The search interface for the scanned plates give information for the plate identifier, coordinates, date, file type (compressed JPEG, TIFF, FITS format), header of the FITS file, file size, and the scan.

Plate processing with the routines supplied by IRAF software packages and IDL astronomy users library.

Application of archived plates for different astronomical tasks.

Exchange of experience in development and application of astronomical databases.

Organization of mirror sites of the databases.

2.2. Stellar catalogues

A large amount of observational data is published by the staff of Belgrade Astronomical Observatory in different stellar catalogues. Such catalogues are published by Sofija Sadžakov, Miodrag Dačić, Zorica Cvetković, Dušan Šaletić, Georgije Popović, Milan Mijatov, Djordje Teleki, Djura Božičković and Veselka Trajkovska (Sadžakov and Saletić, 1972, 1975; Popović, 1974; Sadžakov, 1978; Sadžakov et al., 1981, 1991, 1992, 1996, 1997; Sadžakov and Dačić, 1989, 1990; Mijatov et al., 1991; Cvetković, 1992). Our intention is to include them also in the future in SerVO. Additionally, in SerVO will enter data on around 7000 observed double stars collected by Popović et al. (1998), which are an important reference for double system orbits considerations.

2.3. DSED in SerVO

Members of our team contributed to the development of Dartmouth Stellar Evolution Database which has been recently published (Dotter et al., 2007, 2008). It consists of evolutionary tracks and isochrones for initial stellar mass from one tenth to four solar masses. They were evolved from pre-main sequence state to either of runaway fusion or 100 Gyrs. Metalicities considered were [Fe/H] from −2.5 to +0.5 and [α/Fe] −0.2 to +0.8 and initial mass fraction of helium was changed from 0.25 to 0.4. Our contribution was in the calculation of the outer boundary conditions for the atmospheric structures using general stellar atmosphere code PHOENIX. Using this kind of boundary conditions allows an easy generation of various parameters for population synthesis (i.e. colors, low dispersion spectra of star clusters and galaxies).

In the context of VO we intend to add an option of 'VO table output' for the whole set of data and host a mirror site at SerVO.

2.4. STARK-B

Theory is fairly new addition in the context of Virtual Observatory. At Belgrade Observatory there exist large quantity of calculated data for Stark broadening parameters (line widths and shifts). Namely, in order to provide Stark broadening data needed for investigation and modelling of astrophysical and laboratory plasmas Milan S. Dimitrijević and Sylvie Sahal-Brećhot, to whom joined Luka Č. Popović, Miodrag Dačić, Zorica Cvetković, Andjelka Kovačević, Zoran Simić, partly in collaboration with Magdalena Christova from Sofia, and Nebil Ben Nessib, Walid Mahmoudi, Rafik Hamdi and Besma Zmerli from Tunisia, presented in a series of papers results of determinations of Stark widths and shifts (see e.g. Dimitrijević, 1996) within the semiclassical-perturbation approach (Sahal-Bréchot, 1969a,b). Up to now, results for 79 He, 62 Na, 51 K, 61 Li, 25 Al, 24 Rb, 3 Pd, 19 Be, 270 Mg, 31 Se, 33 Sr, 14 Ba, 189 Ca, 32 Zn, 6 Au, 48 Ag, 18 Ga, 70 Cd I, 9 Cr I, 4 Te I, 25 Ne I, 28 Ca II, 30 Be II, 29 Li II, 66 Mg II, 64 Ba II, 19 Si II, 3 Fe II, 2 Ni II, 22 Ne II, 5 F II, 1 Cd II, 1 Kr II, 2 Ar II, 7 Cr II, 12 B III, 23 Al III, 10 Sc III, 27 Be III, 5 Ne III, 32 Y III, 20 In III, 2 Tl III, 5 F III, 2 Ne IV, 10 Ti IV, 39 Si IV, 90 C IV, 5 O IV, 114 P IV, 2 Pb IV, 19 O V, 30 N V, 25 C V, 51 P V, 34 S V, 16 Si V, 26 V V, 26 Ne V, 30 O VI, 21 S VI, 2 F VI, 15 Si VI, 14 O VII, 10 F VII, 10 Cl VII, 20 Ne VIII, 4 K VIII, 9 Ar VIII, 6 Kr VIII, 4 Ca IX, 30 K IX, 8 Na IX, 57 Na X, 48 Ca X, 4 Sc X, 7 Al XI, 4 Si XI, 18 Mg XI, 4 Ti XI, 10 Sc XI, 9 Si XII, 27 Ti XII, 61 Si XIII and 33 V XIII multiplets are published. In fact, this is the main result of collaboration between M.S. Dimitrijević and S. Sahal-Bréchot, which started in 1978.

In order to complete as much as possible such data, Milan S. Dimitrijević, Luka Č. Popović, Vladimir Kršljanin, Dragana Tankosić, Nenad Milovanović, Saša Simić, Zoran Simić, Miodrag Dačić, Predrag Jovanović and Andjelka Kovačević used the modified semiempirical approach (Dimitrijević and Konjević, 1980) for emitters where atomic data are not sufficiently complete to perform an adequate semiclassical-perturbation calculation. Developed is also collaboration with Tunisia on this type of Stark broadening parameter calculations, so that some of results are obtained with Nebil Ben Nessib, Walid Mahmoudi and Haykel Elabidi as coauthors. Stark line widths and in some cases also shifts of the following emitters spectral lines were calculated: Ar II, Fe II, Pt II, Bi II, Zn II, Cd II, As II, Br II, Sb II, I II, Xe II, Mn II, La II, Au II, Eu II, V II, Ti II, Kr II, Na II, Y II, Zr II, Sc II, Nd II, Be III, B III, S III, C III, N III, O III, F III, Ne III, Na III, Al III, Si III, P III, S III, Cl III, Ar III, Mn III, Ga III, Ge III, As III, Se III, Zn III, Mg III, La III, V III, Ti III, Bi III, Sr III, Cu III, Co III, Cd III, B IV, Cu IV, Ge IV, C IV, N IV, O IV, Ne IV, Mg IV, Si IV, P IV, S IV, Cl IV, Ar IV, V IV, Ge IV, C V, O V, F V, Ne V, Al V, Si V, N VI, F VI, Ne VI, Si VI, P VI, and Cl VI.

Stark broadening of spectral lines is a line broadening mechanism, generated by interaction of emitting/absorbing atoms and ions with charged particles. The corresponding Stark broadening parameters are of interest for diagnostics, modelling, investigation and analysis of laboratory and stellar plasmas as well as for laser produced plasmas, fusion plasmas and plasmas in technology.

BELDATA was a precursor of SerVO and its main content was database on Stark broadening parameters. A history of BELDATA can be traced in Popović et al. (1999a,b, 2002), Milovanović et al. (2000a,b), Dimitrijević and Popović (2006) and Dimitrijević et al. (2003). After intensification of collaboration with French colleagues around MOLAT database of Paris observatory BELDATA became STARK-B. This database is devoted to modellisation and spectroscopic diagnostics of stellar atmospheres. Its content may be also useful for research and design of lasers and light sources based on plasma. In addition, it is also devoted to laboratory plasmas, laser equipments, fusion and technological plasmas. So, the domain of temperatures and densities covered by the tables is wide and depends on the ionization degree of the considered ion. The temperature can vary from several thousands for neutral atoms to several hundred thousands or millions of Kelvin for highly charged ions. The electron or ion density can vary from 10^{12} (case of stellar atmospheres) to several times 10^{22} cm^{-3} (of interest for subphotospheric layers, some laboratory plasmas and inertial fusion research).

The impact approximation and the isolated line approximation are applied. The basis for calculations is the computer code which evaluates electron and ion impact broadening of isolated spectral lines of neutral atoms and ions, using the semiclassical-perturbation approach developed by Sahal-Bréchot (1969a,b, 1974), and supplemented in Fleurier et al. (1977). This computer code has been updated by Dimitrijević and Sahal-Bréchot (1984) and following papers. For the review and all updates see Dimitrijević (1996).

The accuracy of the data varies from about 15–20% to 40% and more, depending on the complexity of the spectrum, degree of excitation of the upper level, and on the quality of the used atomic structure entering the calculation of scattering S-matrix leading to the widths and shifts. The more the upper level is excited, the semiclassical approximation is more suitable, but it is more difficult to find a sufficiently complete set of input atomic data.

The simple graphical interface to the data is provided (see http://stark-b.obspm.fr/elements.php). User first chooses the element of interest from the periodic system of elements. After that the ionization stage, perturber(s), perturber density, transition and plasma temperature can be set and page with description of data and table with shifts and widths is generated. Two mirror sites, one in Meudon and one in Belgrade are planned.

The further development is going to be adaptation of the output to be compatible with the VO standards (which are yet to be fully defined) as well as to add more elements/ionization stages to the database.

3. Virtual Atomic and Molecular Data Centre

Virtual Atomic and Molecular Data Centre (VAMDC) is a new FP7 founded project – core consortium is made of 15 institutions from nine countries. It is foreseen that it starts on July 1st 2009 with budget of 3.35MEuros over 42 months (till December 31st 2012).

Its aim is to build accessible and interoperable e-infrastructure for atomic and molecular data upgrading and integrating extensive portfolio of database services and catering for the needs of variety of data users from academia and industry. The starting points are infrastructure and capabilities developed by EURO-VO EGEE and Astrogrid and aim is creation of core consortium and programing of a series of network and service activities to establish self-sustainable computational and data mining services.

The project consists of eight work packages: Project management, Science/Technical Coordination of the network, Dissemination and training, Infrastructure development, Support of the infrastructure, Interoperability, Publishing tools and New mining tools.

User will navigate seamesly and retrieve from 21 atomic and molecular databases (number will probably increase).

VALD: A collection of atomic and molecular data of astronomical interest maintained by seven European institutes. Main nodes are in Vienna, Uppsala and Moscow, they serve about 1000 users from 70 countries and process over 200 requests per day.

CHIANTI: Critically evaluated set of up-to-date atomic data to analyze the spectra from optically thin astrophysical plasmas. It lists experimental and calculated wavelengths, radiative data and rates for electron and proton collisions.

CDMS: It provides recommendations for spectroscopic transition frequencies and intensities for atoms and molecules of astronomical interest and for studying the Earth atmosphere.

BASECOL: Excitation rate coefficients for ro-vibrational excitation of molecules by electrons, He and H2, mainly used for the study of interstellar, circumstellar and cometary atmospheres.

STSP: Spectroscopic laboratory data of molecular and atomic solids and liquids comprising from the near UV to the far-infrared.

UMIST: Reaction rate data for chemical kinetic modeling of astronomical regions.

KIDA: This database will list chemical reactions that are included in the modeling of the chemistry of the interstellar medium and planetary atmospheres.

PAH: It lists general energetics, ground-state optimized geometries, harmonic vibrational frequencies and IR activities and photoabsorption cross-sections for polycyclic aromatic hydrocarbons and carbon clusters.

LASP: This database contains: (i) IR spectra of molecules in the solid phase for both pure species and their mixtures before and after processing with energetic ions and UV photons; (ii) IR optical constants of molecules in the solid phase and of frozen molecules after processing with energetic ions; (iii) band strengths of IR absorption bands and (iv) density values of frozen samples.

STARK-B – BELDATA: Calculated widths and shifts for isolated atomic lines due to electron and ion collisions. They are used in the modeling and diagnostics of stellar atmospheres and envelopes.

Spectr-W3: Experimental, calculated, and compiled data on ionization potentials, energy levels, wavelengths, radiation transition probabilities and oscillator strengths and parameters for analytical approximations of electron-collisional cross-sections and rates for atoms and ions.

CDSD: Calculated spectral line parameters for seven isotopologues of carbon dioxide.

OZONE: Spectral line parameters, simulated and observed absorption spectra (microwave to IR) and other relevant information for the ozone molecule.

SPECTRA: A compilation of the well-known databases HITRAN, GEISA, HITEMP and other line lists.

W@DIS: Levels, transition and line profile characteristics of the water molecule and its isotopologues.

TOPbase: Contains Opacity Project LS-coupling energy levels, gf-values and photoionization cross sections for light elements ($Z \leqslant 26$) of astrophysical interest.

TIPbase: Contains Intermediate-coupling energy levels, A-values and electron impact excitation cross sections and rates for astrophysical applications ($Z \leqslant 28$). Computed by the IRON Project.

OPserver: Remote, interactive server for the computation of mean opacities for stellar modeling using the Iron Project monochromatic opacities.

XSTAR: An atomic database for the modeling of photoionized plasmas based on the database currently used by the code XSTAR.

HITRAN: It lists individual line parameters for molecules in the gas phase (microwave through to the visible), photoabsorption cross-sections for 39 molecules and refractive indices of several atmospheric aerosols.

NIST: It lists evaluated data on about 77,000 energy levels and 144,000 spectral lines from 99 chemical elements. Additional databases contain critically compiled wavelengths (20,170), energy levels, line classifications and transition probabilities for elements of astrophysical interest and NLTE population kinetics data. It maintains three bibliographic databases with references on atomic energy levels and spectral lines, transition probabilities, spectral line shapes and line broadening parameters.

3.1. Serbian contribution

The main contribution of Serbian astronomers to the VAMDC is through STARK-B database. We also aim to test interoperability and applicability of data from the viewpoint of modelling of stellar atmospheres. We expect to contribute to definition of standards as well as organizing some regional and project meetings for dissemination of results. Of course, using newly defined standards for the communicating of data between different groups will require some intervention in most codes.

In the light of VAMDC more critical evaluation of data is needed. It is not important only to have data but also to be able to use them properly. Also it is expected that through VAMDC producers of atomic and molecular data will get a proper credit.

4. Conclusion

We reviewed recent developments at Serbian and European VO space with emphasis on data for modelling of stellar atmospheres. Initiatives like VAMDC are important for both producers of atomic and molecular data and stellar atmosphere modellers as one of prime users. VAMDC is an example of the global collaborations and innovations in e-science. It is expected to become a major European cyber-infrastructure with worldwide impact.

We can expect very dynamical few years, so watch this space...

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References

Cvetković, Z., 1992. A preliminary compilation of DS-program star positions. A&AS 96, 191.

Dimitrijević, M.S., 1996. J. Appl. Spectrosc. 63, 684.

Dimitrijević, M.S., Konjević, N., 1980. JQSRT 24, 451.

Dimitrijević, M.S., Sahal-Bréchot, S., 1984. JQSRT 31, 301.

Dimitrijević, M.S., Popović, L.Č., Bon, E., Bajčeta, V., Jovanović, P., Milovanović, N., 2003. Publ. Astron. Obs. Belgrade 75, 129.

Dimitrijević, M.S., Popović, L.Č., 2006. In: Tsvetkov, M., Golev, V., Murtagh, F., Molina R. (Eds.). Virtual Observatory; Plate Content Digitization, Archive Mining, Image Sequence Processing. Heron Press Science Series, Sofia, pp. 115-123.

Dotter, A., Chaboyer, B., Ferguson, J.W., Lee, H.-C., Worthey, G., Jevremović, D., Baron, E., 2007. ApJ 666, 403.

Dotter, A., Chaboyer, B., Jevremović, D., Kostov, V., Baron, E., Ferguson, J.W., 2008. ApJS 178, 89.

Fleurier, C., Sahal-Bréchot, S., Chapelle, J., 1977. JQSRT 17, 595.

Mijatov, M., Teleki, G., Bozhichkovitch, Dj., Trajkovska, V., 1991. Catalogue of declinations of 307 bright stars in the zone +65° to +90°. Bul. Obs. Astron. Belgrade 143, 1.

Milovanović, N., Popović, L.Č., Dimitrijević, M.S., 2000a. Publ. Astron. Obs. Belgrade 68, 117.

Milovanović, N., Popović, L.Č., Dimitrijević, M.S., 2000b. Baltic Astron. 9, 595.

Popović, G.M., 1974. The first general catalogue of double-star observations made in Belgrade in 1951–1971. Publ. Astron. Obs. Belgrade, 19.

Popović, G.M., Pavlović, R., Živkov, V., 1998. Catalogue of Double star observations made at the Belgrade observatory CDSO. Publ. Astron. Obs. Belgrade 60, 114.

Popović, L.Č., Dimitrijević, M.S., Milovanović, N., Trajković, N., 1999a. Publ. Astron. Obs. Belgrade 65, 225.

Popović, L.Č., Dimitrijević, M.S., Milovanović, N., Trajković, N., 1999b. J. Res. Phys. 28, 307–309.

Popović, L.Č., Mediavilla, E., Bon, E., Ilić, D., 2002. In: Radović, M.K., Jovanović, M.S. (Eds.). Proceedings of the XXII SPIG, Sokobanja, p. 580.

Sadžakov, S.N., 1978. General catalogue of latitude stars (IKŠZ). Publ. Astron. Obs. Belgrade, 24.

Sadžakov, S., Dačić, M., 1989. A catalogue of right ascension and declination of FK4 stars. A&AS 77, 411.

Sadžakov, S.N., Dačić, M.D., 1990. Belgrade catalogue of double stars. Publ. Astron. Obs. Belgrade, 38.

Sadžakov, S.N., Saletić, D.P., 1972. Catalogue of declinations of the latitude program stars (KŠZ). Publ. Astron. Obs. Belgrade, 17.

Sadžakov, S., Šaletić, D., 1975. Declinations and proper motions of the stars of the International Latitude Service on the basis of Meridian catalogues from 1929 to 1972. Publ. Astron. Obs. Belgrade, 21.

Sadžakov, S., Šaletić, D.P., Dačić, M.D., 1981. Catalogue of NPZT program stars. Publ. Astron. Obs. Belgrade, 30.

Sadžakov, S.N., Dačić, M.N., Cvetković, Z., 1991. A catalogue of positions of 290 stars situated in the vicinity of radio sources. AJ 101, 713.

Sadžakov, S.N., Dačić, M.D., Cvetković, Z., 1992. Catalogue of positions of 223 Ondrejov PZT stars observed at the Belgrade Observatory, Bull. Astron. Belgrade 146, 1.

Sadžakov, S.N., Dačić, M.D., Cvetković, Z., 1996. Position catalogue of 146 HLS stars and 78 radio stars observed with the Belgrade meridian circle. Bull. Astron. Belgrade 153, 1.

Sadžakov, S.N., Dačić, M.D., Cvetković, Z., 1997. Position catalogue of 351 stars situated in the vicinity of radio sources observed with the Belgrade meridian circle. Bull. Astron. Belgrade 155, 3.

Sahal-Bréchot, S., 1969a. A&A 1, 91.

Sahal-Bréchot, S., 1969b. A&A 2, 322.

Sahal-Bréchot, S., 1974. A&A 35, 319.

Tsvetkova, K., Tsvetkov, M., Protić-Benišek, V., Dimitrijević, M.S., 2009. Publ. Astron. Soc. Rudjer Bošković 9, 255.

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Stark broadening of spectral lines in chemically peculiar stars: Te I lines and recent calculations for trace elements

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ABSTRACT

With the development of astronomical observations from space, spectral lines of trace elements can now be observed in stellar spectra with good resolution, and atomic data for such atoms and ions have an increasing significance. We review here work in Belgrade on the influence of Stark broadening of trace elements on stellar spectra and present new determinations of Stark broadening parameters of neutral tellurium. Also the corresponding Stark and Doppler widths are compared in atmospheres of A type stars.
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1. Introduction

Stark broadening of neutral atom and ion lines is of interest not only for laboratory, laser produced, fusion or technological plasma investigation but also for astrophysical plasma, particularly for synthesis and analysis of high-resolution spectra obtained from space born instruments.

With the development of new space techniques, importance of data on trace element spectra increases. The spectral lines of tellurium, one of the least abundant elements in the Earth's lithosphere, but with cosmic abundance larger than for any element with atomic number greater than 40 (Cohen, 1984), are observed in stellar spectra. For example, Yuschenko and Gopka (1996), identified one line of tellurium in the Procyon photosphere spectrum, and determined the abundance of this element as $\log N(\mathrm{Te}) = 3.04$ (in the scale $\log N(\mathrm{H}) = 12.00$). de Lester (1994) notes that the three s-only isotopes of tellurium Te-122, 123 and 124 provide a unique opportunity to investigate s-process systematics, and for the estimation of the temperature and neutron density during helium burning in red giant stars. Chayer et al. (2005) observed tellurium spectral lines in ultraviolet spectra of the cool DO white dwarf HD199499, obtained with the Far Ultraviolet Spectroscopy Explorer (FUSE), the Goddard High Resolution Spectrograph (GHRS – on the Hubble Space Telescope) and the International Ultraviolet Explorer. They report as well presence of tellurium lines in FUSE and GHRS spectra of the cool DO dwarf HZ21. Since the DO white dwarfs represent the non-DA white dwarf cooling sequence with effective temperatures from approximately 45,000 K up to around 120,000 K (Dreizler and Werner, 1996), Stark broadening is very important for analysis of their spectra. Consequently, the corresponding line broadening parameters for Te I at the low temperature limit (45,000–50,000 K) and tellurium in various ionization stages for the whole temperature range of interest for DO white dwarf atmospheres are needed.

Atomic data for other trace elements are also important. For example, chromium is one of the most peculiar elements in the atmospheres of magnetic chemically peculiar stars. Cr II lines were found for example in Alpha UMi (Polaris) and HR 7308 by Andrievsky et al. (1994). Spectral lines of Cu III are of particular interest for the diagnostics and modelling of plasma created in electromagnetic macro particle accelerators (see Rasheig and Marshall, 1978). Moreover, analysis of 11 spectra of HgMn stars (Jacobs and Dworetsky, 1981), where Stark broadening is the main pressure broadening mechanism, showed the clear presence of copper and even its overabundance in 10 of 11 investigated stars. Recently for example, copper abundances in a large sample of metal-poor

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stars have been investigated (Primas and Sobeck, 2008), and zinc spectral lines are also identified in stellar spectra (Adelman, 1994). Selenium, a trace element without previous astrophysical significance, is now detected in the atmospheres of cool DO white dwarfs (Chayer et al., 2005). Many examples show presence in hot stellar atmospheres of ionized manganese, gold, indium, tin, ruthenium, rare earths and other trace elements which before the epoch of space born stellar spectroscopy were astrophysically insignificant, but now the need for their atomic data is increasing.

High-resolution spectra allow us to study different broadening effects using well-resolved line profiles. Stark broadening is the most important pressure broadening mechanism for A type stars and especially for white dwarfs. Neglecting this mechanism may therefore introduce significant errors into abundance determinations and spectra modellisation.

Here we use the semiclassical perturbation method (Sahal-Bréchot, 1969a,b) to calculate the Stark broadening parameters for 4 Te I multiplets within the ultraviolet, visible and infrared wavelength range, for temperatures between 2500 K and 50,000 K. Within this range are temperatures of interest for A and B type stars and DA, DB and cool DO white dwarfs where Stark broadening is of interest. Such temperatures may be of interest also for the modelling of subphotospheric layers even in cooler stars. Results obtained will be used for analyzing the influence of Stark broadening in A type stellar atmospheres. Also a review of work performed in Belgrade on the investigations of Stark broadening influence in stellar spectra is given.

2. Theory

Calculations have been performed within the semiclassical perturbation formalism, developed and discussed in detail by Sahal-Bréchot (1969a,b). This formalism, as well as the corresponding computer code, has been optimized and updated several times (see e.g. Sahal-Bréchot, 1974; Dimitrijević and Sahal-Bréchot, 1984; Dimitrijević et al., 1991; see also review Dimitrijević, 1996).

Within this formalism, the full width of an isolated spectral line of a neutral emitter broadened by electron impact (W) can be expressed in terms of cross sections for elastic and inelastic processes as

$$W = \frac{\lambda^2}{\pi c} N \int v f(v) dv \left(\sum_{i' \neq i} \sigma_{ii'}(v) + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_{el} + W_R \right), \tag{1}$$

and the corresponding line shift d as

$$d = \frac{\lambda^2}{2\pi c} N \int v f(v) dv \int_{R_3}^{R_D} 2\pi \rho d\rho \sin 2\phi_p \cdot s. \tag{2}$$

Here, λ is the wavelength of the line originating from the transition with initial atomic energy level i and final level f, c is the velocity of light, N is the electron density, $f(v)$ is the Maxwellian velocity distribution function for electrons, ρ denotes the impact parameter of the incoming electron, and ϕ_p is the phase shift due to the polarization potential. The inelastic cross sections $\sigma_{ij'}(v)$ (where $j = i$ or f) and elastic cross section σ_{el} are determined according to Chapter 3 in Sahal-Bréchot (1969b). The cut-offs (needed for the calculation of inelastic and elastic cross sections and the shift), included in order to maintain for the unitarity of the S-matrix, and to take into account Debye screening are described in Section 1 of Chapter 3 in Sahal-Bréchot (1969b). W_R gives the contribution of the Feshbach resonances (Fleurier et al., 1977) and this term is zero if the emitters are neutral atoms. Other differences between neutral and ionized emitters is that for calculations of the cross sections rectilinear perturber paths are taken for neutral ones and hyperbolic paths for ionized species.

The theoretical and computational differences between calculations performed by our group using the theory of Sahal-Bréchot (1969a,b) and semi-classical Stark broadening results given in Griem (1974) are explained in detail in Dimitrijević and Sahal-Bréchot (1996).

The formulae for the ion-impact broadening parameters are analogous to the formulae for electron-impact broadening. We note that the fact that the colliding ions could be treated using impact approximation in the far wings should be checked, even for stellar atmosphere densities.

It is possible also to perform calculations ab initio, using atomic energy levels and oscillator strengths calculated together with the Stark broadening parameters (Ben Nessib et al., 2004; Ben Nessib, 2009).

When the semiclassical perturbation formalism can not be applied in an adequate way, due to the lack of reliable atomic data, a modified semiempirical formalism has been used.

According to the modified semiempirical (MSE) approach (Dimitrijević and Konjević, 1980; Dimitrijević and Kršljanin, 1986, for review see Dimitrijević and Popović, 2001) the electron impact full width at half maximum (FHWM) of an isolated ion line is given by

$$W = N \frac{4\pi}{3c} \frac{\hbar^2}{m^2} \left(\frac{2m}{\pi k T} \right)^{1/2} \frac{\lambda^2}{\sqrt{3}} \cdot \left\{ \sum_{\ell_i \pm 1} \sum_{L_{i'} J_{i'}} R^2_{\ell_i, \ell_i \pm 1} \tilde{g}(x_{\ell_i, \ell_i \pm 1}) + \sum_{\ell_f \pm 1} \sum_{L_{f'} J_{f'}} R^2_{\ell_f, \ell_f \pm 1} \tilde{g}(x_{\ell_f, \ell_f \pm 1}) + \left(\sum_{i'} R^2_{ii'} \right)_{\Delta n \neq 0} g(x_{n_i, n_i + 1}) + \left(\sum_{f'} R^2_{ff'} \right)_{\Delta n \neq 0} g(x_{n_f, n_f + 1}) \right\}, \tag{3}$$

where n and ℓ are principal and angular momentum quantum numbers, and $R^2_{\ell_k, \ell_{k'}}$, $k = i, f$ is given by

$$\left(\sum_{k'} R^2_{kk'} \right)_{\Delta n \neq 0} = \left(\frac{3 n^*_k}{2Z} \right)^2 \frac{1}{9} \left(n^{*2}_k + 3\ell^2_k + 3\ell_k + 11 \right), \tag{4}$$

in the Coulomb approximation.

In Eq. (3)

$$x_{\ell_k, \ell_{k'}} = E / \Delta E_{\ell_k, \ell_{k'}}, \tag{5}$$

$k = i, f$ where $E = \frac{3}{2} kT$ is the electron kinetic energy and

$$\Delta E_{\ell_k, \ell_{k'}} = \left| E_{\ell_k} - E_{\ell_{k'}} \right|, \tag{6}$$

is the energy difference between levels ℓ_k and $\ell_k \pm 1 (k = i, f)$. Also

$$x_{n_k, n_k + 1} \approx E / \Delta E_{n_k, n_k + 1}, \tag{7}$$

where for $\Delta n \neq 0$ the energy difference between energy levels with n_k and $n_k + 1$, $\Delta E_{n_k, n_k + 1}$, is estimated as

$$\Delta E_{n_k, n_k + 1} \approx 2 Z^2 E_H / n^{*3}_k. \tag{8}$$

In Eq. (4) the effective principal quantum number is defined by

$$n^*_k = \left[E_H Z^2 / (E_{ion} - E_k) \right]^{1/2}, \tag{9}$$

Z is the residual ionic charge i.e. the charge of the rest of atom as "seen" by optical electron (for example $Z = 1$ for neutral atoms, 2 for singly charged ions, etc.), and E_{ion} is the appropriate spectral series limit.

In Eq. (3) T is the electron temperature, while $g(x)$ (Griem, 1968) and $\tilde{g}(x)$ (Dimitrijević and Konjević, 1980) denote the corresponding effective Gaunt factors.

In comparison with the semiclassical perturbation approach (Sahal-Bréchot, 1969a,b), the modified semiempirical approach requires much less atomic input data. In fact, if there are not perturbing levels strongly violating the assumed approximation, we only

need the energy levels with $\Delta n = 0$ and $\ell_{if} = \ell_{if} \pm 1$, since all perturbing levels with $\Delta n \neq 0$, needed for a full semiclassical calculation are lumped together and estimated approximately. If for the nearest perturbing levels the condition $E/\Delta E \leqslant 2$ is satisfied the simplified version of the Eq. (3) (Dimitrijević and Konjević, 1986) can be used.

3. Results and discussions

Using the semiclassical perturbation method we obtained Stark widths and shifts of four Te I multiplets for a perturber density of 10^{16} cm^{-3} and temperatures from 2500 up to 50,000 K. Calculations were performed using the atomic energy levels given by Moore (1971). The oscillator strengths required were calculated using the Coulomb approximation method described by Bates and Damgaard (1949) and the tables of Oertel and Shomo (1968). For higher levels, the method described by van Regemorter et al. (1979) was applied. Results obtained for electron-, proton-, and helium ion-impact broadening parameters are shown in Table 1. The quantity C (given in Å cm^{-3}), when divided by the corresponding full width at half maximum, gives an estimate for the maximum perturber density for which the line may be treated as isolated and the tabulated data may be used. WIDTH (Å) denotes the full line width at half maximum in Å, while SHIFT (Å) denotes line shift in Å. We note that, in the wings, the impact approximation for ions should be checked and that ions will be quasi-static in the far wings. For perturber densities lower than those tabulated here, Stark broadening parameters vary linearly with perturber density. The nonlinear behaviour of Stark broadening parameters at higher densities is the consequence of the influence of Debye shielding and was analyzed in detail in Dimitrijević and Sahal-Bréchot (1984).

As an example of the influence of Stark broadening in atmospheres of hot stars we present in Figs. 1 and 2 Stark widths of the 6s ^{5}S^o–7p ^{5}P (5125.2 Å) multiplet, and the Te I 6s ^{5}S^o–6p ^{5}P (9903.9 Å) multiplet compared with Doppler widths for a model ($T_{eff} = 10,000$ K, $\log g = 4.5$) of A type star atmosphere (Kurucz, 1979). Doppler broadening in hot atmospheres is an important broadening mechanism and by comparison of Stark and Doppler widths one can judge its importance. Even if Doppler broadening dominates the line centre, Stark broadening may influence line wings. Our results are presented in Fig. 1 as a function of Rosseland optical depth τ. It is interesting that the Stark broadening mechanism is absolutely dominant in comparison with the thermal Doppler mechanism in deeper layers of the stellar atmosphere ($\log\tau > 0.8$) for the 5125.2 Å multiplet.

There is no experimental or other theoretical data for the comparison with the calculated Stark broadening parameters of Te I spectral lines. The present demonstration in Figs. 1 and 2 that Stark broadening of Te I lines is important in deeper layers in A type star atmospheres for modelling and analyzing of neutral tellurium spectra, confirms previous findings for a number of trace elements.

The investigations of the influence of Stark broadening in stellar spectra started in Belgrade in 1988, when the influence of this broadening mechanism was analyzed for a typical late B type stellar atmosphere with $T_{eff} = 13,000$ K and $\log g = 4.2$ (Lanz et al., 1988). Attention was drawn to the errors introduced by the practice of taking 10 times the classical value of the natural width when the Stark width of a spectral line is unknown, and demonstrated the significance of taking into account this broadening mechanism.

Stark broadening of rare earth ions (La II, La III, Eu II and Eu III) was considered in chemically peculiar Ap stars by Popović et al. (1999a) and found that its neglect introduces errors in equivalent width synthesis and corresponding abundance determination. Also, the influence of Stark broadening on the so called "zirconium conflict", namely the difference in abundances obtained from weak Zr II optical lines and strong Zr III lines (detected in UV) in the spectrum of HgMn star χ Lupi, was considered (Popović et al., 2001a).

Table 1
This table shows electron-, proton- and He II- impact broadening parameters for Te I for perturber density of 10^{16} cm^{-3} and temperatures from 2500 up to 50,000 K. Transitions and wavelengths (Å) are also given in the table. By dividing C by the corresponding full width at half maximum (Dimitrijević et al., 1991), we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used. The validity of the impact approximation has been estimated for data shown in this table, by checking if the collision volume (V) multiplied by the perturber density (N) is much less than one (Sahal-Bréchot, 1969a,b). An asterisk denotes values where $0.1 < NV \leqslant 0.5$. Values with $NV > 0.5$ are deleted from the table.

Perturbers		Electrons		Protons		Helium ions	
Transition	T (K)	WIDTH (Å)	SHIFT (Å)	WIDTH (Å)	SHIFT (Å)	WIDTH (Å)	SHIFT (Å)
TeI 5p^4^{3}P–6s^{3}S^o (2244.9 Å) C = 0.46E+19	2500	0.413E−02	0.360E−02	0.111E−02	0.965E−03	0.884E−03	0.754E−03
	5000	0.492E−02	0.419E−02	0.124E−02	0.112E−02	0.992E−03	0.879E−03
	10,000	0.586E−02	0.492E−02	0.139E−02	0.128E−02	0.111E−02	0.101E−02
	20,000	0.662E−02	0.556E−02	0.156E−02	0.145E−02	0.125E−02	0.115E−02
	30,000	0.690E−02	0.571E−02	0.167E−02	0.156E−02	0.134E−02	0.124E−02
	50,000	0.721E−02	0.552E−02	0.182E−02	0.171E−02	0.145E−02	0.136E−02
TeI 5p^4^{3}P–6s^{5}S^o (2372.7 Å) C = 0.57E+19	2500	0.387E−02	0.343E−02	0.106E−02	0.925E−03	0.844E−03	0.724E−03
	5000	0.457E−02	0.399E−02	0.118E−02	0.107E−02	0.946E−03	0.841E−03
	10,000	0.548E−02	0.467E−02	0.133E−02	0.122E−02	0.106E−02	0.965E−03
	20,000	0.625E−02	0.531E−02	0.149E−02	0.138E−02	0.119E−02	0.110E−02
	30,000	0.656E−02	0.547E−02	0.159E−02	0.149E−02	0.127E−02	0.118E−02
	50,000	0.687E−02	0.533E−02	0.173E−02	0.162E−02	0.138E−02	0.129E−02
TeI 6s^{5}S^o–7p^{5}P (5125.2 Å) C = 0.57E+19	2500	0.125	0.758E−01	*0.818E−01	*0.180E−01		
	5000	0.146	0.912E−01	*0.842E−01	*0.215E−01	*0.825E−01	*0.167E−01
	10,000	0.170	0.944E−01	0.855E−01	0.251E−01	*0.842E−01	*0.197E−01
	20,000	0.196	0.894E−01	0.865E−01	0.288E−01	*0.851E−01	*0.227E−01
	30,000	0.212	0.770E−01	0.871E−01	0.311E−01	*0.855E−01	*0.246E−01
	50,000	0.230	0.638E−01	0.880E−01	0.341E−01	0.861E−01	0.271E−01
TeI 6s^{5}S^o–6p^{5}P (9903.9 Å) C = 0.99E+20	2500	0.143	−0.698E−01	0.680E−01	−0.188E−01	0.668E−01	−0.146E−01
	5000	0.151	−0.808E−01	0.688E−01	−0.217E−01	0.677E−01	−0.171E−01
	10,000	0.170	−0.948E−01	0.697E−01	−0.248E−01	0.684E−01	−0.196E−01
	20,000	0.194	−0.109	0.707E−01	−0.282E−01	0.690E−01	−0.224E−01
	30,000	0.209	−0.113	0.714E−01	−0.303E−01	0.694E−01	−0.241E−01
	50,000	0.226	−0.112	0.724E−01	−0.331E−01	0.700E−01	−0.264E−01

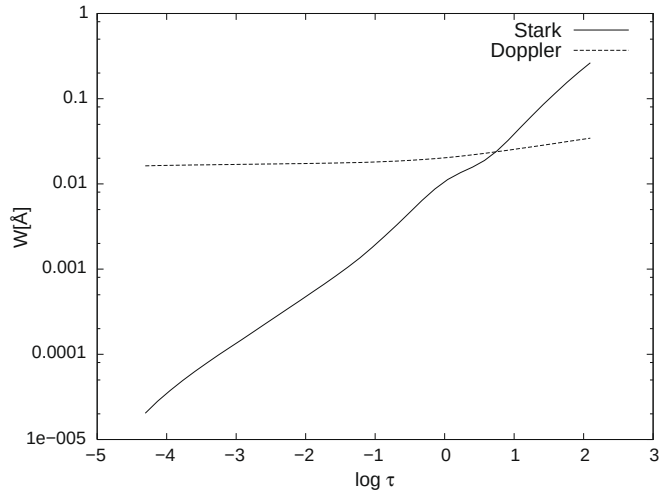

Fig. 1. Thermal Doppler and Stark widths for TeI $6s^5S^o-7p^5P$ (5125.2 Å) multiplet as functions of optical depth for an A type star ($T_{eff} = 10,000$ K, $\log g = 4.5$).

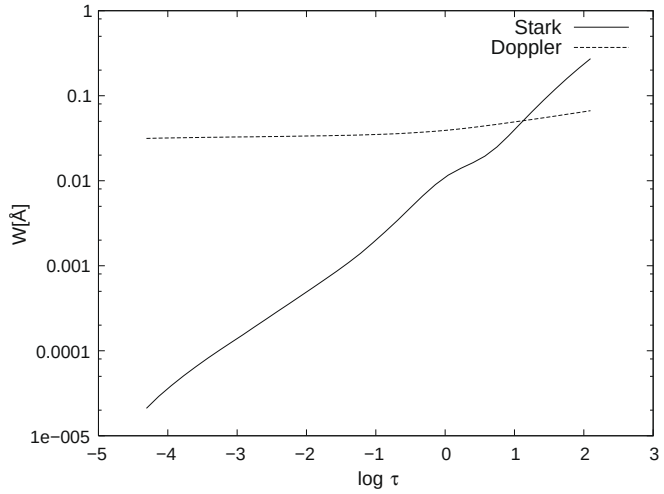

Fig. 2. Thermal Doppler and Stark widths for Te I $6s^5S^o-6p^5P$ (9903.9 Å) multiplet as functions of optical depth for an A type star ($T_{eff} = 10,000$ m, $\log g = 4.5$).

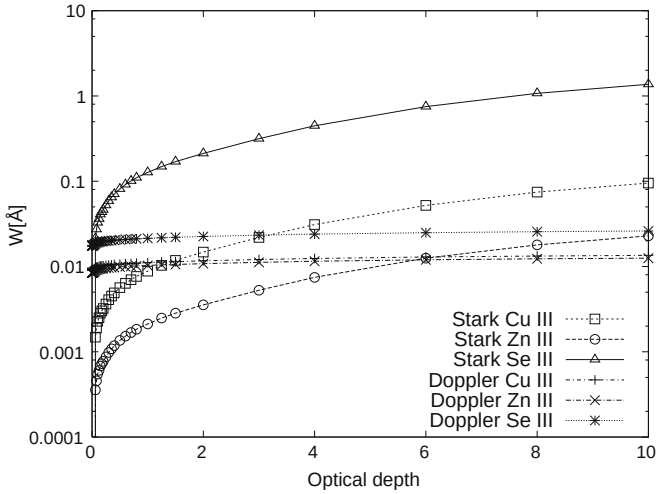

Fig. 3. Thermal Doppler and Stark widths for Cu III 4s $^2F-4p^2G^o$ ($\lambda = 1774.4$ Å), Zn III 4s $^3D-4p\ ^3P^o$ ($\lambda = 1667.9$ Å) and Se III4p5s $^3P^o-5p^3D$ ($\lambda = 3815.5$ Å) spectral lines for a DB white dwarf atmosphere model with $T_{eff} = 15,000$ K and $\log g = 7$, as a function of optical depth τ_{5150}.

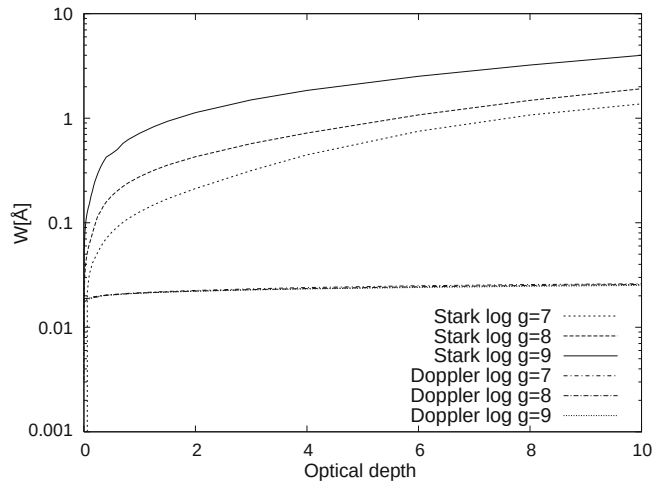

Fig. 4. Thermal Doppler and Stark widths for Se III spectral line 5s $^3P^o-5p\ ^3D$ ($\lambda = 3815.5$ Å) for a DB white dwarf atmosphere model with $T_{eff} = 150,00$ K and $7 \leqslant \log g \leqslant 9$, as a function of optical depth τ_{5150}.

In a number of papers, the influence of Stark broadening on Au II (Popović et al., 1999b), Co III (Tankosić et al., 2003), Ge I (Dimitrijević et al., 2003a), Ga I (Dimitrijević et al., 2004) and Cd I (Simić et al., 2005) on spectral lines in chemically peculiar A type stellar atmospheres was investigated and for each spectrum investigated atmospheric layers are found where the contribution of this broadening mechanism is dominant or could not be neglected. As a model for the atmosphere of an A type chemically peculiar star, a model with stellar parameters close to those of χ Lupi HgMn star of Ap type was used. Such investigations were also performed for DA and DB white dwarf atmospheres (Popović et al., 1999b; Tankosić et al., 2003) and it was found that for such stars Stark broadening is dominant in practically all relevant atmospheric layers.

For example, the influence of Stark broadening on Cu III, Zn III and Se III spectral lines in DB white dwarf atmospheres was also investigated by Simić et al. (2006) for 4s $^2F-4p\ ^2G^o$ ($\lambda = 1774.4$ Å), 4s $^3D-4p\ ^3P^o$ ($\lambda = 1667.9$ Å) and 4p5s $^3P^o-5p\ ^3D$ ($\lambda = 3815.5$ Å) by using the corresponding model with $T_{eff} = 15,000$ K and $\log g = 7$ (Wickramasinghe, 1972). For the model atmosphere of the DB white dwarfs the prechosen optical depth points at the standard wavelength $\lambda_s = 5150$ Å (τ_{5150}) are used in Wickramasinghe (1972) and in Simić et al. (2006). As one can see in Figs. 3 and 4, for the plasma conditions in the DB white dwarf atmospheres, thermal Doppler broadening is much less important compared to Stark broadening. For example the Stark width of the Se III 3815.5 Å line is larger than the Doppler one by up to two orders of magnitude within the range of optical depths considered. Much larger Stark widths in DB white dwarf atmospheres in comparison with A type stars are the consequence of larger electron densities due to much larger $\log g$ and larger T_{eff}, so that electron-impact (Stark) broadening is more effective.

Hamdi et al. (2008) investigated the influence of Stark broadening on Si VI lines in DO white dwarf spectra for $50,000\ \text{K} \leqslant T_{eff} \leqslant 100,000$ K and $6 \leqslant \log g \leqslant 9$. It was found that the influence increases with $\log g$ and is dominant in broad regions of the atmospheres considered.

In Popović et al. (2001b), Stark broadening of 38 Nd II lines was analyzed in spectra of B, A, F and G type stellar atmospheres. It was found that the maximum influence of Stark broadening of Nd II lines is for A type stars. For G and F type stars the influence of Stark broadening decreases due to the decrease of effective electron

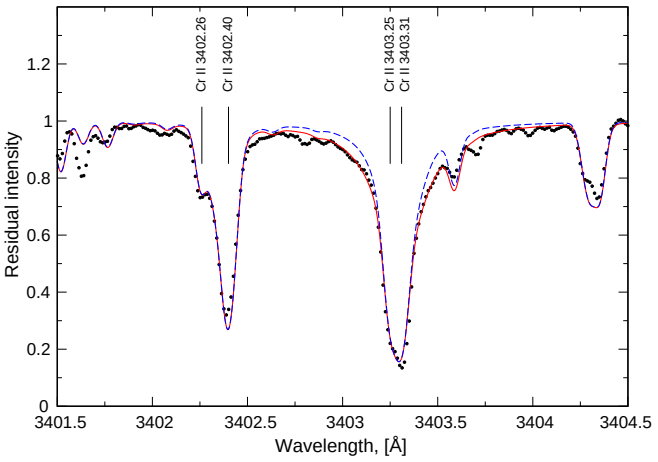

Fig. 5. Comparison between the observed Cr II 3403.30 line profile (dots) and synthetic calculations with the Stark parameters from paper by Dimitrijević et al. (2007) (full line) and those from Kurucz (1993) (dashed line).

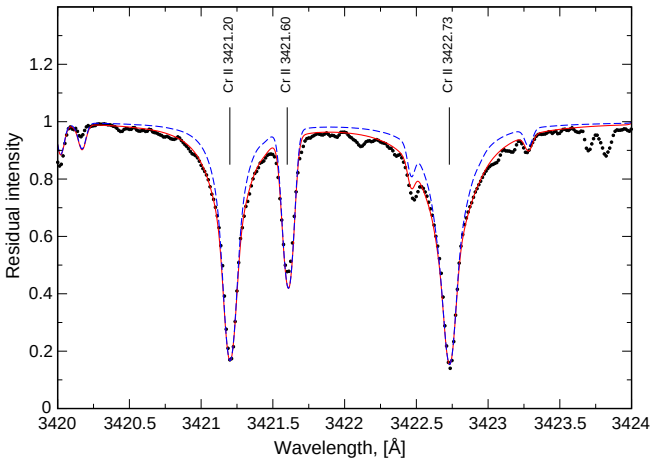

Fig. 6. The same as in Fig. 5 but for the Cr II 3421.20, 3422.73 lines.

temperature and degree of ionization. Namely at T around 10,000 K, which is typical for A type stars, hydrogen becomes mainly ionized and the role of Stark broadening increases. For B type stars this influence decreases due to decrease of the surface gravity and related electron density. Also with the increase of temperature the number of Nd II ions decrease, and that of Nd III increases so that Nd II emission is weaker. It was demonstrated also that the neglecting of Stark broadening mechanism introduces for the Nd II lines in A type stars an error of between 10% and 45% in the equivalent widths and corresponding errors in the abundances. A detailed investigation of Stark broadening of Cd III lines in F0–B0 type stars and DA and DB white dwarfs was performed by Milovanović et al. (2004) with similar conclusions.

Dimitrijević et al. (2003b) investigated the influence of Stark broadening on neutral silicon lines in spectra of normal late type A star HD 32115 and Ap stars HD 122970 and 10 Aql. They found that the synthetic profile of the λ 6155.13 Å Si I line fits much better with the observed one when it was calculated using the Stark width and shift. Also authors reproduced the asymmetric and shifted profile of this line in HD 122970 reasonably well using the uniform distribution of neutral silicon and their results for Stark broadening parameters. Authors stressed that with their theoretical Stark broadening parameters the sensitivity of Si I λ 6155.13 Å asymmetry to Si abundance changes in the 10 Aql atmosphere, can be successfully used in empirical studies of abundance stratification. They found also that for the Si I lines considered the contribution of electron impact is dominant, but impact with protons and He II ions should be taken into account as well. Similar results were found by Dimitrijević et al. (2005) for neutral chromium lines in the spectrum of magnetic Ap star β Cr B where, depending on the electron temperature the contribution of proton-impact broadening may be even larger than the electron-impact contribution.

Cr II lines in the spectrum of the Ap star HD 133792, for which careful abundance and stratification analysis has recently been performed by Kochukhov et al. (2006) were analyzed by Dimitrijević et al. (2007). HD 133792 has an effective temperature of $T_{eff} = 9400$ K, $\log g = 3.7$, and a mean Cr overabundance +2.6 dex relative to the solar Cr abundance (Kochukhov et al., 2006). All calculations were carried out with the improved version SYNTH3 of the code SYNTH for synthetic spectrum calculations. Stark damping parameters were introduced in the spectrum synthesis code. The stratified Cr distribution in the atmosphere of HD 133972 derived by Kochukhov et al. (2006) was used. Fig. 5 shows a comparison between the observed line profiles of Cr II lines 3403.30 Å and synthetic calculations with the Stark damping constants from Kurucz (1993) line lists and with the data of Dimitrijević et al. (2007). Good agreement between observations and calculations for a set of weak Cr II lines proves the use of the stratified Cr distribution, while all four strong Cr II lines demonstrate a good accuracy for the theoretical Stark broadening parameters obtained (Dimitrijević et al., 2007) (Fig. 6).

This opens up a new possibility of checking the theoretical and experimental Stark broadening results with the help of stellar spectra, which will be particularly interesting with the development of space born spectroscopy, building of giant telescopes of the new generation and increase of accuracy of computer codes for modellisation of stellar atmospheres. The Cr II lines analyzed in Dimitrijević et al. (2007) are particularly suitable for such purpose since they have good clean wings where the influence of Stark broadening is the most important.

Acknowledgements

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References

Adelman, S.J., 1994. MNRAS 271, 355.
Andrievsky, S.M., Kovtyukh, V.V., Usenko, A., 1994. A&A 281, 465.
Bates, D.R., Damgaard, A., 1949. Trans. Roy. Soc. Lond., Ser. A 242, 101.
Ben Nessib, N., 2009. New Astron. Rev. 53, 255.
Ben Nessib, N., Dimitrijević, M.S., Sahal-Bréchot, S., 2004. A&A 423, 397.
Chayer, P., Vennes, S., Dupuis, J., Kruk, J.W., 2005. ApJ 630, L169.
Cohen, B.L., 1984. Geochim. Cosmochim. Acta 48, 203.
de Lester, J.R., 1994. ApJ 434, 695.
Dimitrijević, M.S., 1996. Zh. Priklad. Spektrosk. 63, 810.
Dimitrijević, M.S., Konjević, N., 1980. JQSRT 24, 451.
Dimitrijević, M.S., Konjević, N., 1986. A&A 172, 345.
Dimitrijević, M.S., Kršljanin, V., 1986. A&A 165, 269.
Dimitrijević, M.S., Popović, L.Č., 2001. J. Appl. Spectrosc. 68, 893.
Dimitrijević, M.S., Sahal-Bréchot, S., 1984. A&A 136, 289.
Dimitrijević, M.S., Sahal-Bréchot, S., 1996. Phys. Scripta 54, 50.
Dimitrijević, M.S., Jovanović, P., Simić, Z., 2003a. A&A 410, 735.
Dimitrijević, M.S., Sahal-Bréchot, S., Bommier, V., 1991. A&AS 89, 581.
Dimitrijević, M.S., Dačić, M., Cvetković, Z., Simić, Z., 2004. A&A 425, 1147.
Dimitrijević, M.S., Ryabchikova, T., Popović, L.Č., Shylyak, D., Khan, S., 2005. A&A 435, 1191.
Dimitrijević, M.S., Ryabchikova, T., Popović, L.Č., Shylyak, D., Tsymbal, V., 2003b. A&A 404, 1099.
Dimitrijević, M.S., Ryabchikova, T., Simić, Z., Popović, L.Č., Dačić, M., 2007. A&A 469, 681.
Dreizler, S., Werner, K., 1996. A&A 314, 217.
Fleurier, C., Sahal-Bréchot, S., Chapelle, J., 1977. JQSRT 17, 595.

Griem, H.R., 1968. Phys. Rev. 165, 258.
Griem, H.R., 1974. Spectral Line Broadening by Plasmas. Academic Press, New York.
Hamdi, R., Ben Nessib, N., Milovanović, N., Popović, L.Č., Dimitrijević, M.S., Sahal-Bréchot, S., 2008. MNRAS 387, 871.
Jacobs, J.M., Dworetsky, M.M., 1981. In chemically peculiar stars of the upper main sequence. In: 23rd Int. Coll. Astrophys., Liege, Reports, Univ. Liege, p. 153.
Kochukhov, O., Tsymbal, V., Ryabchikova, T., Makaganyk, V., Bagnulo, S., 2006. A&A 460, 831.
Kurucz, R.L., 1979. Astrophys. J. Suppl. Ser. 40, 1.
Kurucz, R.L., 1993, CDROMs 13, 22, 23, SAO, Cambridge.
Lanz, T., Dimitrijević, M.S., Artru, M.C., 1988. A&A 192, 249.
Milovanović, N., Dimitrijević, M.S., Popović, L.Č., Simić, Z., 2004. A&A 417, 375.
Moore, C.E., 1971. Atomic energy levels. US Department of Commerce, vol. II. NBS, Government Printing Office, Washington, DC.
Oertel, G.K., Shomo, L.P., 1968. ApJS 16, 175.
Popović, L.Č., Dimitrijević, M.S., Ryabchikova, T., 1999a. A&A 350, 719.
Popović, L.Č., Dimitrijević, M.S., Tankosić, D., 1999b. A&AS 139, 617.
Popović, L.Č., Milovanović, N., Dimitrijević, M.S., 2001a. A&A 365, 656.
Popović, L.Č., Simić, S., Milovanović, N., Dimitrijević, M.S., 2001b. ApJS 135, 109.
Primas, F., Sobeck, J., 2008. AIP, Conf. Proc. 1001, 230.
Rasheig, S.C., Marshall, R.H.J., 1978. J. Appl. Phys. 49, 2540.
Sahal-Bréchot, S., 1969a. A&A 1, 91.
Sahal-Bréchot, S., 1969b. A&A 2, 322.
Sahal-Bréchot, S., 1974. A&A 35, 321.
Simić, Z., Dimitrijević, M.S., Milovanović, N., Sahal-Bréchot, S., 2005. A&A 441, 391.
Simić, Z., Dimitrijević, M.S., Popović, L.Č., Dačić, M., 2006. New Astron. 12, 187.
Tankosić, D., Popović, L.Č., Dimitrijević, M.S., 2003. A&A 399, 795.
van Regemorter, H., Hoang Binh, Dy., Prud'homme, M., 1979. J. Phys. B 12, 1073.
Wickramasinghe, D.T., 1972. Mem. R. Astron. Soc. 76, 129.
Yuschenko, A.V., Gopka, V.F., 1996. Astron. Astrophys. Trans. 10, 307.

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Editorial

Preface

The spectral lines, their widths, and shapes, are powerful tools for emitting/absorbing gas diagnostics in different astrophysical objects (from the Solar system to the most distant objects in the Universe – quasars). The emission/absorption lines of astrophysical objects are produced over a wide range of distances from an observer and under a wide range of physical and kinematical conditions. Therefore in astrophysical objects the lines from X-ray (Fe Kα) to the radio (radio recombination line) have been observed. On the other hand, the experimental and theoretical investigations of laboratory plasma have been applied in spectroscopic astrophysical research, especially atomic data needed for line shape calculations. The idea of the SCSLSA conference is to bring together astronomers (observers and theoreticians) and physicists to review the present stage of investigation (Serbia and elsewhere), with the aim of improving our knowledge in this field, and to better understand the significance of emission/absorption lines for future astrophysical investigations.

We started with this series of conferences with an idea to have a possibility to meet with our colleagues in the years when there is no ICSLS (International Conference on Spectral Line Shape) meeting, to give possibility to young people to participate and to exchange ideas and discuss results with colleagues working in this field in Serbia and elsewhere. The first Yugoslav Conference on Spectral Line Shapes, was held in Krivaja near Bačka Topola, 11–14 September 1995, the second in Bela Crkva, 29th September–2nd October 1997, and the third in Brankovac on Fruška Gora, 4–6 September 1999. The next one in 2001 was not organized, so we took again organization and with a change of the name, organized in Arandjelovac, 10–15 October 2003, IV Serbian Conference on Spectral Line Shapes. Since previous meetings proved that the principal interest for them was mainly from astrophysicists, the conference is organized from 6th to 10th June 2005 in Vršac as V Serbian Conference on Spectral Line Shapes in Astrophysics (SCSLSA). The VI SCSLSA was organized in Sremski Karlovci, June 11–15, 2007.

This conference (VII SCSLSA) was held in Zrenjanin, from 15th to 19th June 2009. Contributions were on the investigation of spectral line shapes in extragalactic objects like active galactic nuclei, stellar atmospheres and astrophysical spectra in general, as well as on atomic spectral line shapes in various discharges and plasma devices.

The main purpose of the conference was to present and discuss new results of participants working in this research field, and to review the most significant topics. Participants were known specialists in this field from 12 countries from America, Europe and Africa and Ph.D. students. In this special issue of New Astronomy Review are review lectures of interest for specialists and Ph.D. students and research papers providing an information about the new research in the covered topics.

We hope that this series of meetings will be useful and interesting for our colleagues interested in spectral line shapes research, will provide an additional possibility for exchange of ideas and for development of collaboration and friendship, and will contribute to the education of young collaborators.

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Electron impact broadening of multicharged ion lines of astrophysical interest: Ne VII, Ne VIII and Si XI

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Abstract

The modified semi-empirical method, often used in the investigations of stellar plasma for the determination of needed Stark line widths, is adapted here to use more accurate collision strengths instead of Gaunt factor. It is demonstrated that in such a way its applicability is extended to highly charged ions and good agreement is obtained with the more sophisticated semi-classical perturbation approach up to Si XI. Using this method, Stark line widths of several complex ions: two Be-like ions (Ne VII and Si XI) and one Li-like neon (Ne VIII) were calculated. The obtained results were compared with experiments and other theoretical approaches.
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1. Introduction

Stellar and laboratory plasma diagnostic, atomic abundances, opacity calculations, all have led to a need for knowledge about Stark broadening of multicharged ion spectral lines. For the calculations of the Stark broadening parameters, sophisticated quantum-mechanical and semi-classical methods (see e.g. Griem, 1974) exist, but they often require a considerable labor even for the evaluation of a single line width. Moreover, when quick estimate is needed, the approximate approaches may be very useful.

One such approximate method is the modified (Dimitrijević and Konjević, 1980, 1981) semi-empirical (Griem, 1968) formula suitable for singly as well as for multiply charged ion lines, based on the Gaunt factor approximation for inelastic cross-sections (see e.g. Griem, 1974). This method and Stark broadening data obtained using it were often applied in astrophysics as, e.g. to the study of elemental abundances in early B-type stars (Gies and Lambert, 1992), normal late-B and Hg–Mn stars (Smith, 1993) and hot white dwarfs (Chayer et al., 1995a), elemental abundance analysis (Bolcal et al., 1992), calculation of radiative acceleration in stellar envelopes (Le Blanc and Michaud, 1995), consideration of radiative levitation in hot white dwarfs (Chayer et al., 1995b), calculation and study of stellar opacities (Rogers and Iglesias, 1992). The modified semi-empirical method entered also in computer codes e.g. the OPAL code for stellar opacities (Rogers and Iglesias, 1995). A comparison with the experiments showed however, as can be seen, e.g. in (Uzelac et al., 1993), where Stark broadening of Ne II–Ne VI and F IV–F V spectral lines was investigated, that "the modified semi-empirical formula seems to be better suited for the low ionization stages".

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Since the Gaunt factor is proportional to the ratio of the collision strength (Ω) and the line strength, and since often may be found in the literature more sophisticated calculations of Ω, it is of interest to demonstrate how such data may be included in the modified semi-empirical formula (Dimitrijević and Konjević, 1980) in order to obtain more accurate results, and extend its applicability to highly charged ion lines. In this work, we use instead of the semi-empirical Gaunt factor used in Dimitrijević and Konjević (1980, 1981), electron impact excitation collision strengths, obtained in the distorted wave approximation in LS coupling.

Since silicon and neon are important for stellar plasma research and Stark broadening parameters of multicharged ions are of interest for subphotospheric layers modelisation and investigation (see e.g. Seaton, 1987), the modified semi-empirical method (Dimitrijević and Konjević, 1980, 1981), adapted to include collision strengths instead of Gaunt factors for $\Delta n = 0$, is used here for the Stark line width calculations of Ne VII, Ne VIII and Si XI.

2. Theory

In the modified semi-empirical method, the full Stark width W of an isolated ionic line can be calculated from the following expression (Dimitrijević and Konjević, 1981):

$$W = N\frac{8\pi}{3}\left(\frac{\hbar}{m}\right)^2\left(\frac{2m}{\pi kT}\right)^{\frac{1}{2}}\frac{\pi}{\sqrt{3}} \times \left[R^2_{l_i,l_{i+1}}\tilde{g}\left(\frac{E}{\Delta E_{l_i,l_{i+1}}}\right) + R^2_{l_i,l_{i-1}}\tilde{g}\left(\frac{E}{\Delta E_{l_i,l_{i+1}}}\right) + R^2_{l_f,l_{f+1}}\tilde{g}\left(\frac{E}{\Delta E_{l_f,l_{f-1}}}\right) + R^2_{l_f,l_{f-1}}\tilde{g}\left(\frac{E}{\Delta E_{l_f,l_{f-1}}}\right) + \sum_{i'}(R^2_{ii'})_{\Delta n\neq 0}g\left(\frac{3kTn_i^3}{4Z^2E_{\mathrm{H}}}\right) + \sum_{f'}(R^2_{ff'})_{\Delta n\neq 0}g\left(\frac{3kTn_f^3}{4Z^2E_{\mathrm{H}}}\right)\right], \quad (1)$$

where $E \approx 3kT/2$ is the energy of the perturbing electrons, $\Delta E_{jj'} = |E_{j'} - E_j|$ is the energy difference between the initial ($j = i$) or final ($j = f$) levels, and their perturbing levels ($j' = i', f'$), n is the effective principal quantum number, Z is the charge "seen" by the optical electron ($Z = 2$ for singly-, 3 for doubly-charged ions, etc.) and E_{H} is the ionization energy of hydrogen. The semi-empirical procedure for the calculation of electron impact widths accounts explicitly for interactions from "weak" collisions only (Griem, 1968). It is assumed (Griem, 1968) that the contribution of elastic collisions can be neglected for higher energies, and taken into account for lower energies by extrapolation of Gaunt factor below the threshold for the corresponding inelastic process.

The effective semi-empirical Gaunt factor (Griem, 1968) is given by $g(x) = 0.20$ for $x \leqslant 2$ and $g(x) = 0.24, 0.33, 0.56, 0.98$, and 1.33 for $x = 3, 5, 10, 30$, and 100 where $x = E/\Delta E_{jj'}$. In Eq. (1) all perturbing levels with $\Delta n \neq 0$ are lumped together and the corresponding nearest perturbing level is estimated from $\Delta E_{n,n+1} \approx 2Z^2E_{\mathrm{H}}/n^3$. The effective Gaunt factors $\tilde{g}(x)$ for the transitions with the principal quantum number n unchanged (Dimitrijević and Konjević, 1980) is taken as

$$\tilde{g}(x) = 0.7 - \frac{1.1}{Z} + g(x). \quad (2)$$

At high temperatures, say ($x \geqslant 50$), all Gaunt factors are calculated in accordance with the GBKO high temperature limit (Griem et al., 1962)

$$\tilde{g}_{jj'} = g_{jj'} = \frac{\sqrt{3}}{\pi}\left[\frac{1}{2} + \ln\left(\frac{2ZkT}{n^2\Delta E_{jj'}}\right)\right] \quad (3)$$

and within the Coulomb approximation

$$R^2_{l,l'} = \left(\frac{3n}{2Z}\right)^2\frac{\max(l,l')}{2l+1}[n^2 - \max^2(l,l')]\phi^2, \quad (4)$$

where ϕ represents the Bates and Damgaard factor (Bates and Damgaard, 1949), tabulated by Oertel and Shomo (1968), and

$$\sum_{j'}(R^2_{jj'})_{\Delta n\neq 0} = \left(\frac{3n_j}{2Z}\right)^2\frac{1}{9}(n_j^2 + 3l_j^2 + 3l_j + 11) \quad (5)$$

where n is the effective principal quantum number. Using the relation between the Gaunt factor, the collision strength Ω and the line strength S:

$$\tilde{g} = \frac{3\sqrt{3}}{8\pi}\frac{\Omega_{jj'}}{S_{jj'}} \quad (6)$$

and the relation

$$S_{jj'} = g_jR^2_{jj'} \quad (7)$$

where g_j is the statistical weight of the level j ($j = i, f$). With Eqs. (6) and (7) we find that

$$R^2_{jj'}\tilde{g} = \frac{3\sqrt{3}}{8\pi}\frac{\Omega_{jj'}}{g_j}. \quad (8)$$

Finally, the corresponding relation for the calculation of full Stark width of ionic spectral lines adapted to use the collision strengths for transitions with the same principal quantum number and in terms of Gaunt factors for transitions with $\Delta n \neq 0$ is

$$W = \pi N\left(\frac{\hbar}{m}\right)^2\left(\frac{2m}{\pi KT}\right)^{\frac{1}{2}}\left[\frac{1}{g_i}\sum_{i'}\Omega_{l_il_{i'}} + \frac{1}{g_f}\sum_{f'}\Omega_{l_fl_{f'}} + \frac{8\pi}{3\sqrt{3}}\sum_{i'}(R^2_{ii'})_{\Delta n\neq 0}g\left(\frac{3kTn_i^3}{4Z^2E_{\mathrm{H}}}\right) + \frac{8\pi}{3\sqrt{3}}\sum_{f'}\left(R^2_{ff'}\right)_{\Delta n\neq 0} \times g\left(\frac{3kTn_f^3}{4Z^2E_{\mathrm{H}}}\right)\right]. \quad (9)$$

In a previous paper, Dimitrijević (1984) calculated electron impact widths of the resonance lines $2s^2\,{}^1S$–$2s2p\,{}^1P^0$ of Be-like ions ($g_i = 1$ and $g_f = 3$) in a similar way. For this case, Eq. (9) may be simplified since

$$\frac{1}{g_i}\sum_{i'}\Omega_{l_i l_{i'}}+\frac{1}{g_f}\sum_{f'}\Omega_{l_f l_{f'}}=\frac{4}{3}\Omega. \quad (10)$$

where $l_{j'}=l_j\pm 1$.

He used for Ω the fit for Be-like sequence obtained by Younger (1980) for the considered transition

$$\Omega=\alpha_1+\frac{\alpha_2}{x}+\alpha_3\ln(x) \quad (11)$$

where $x=\frac{E}{\Delta E_{jj'}}$

$$\alpha_1=\frac{0.0348}{z}+\frac{65.9}{z^2}+\frac{174}{z^3}$$
$$\alpha_2=\frac{3.37}{z}+\frac{45.7}{z^2}+\frac{115}{z^3}$$
$$\alpha_3=\frac{0.897}{z}+\frac{38.1}{z^2}+\frac{58.6}{z^3}$$

and z is the effective charge of the ion: $z=Z-1$.

In order to take into account elastic collisions and the contribution of resonances below the threshold for an inelastic process, the collision strength is extrapolated below the threshold: $\Omega=\alpha_1+\alpha_2$ for $0\leqslant x\leqslant 1$.

Here, the collision strengths were estimated in the following way: we begin by the calculation of the atomic data: the wavefunctions, the energy levels, the wavelengths... using the SUPERSTRUCTURE code (Eissner et al., 1974). First, this program determines a set of non-relativistic wavefunctions by diagonalisation of the non-relativistic Hamiltonian using orbitals calculated in a scaled potential $V_{\lambda_l}(r)$; the scaling parameters λ_l being obtained by a self consistent energy minimization procedure. In the second step, the program diagonalises the relativistic Breit–Pauli Hamiltonian, and the multiconfigurational wave functions obtained contain both the correction and the relativistic effects in the configuration mixing coefficients.

The collision strengths Ω in Eq. (9) are calculated using the distorted wave program DW (Eissner, 1998). It is a non-relativistic code which calculates the transition matrix **T** elements in LS coupling. For the ionization stages examined here, the relativistic fine structure effects are negligible. One can see for example in Table 1 of Martin and Wiese (1976), where relativistic and non-relativistic oscillator strength values within the lithium isoelectronic sequence are compared, that differences start to be noticeable after P XIII and S XIV, and are less than ten percent up to Sc XIX. In Elabidi et al. (2004) an example of how relativistic fine structure effects may be taken into account by the Breit–Pauli Hamiltonian is given. Consequently, the collision strength in this coupling is

$$\Omega_{jj'}=\frac{1}{2}\sum_{ll'}\sum_{SL\pi}(2S+1)(2L+1)|T^{SL\pi}(\Gamma_j S_j L_j ls;\Gamma_{j'} S_{j'} L_{j'} l's)|^2. \quad (12)$$

where S_j and L_j are the spin and the orbital angular momentum quantum numbers of the target in level j, while s and l are the spin and the orbital angular momentum quantum numbers of the colliding electron. S and L are the spin and the orbital angular momentum quantum numbers of the system (ion + electron). The distorted

Table 1
Target state energies E (in cm^{-1}) relative to the $1s^22s^2\,{}^1S$ ground state of Ne VII, and collision strengths $\Omega_{i'i}$ in LS coupling at energy $E=22.24$ Ry

i	Configuration	Term	E	$\Omega_{i'i}$ ($i'=1$)	$\Omega_{i'i}$ ($i'=2$)	$\Omega_{i'i}$ ($i'=3$)
1	$1s^22s^2$	^1S	0.0	–	–	–
2	$1s^22s2p$	$^3P^0$	111,653	0.036806	–	–
3	$1s^22s2p$	$^1P^0$	222,548	3.145870	0.071657	–
4	$1s^22p^2$	^3P	290,805	0.001182	14.391516	0.038980
5	$1s^22p^2$	^1D	323,906	0.022599	0.062319	9.118772
6	$1s^22p^2$	^1S	404,377	0.003947	0.005758	2.947338
7	$1s^22s3s$	^3S	974,992	0.003846	0.103781	0.004084
8	$1s^22s3s$	^1S	996,526	0.131331	0.004974	0.021137
9	$1s^22s3p$	$^1P^0$	1,023,328	0.098783	0.025852	0.132475
10	$1s^22s3p$	$^3P^0$	1,025,615	0.008951	0.925291	0.023613
11	$1s^22s3d$	^3D	1,052,031	0.021754	2.995939	0.048912
12	$1s^22s3d$	^1D	1,073,216	0.193976	0.043628	1.077302
13	$1s^22p3s$	$^3P^0$	1,118,030	0.000174	0.514975	0.008669
14	$1s^22p3s$	$^1P^0$	1,142,135	0.002640	0.005516	0.394448
15	$1s^22p3p$	^1P	1,144,302	0.000067	0.004407	0.098474
16	$1s^22p3p$	^3D	1,151,741	0.001050	0.113663	0.010245
17	$1s^22p3p$	^3S	1,162,469	0.000090	0.048131	0.002093
18	$1s^22p3p$	^3P	1,170,662	0.000208	0.118077	0.005408
19	$1s^22p3d$	$^1D^0$	1,175,394	0.000130	0.068072	0.073022
20	$1s^22p3d$	$^3F^0$	1,176,117	0.000652	0.440273	0.095768
21	$1s^22p3p$	^1D	1,187,075	0.000652	0.007899	0.167960
22	$1s^22p3d$	$^3D^0$	1,190,481	0.000200	0.311717	0.014012
23	$1s^22p3d$	$^3P^0$	1,196,833	0.000522	0.176502	0.008602
24	$1s^22p3d$	$^1F^0$	1,216,929	0.001026	0.018142	0.141940
25	$1s^22p3p$	^1S	1,218,225	0.000442	0.001218	0.008838
26	$1s^22p3d$	$^1P^0$	1,220,283	0.006542	0.006472	0.075913

i is an index label for the 26 terms.

wave approximation is used for low partial wave l ($l < 20$). This method becomes very cumbersome and inaccurate for large l but their contribution to collision strengths cannot be neglected. To take into account the contribution of high partial wave (l up to 150), two methods have been used: for dipole transitions, this contribution is calculated with the Coulomb–Bethe approximation and for non-dipole transitions contribution has been estimated assuming that the sum over the high partial collision strengths is asymptotic to a geometric series (Ben Nessib et al., 2005). The transition matrix $\mathbf{T}$ is related to the reactance matrix $\mathbf{R}$ by:

$$\mathbf{T} = \frac{2\mathrm{i}\mathbf{R}}{1 - \mathrm{i}\mathbf{R}}. \quad (13)$$

Here, the needed collision strengths are estimated by the distorted wave approximation, which is more accurate, but this is not of principal importance. Our aim is namely to demonstrate how collision strengths existing in the literature, which are of higher accuracy than semi-empirical Gaunt factors, might be used to increase the accuracy of the modified semi-empirical approach. Consequently, we calculate the elastic collision strengths at the threshold energy and extrapolate them below the threshold as in Griem (1968) and Dimitrijević and Konjević (1980), and not using a more sophisticated method. Moreover, it has been shown that the elastic contribution to the line width becomes less important with the increase in temperature (Ralchenko et al., 1999).

3. Results and discussions

3.1. Structure and collisional data

In Tables 1–3, we report target state energies calculated by the SUPERSTRUCTURE program for Ne VII, Ne VIII and Si XI, respectively, and collision strengths values calculated at the double of the highest excitation threshold converted to Rydbergs for each ion. In order to check our obtained energies, they were compared with the energies of TOPbase (Butler et al., 1993; Cunto et al., 1993).

3.2. Line widths of Ne VII

In Table 4 are presented our theoretical, experimental (Wrubel et al., 1996) and other theoretical Stark widths of investigated 2s3s–2s3p transitions of Beryllium-like neon: calculations after Dimitrijević and Konjević (1980), Griem (1974), Hey and Breger (1980, 1982) and Alexiou (1995) performed in Wrubel et al. (1996), as well as the quantum mechanical calculations of Ralchenko et al. (1999). The averaged ratio of experimental results and our theoretical ones (W_{exp}/W) for the two transitions is 1.56. One can see that the best agreement with experiment gives the approximate method of Hey and Breger (1980, 1982) based on the quasiclassical Gaunt factor approximation. This is very encouraging for the use of this method, much simpler than, e.g. sophisticated quantum mechanical approach of Ralchenko et al. (1999).

3.3. Line widths of Ne VIII

We present in Table 5 our theoretical, experimental (Glenzer et al., 1992; Hegazy et al., 2003) and other theoretical results for 3s–3p transition of Lithium-like neon: calculations after Dimitrijević and Konjević (1980, 1981), Griem (1974) and Hey and Breger (1980, 1982) performed in Glenzer et al. (1992); semi-classical calculations of Dimitrijević and Sahal-Bréchot (1993, 1994) and the quantum mechanical calculations of Seaton (1988) and Ralchenko et al. (2003). The averaged ratio W_{exp}/W of experimental results and our theoretical ones for the three temperatures is 2.24. It is also shown in Table 4 and Fig. 1 that the calculations for Be-like neon are closer to the

Table 2
Target state energies E (in cm^{-1}) relative to the 2s^{2}S ground state of Ne VIII, and collision strengths $\Omega_{i'i}$ in LS coupling at energy $E = 30.00$ Ry

i	Configuration	Term	E	$\Omega_{i'i}$ ($i' = 1$)	$\Omega_{i'i}$ ($i' = 2$)	$\Omega_{i'i}$ ($i' = 3$)
1	2s	^{2}S	0.0	–	–	–
2	2p	^{2}P^0	127,776	5.609966	–	–
3	3s	^{2}S	1,097,008	0.086957	0.050136	–
4	3p	^{2}P^0	1,131,678	0.146574	0.350092	36.721519
5	3d	^{2}D	1,143,373	0.259614	2.285725	1.449936
6	4s	^{2}S	1,465,935	0.016139	0.008627	0.538142
7	4p	^{2}P^0	1,480,060	0.028573	0.068251	0.628950
8	4d	^{2}D	1,484,939	0.040108	0.361810	0.781860
9	4f	^{2}F^0	1,485,141	0.017757	0.070847	0.566379
10	5s	^{2}S	1,633,484	0.006040	0.003460	0.100070
11	5p	^{2}P^0	1,640,565	0.010846	0.026338	0.119102
12	5d	^{2}D	1,643,049	0.013931	0.127837	0.153523
13	5f	^{2}F^0	1,643,163	0.009107	0.035249	0.056967
14	5g	^{2}G	1,643,165	0.000663	0.002392	0.087536

i is an index label for the 14 terms.

Table 3
Target state energies E (in cm^{-1}) relative to the $1s^2 2s^2\ ^1S$ ground state of Si XI, and collision strengths $\Omega_{i'i}$ in LS coupling at energy $E = 47.50$ Ry

i	Configuration	Term	E	$\Omega_{i'i}$ $(i' = 1)$	$\Omega_{i'i}$ $(i' = 2)$	$\Omega_{i'i}$ $(i' = 3)$
1	$1s^2 2s^2$	^1S	0.0	–	–	–
2	$1s^2 2s2p$	$^3P^0$	169,127	0.015958	–	–
3	$1s^2 2s2p$	$^1P^0$	331,977	1.641963	0.030443	–
4	$1s^2 2p^2$	^3P	438,811	0.000512	7.366446	0.034758
5	$1s^2 2p^2$	^1D	490,632	0.008203	0.041694	4.602189
6	$1s^2 2p^2$	^1S	609,733	0.001848	0.002527	1.490344
7	$1s^2 2s3s$	^3S	2,201,590	0.001696	0.034489	0.001746
8	$1s^2 2s3s$	^1S	2,234,412	0.058654	0.002116	0.005612
9	$1s^2 2s3p$	$^1P^0$	2,276,556	0.051990	0.022413	0.045731
10	$1s^2 2s3p$	$^3P^0$	2,280,317	0.009063	0.383522	0.015633
11	$1s^2 2s3d$	^3D	2,322,659	0.010849	1.403230	0.022504
12	$1s^2 2s3d$	^1D	2,355,916	0.098865	0.021408	0.438614
13	$1s^2 2p3s$	$^3P^0$	2,415,316	0.000109	0.233804	0.004437
14	$1s^2 2p3s$	$^1P^0$	2,451,681	0.002516	0.002517	0.161608
15	$1s^2 2p3p$	^1P	2,457,307	0.000037	0.003976	0.039619
16	$1s^2 2p3p$	^3D	2,468,730	0.000454	0.068658	0.010287
17	$1s^2 2p3p$	^3S	2,485,593	0.000036	0.027753	0.001484
18	$1s^2 2p3p$	^3P	2,497,178	0.000089	0.076136	0.003168
19	$1s^2 2p3d$	$^1D^0$	2,506,546	0.000068	0.046588	0.017118
20	$1s^2 2p3d$	$^3F^0$	2,507,271	0.000280	0.206286	0.057848
21	$1s^2 2p3p$	^1D	2,522,981	0.000652	0.003615	0.093124
22	$1s^2 2p3d$	$^3D^0$	2,531,406	0.000143	0.003615	0.007146
23	$1s^2 2p3d$	$^3P^0$	2,540,585	0.000248	0.089496	0.004406
24	$1s^2 2p3p$	^1S	2,568,383	0.000187	0.000555	0.006577
25	$1s^2 2p3d$	$^1F^0$	2,574,594	0.000442	0.008811	0.071875
26	$1s^2 2p3d$	$^1P^0$	2,577,899	0.004161	0.003414	0.036316

i is an index label for the 26 terms.

Table 4
Stark line widths in Å for Ne VII: the present calculations (W) and calculated widths evaluated in Wrubel et al. (1996) after Dimitrijević and Konjević (1980 – index DK), Griem (1974 – index G), Hey and Breger (1980, 1982 – index HB), and Alexiou (1995, 1997 – index A – the first number concerns the Ref. from 1995 and the second one in brackets from 1997), as well as quantum mechanical calculations of Ralchenko et al. (1999 – index R) are compared with experimental widths (W_{exp}) of Wrubel et al. (1996)

Transition	W	W_{exp}/W	W_{exp}/W_{DK}	W_{exp}/W_G	W_{exp}/W_{HB}	W_{exp}/W_A	W_{exp}/W_R
Ne VII $2s3s\ ^1S$–$2s3p\ ^1P^0$ $\lambda = 3643.6$ Å $N = 3.5 \times 10^{18}$ cm^{-3} $T = 2.205 \times 10^5$ K	1.123	1.57	1.57	1.28	1.15	0.88(0.77)	1.70
Ne VII $2s3s\ ^3S$–$2s3p\ ^3P^0$ $\lambda = 1981.97$ Å $N = 3.0 \times 10^{18}$ cm^{-3} $T = 2.380 \times 10^5$ K	0.290	1.55	1.91	1.53	1.29	0.94(0.82)	1.96

Table 5
Stark line widths in Å for the Ne VIII $3s\ ^2S$–$3p\ ^2P^0$, transition at $\lambda = 2820.7$ Å: the present calculations (W) and calculated widths evaluated in Glenzer et al. (1992) after Dimitrijević and Konjević (1980 – index DK), Griem (1974 – index G), and Hey and Breger (1980, 1982 – index HB) as well as semi-classical calculations of Dimitrijević and Sahal-Bréchot (1993, 1994 – index DSB) and quantum mechanical calculations of Seaton (1988 – index S) and Ralchenko et al. (2003 – index R) are compared with experimental widths (W_{exp}) of Glenzer et al. (1992) and Hegazy et al. (2003 – theoretical values for $T = 4.642 \times 10^5$ K are interpolated with the help of $T^{-1/2}$ dependence)

Transition	W	W_{exp}/W	W_{exp}/W_{DK}	W_{exp}/W_G	W_{exp}/W_{HB}	W_{exp}/W_S	W_{exp}/W_{DSB}	W_{exp}/W_R
$T = 3.447 \times 10^5$ K $N = 2.8 \times 10^{18}$ cm^{-3}	0.490	2.45	2.55	2.22	1.83	3.29	1.91	–
$N = 1.0 \times 10^{18}$ cm^{-3} $T = 4.642 \times 10^5$ K	0.158	1.84	1.92	1.65	1.39	2.58	1.36	2.3
$N = 3.2 \times 10^{18}$ cm^{-3} $T = 4.932 \times 10^5$ K	0.495	2.42	2.45	2.07	1.77	3.47	1.67	–

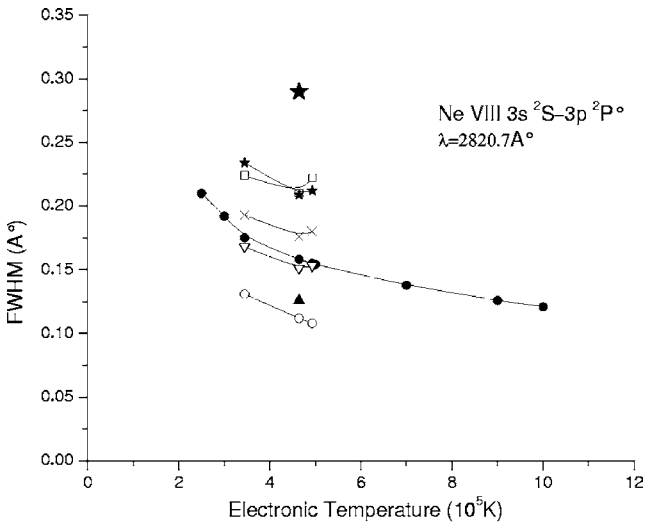

Fig. 1. Stark width (FWHM) as a function of the electron temperature for an electron density of 10^{18} cm^{-3} for the Ne VIII $3s\,^2S$–$3p\,^2P^0$ transition. (●) Present work, (▽) Glenzer et al. (1992) after Dimitrijević and Konjević (1980), (×) Glenzer et al. (1992) after Griem (1974), (⋆) Glenzer et al. (1992) after Hey and Breger (1980, 1982), (○) results of Seaton (1988), (□) results of Dimitrijević and Sahal-Bréchot (1993, 1994), (▲) results of Ralchenko et al. (2003) and (★) denotes the experimental result of Hegazy et al. (2003).

experimental results than those for Li-like neon. The averaged ratio of the semi-classical results and our ones (W_{DSB}/W) is 1.36, which is better than for the calculations using the modified semi-empirical method with Gaunt factors, where such ratio (W_{DSB}/W_{DK}) is 1.39. The best agreement with experimental results has the semi-classical perturbation calculations (Dimitrijević and Sahal-Bréchot, 1993, 1994), with the averaged ratio (W_{exp}/W_{DSB}) of 1.65. We note also the excellent agreement of the quasiclassical Gaunt factor approximation method of Hey and Breger (1980, 1982) with more sophisticated semi-classical perturbation method. For the method of Hey and Breger (1980, 1982), the averaged ratio (W_{exp}/W_{HB}) is 1.67.

3.4. Line widths of Si XI

We have calculated Stark full widths at half intensity maximum (FWHM) in Å of $2s^2\,^1S$–$2s2p\,^1P^0$ and $2s2p\,^1P^0$–$2s3s\,^1S$ transitions of Si XI at temperatures (5×10^5 K, 7.5×10^5 K, 10^6 K, 2×10^6 K, 3×10^6 K, and 5×10^6 K) and at electron density $N_e = 10^{18}$ cm^{-3}. A comparison between the semi-classical results of Dimitrijević and Sahal-Bréchot (1997, 1998) (W_{DSB}) and the present ones (W) reported in Table 6 shows that the two calculations agree with each other (the averaged W_{DSB}/W is 1.32 for the transitions and temperatures considered in this work). One can see in Fig. 2 that the Stark width temperature dependence is similar for the semi-classical perturbation calculations (Dimitrijević and Sahal-Bréchot, 1997, 1998) and the present ones. Also, our results are systematically lower.

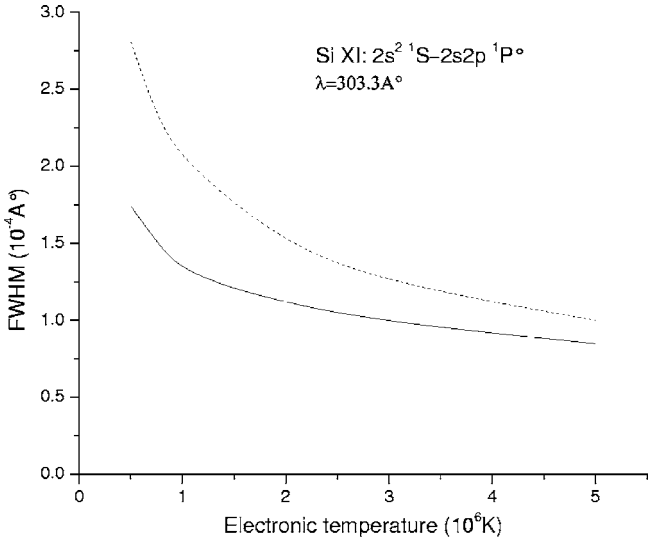

Fig. 2. Stark width (FWHM) as a function of the electron temperature for an electron density of 10^{18} cm^{-3} for the Si XI $2s^2\,^1S$–$2s2p\,^1P^0$ transition. The solid line denotes our present calculations and the dashed line semi-classical calculations of Dimitrijević and Sahal-Bréchot (1997, 1998).

Table 6
Stark line width (FWHM) in Å for Si XI for an electron density of $N = 10^{18}$ cm^{-3}

Transition	T (K)	W	W_{DSB}	W_{DSB}/W
Si XI	5.0×10^5	1.74×10^{-4}	2.81×10^{-4}	1.62
	7.5×10^5	1.51×10^{-4}	2.32×10^{-4}	1.53
$2s^2\,^1S$–$2s2p\,^1P^0$	1.0×10^6	1.30×10^{-4}	2.03×10^{-4}	1.56
$\lambda = 303.3$ Å	2.0×10^6	1.11×10^{-4}	1.48×10^{-4}	1.33
	3.0×10^6	0.986×10^{-4}	1.24×10^{-4}	1.26
	5.0×10^6	0.848×10^{-4}	1.00×10^{-4}	1.18
Si XI	5.0×10^5	1.39×10^{-5}	1.78×10^{-5}	1.28
	7.5×10^5	1.23×10^{-5}	1.52×10^{-5}	1.24
$2s2p\,^1P^0$–$2s3s\,^1S$	1.0×10^6	1.11×10^{-5}	1.37×10^{-5}	1.23
$\lambda = 52.3$ Å	2.0×10^6	0.888×10^{-5}	1.07×10^{-5}	1.20
	3.0×10^6	0.767×10^{-5}	0.925×10^{-5}	1.21
	5.0×10^6	0.626×10^{-5}	0.775×10^{-5}	1.24

Present (W) results and the semi-classical ones (W_{DSB}) of Dimitrijević and Sahal-Bréchot (1997, 1998).

It is demonstrated here how one can include in the modified semi-empirical method (Dimitrijević and Konjević, 1980) the data on collision strengths available in the literature, which are of higher accuracy than semi-empirical Gaunt factors. In such a way, one may not only obtain results with better accuracy, but also the method becomes more reliable for ions in high ionization stages. We have demonstrated that even for Si XI the ratio W_{DSB}/W is 1.32, so that the applicability of the modified semi-empirical method could be in such a way extended toward highly ionized emitters. This is of interest since more sophisticated methods, like the semi-classical perturbation one, need much larger set of perturbing energy levels for an adequate application, which is often not available, especially for multiply charged ions. Consequently, the proposed method could be applied in the cases when there is no enough atomic data for the adequate use of the semi-classical perturbation method, or of the full quantum mechanical approach.

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References

Alexiou, S., 1995. PhRvL 75, 3406.
Alexiou, S., 1997. Spectral Line Shapes XI, Zoppi, M., Ulivi, L. (Eds.), AIP Conf. Proc., vol. 386, p. 89.
Bates, D.R., Damgaard, A., 1949. PTRSL 242, 101.
Ben Nessib, N., Elabidi, H., Cornille, M., Dubau, J., 2005. PhyS 72, 23.
Bolcal, Ç, Koçer, D., Adelman, S.J., 1992. MNRAS 258, 270.
Butler, K., Mendoza, C., Zeippen, C.J., 1993. J. Phys. B 26, 4409.
Cunto, W., Mendoza, C., Ochsenbein, F., Zeippen, C.J., 1993. A&A 275, L5.
Chayer, P., Fontaine, G., Wesemael, F., 1995b. ApJS 99, 189.
Chayer, P., Venness, S., Pradhan, A.K., Thejli, P., Beauchamp, A., Fontaine, G., Wesemael, F., 1995a. ApJ 454, 429.
Dimitrijević, M.S., 1984. A&A 131, 327.
Dimitrijević, M.S., Konjević, N., 1980. JQSRT 24, 451.
Dimitrijević, M.S., Konjević, N., 1981. In: Wende, B. (Ed.), Spectral Line Shapes. de Gruyter, Berlin, New York, p. 211.
Dimitrijević, M.S., Sahal-Bréchot, S., 1993. BOBeo 148, 29.
Dimitrijević, M.S., Sahal-Bréchot, S., 1994. A&AS 107, 349.
Dimitrijević, M.S., Sahal-Bréchot, S., 1997. BOBeo 156, 113.
Dimitrijević, M.S., Sahal-Bréchot, S., 1998. A&AS 129, 155.
Eissner, W., 1998. Comput. Phys. Commun. 114, 295.
Eissner, W., Jones, M., Nussbaumer, H., 1974. Comput. Phys. Commun. 8, 270.
Elabidi, H., Ben Nessib, N., Sahal-Bréchot, S., 2004. J. Phys. B 37, 63.
Gies, D.R., Lambert, D.L., 1992. ApJ 387, 673.
Glenzer, S., Uzelac, N.I., Kunze, H.J., 1992. PhRvA 45, 8795.
Griem, H.R., Baranger, M., Kolb, A.C., Oertel, G., 1962. PhRv 125, 1977.
Griem, H.R., 1968. PhRv 165, 258.
Griem, H.R., 1974. Spectral Line Broadening by Plasmas. McGraw-Hill, New York.
Hegazy, H., Seidel, S., Wrubel, Th., Kunze, H.J., 2003. JQSRT 81, 221.
Hey, J.D., Breger, P., 1980. JQSRT 24, 349.
Hey, J.D., Breger, P., 1982. S. Afr. J. Phys. 5, 111.
Le Blanc, F., Michaud, G., 1995. A&A 303, 166.
Martin, G.A., Wiese, W.L., 1976. J. Phys. Chem. Ref. Data 5, 537.
Oertel, G.K., Shomo, L.P., 1968. ApJ 136, 906.
Ralchenko, Yu.V., Griem, H.R., Bray, I., Fursa, D.V., 1999. PhRvA 59, 1890.
Ralchenko, Yu.V., Griem, H.R., Bray, I., 2003. JQSRT 81, 371.
Rogers, F.J., Iglesias, C.A., 1992. ApJS 79, 507.
Rogers, F.J., Iglesias, C.A., 1995. Adelman, S.J., Wiese, W.L. (Eds.), ASP Conf. Ser., Astrophysical Applications of Powerful New Databases, vol. 78, p. 31.
Seaton, M.J., 1987. J. Phys. B 20, 6363.
Seaton, M.J., 1988. J. Phys. B 21, 3033.
Smith, K.C., 1993. A&A 276, 393.
Uzelac, N.I., Glenzer, S., Konjević, N., Hey, J.D., Kunze, H.J., 1993. PhRvE 47, 3623.
Wrubel, Th., Glenzer, S., Büscher, S., Kunze, H.J., Alexiou, S., 1996. A&A 306, 1023.
Younger, S.M., 1980. JQSRT 23, 489.

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Stark broadening parameters for Cu III, Zn III and Se III lines in laboratory and stellar plasma

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Abstract

Using the modified semiempirical approach, we have considered Stark widths for 6 Cu III, 6 Zn III and 3 Se III transitions where the full semiclassical perturbation approach is not applicable in an adequate way due to the lack of reliable atomic data. Results are obtained as a function of temperature, for perturber density of 10^{17} cm^{-3}. Calculated results have been used to consider the influence of Stark broadening for A type star and DB white dwarf atmospheric conditions.
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Keywords: Stark broadening; Line profiles; Atomic data; Stellar atmospheres

1. Introduction

Stark broadening of ion and atom lines is of interest for the investigation of astrophysical plasma, particularly for synthesis and analysis of high resolution spectra obtained from space born instruments. With the development of new techniques, importance of data on trace element spectra like Se or Cu increases. For example, from the analysis of 11 Hg–Mn star spectra (Jacobs and Dworetsky, 1981), where Stark broadening is the main pressure broadening mechanism, it follows that copper is clearly present and overabundant in ten of the investigated stars. Also, the knowledge of Stark broadening parameters is of interest for the investigation of laboratory and technological plasmas.

For example, spectral lines of Cu III and Cu IV are of particular interest for the diagnostic and modelling of plasma created in electromagnetic macro particle accelerators (see Rasheig and Marshall, 1978), where in experimental work, the plasma is usually created by Cu or Al foil evaporation. Stark widths for six Cu IV multiplets of interest for such plasma have been calculated within the modified semiempirical approach (Dimitrijević and Konjević, 1980) in Dimitrijević et al. (1994). One of our aims here is to complete such data with the relevant Stark broadening data for Cu III lines.

Zinc spectral lines are present in stellar spectra (see Adelman, 1994; Cowley et al., 2000; Ryabchikova et al., 2000; Piskunov and Kupka, 2001). Moreover, doubly charged zinc ion is a member of the nickel isoelectronic sequence, known to include possible candidates for development of ultraviolet lasers (Gayasov and Ryabtsev, 1992).

Selenium, a trace element without an astrophysical significance before, is now detected in the atmospheres of cool DO white dwarfs (Chayer et al., 2005a,b).

Here, we present Stark widths for six transitions of Cu III, six transitions of Zn III and three transitions of Se III calculated by using the modified semiempirical approach (see Dimitrijević and Konjević, 1980a; Dimitrijević and Popović, 2001). Calculated results will be used here also to consider the influence of Stark broadening

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on spectral line shapes for A type stars and DB white dwarf atmospheres conditions. There are no other experimental or theoretical data for Cu III, Zn III and Se III.

2. Theory

According to the modified semiempirical (MSE) approach (Dimitrijević and Konjević, 1980), the electron impact full width at half maximum (FHWM) of an isolated ion line is given as

$$w_{\mathrm{MSE}} = N\frac{4\pi}{3c}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\lambda^2}{\sqrt{3}} \times \left\{\sum_{\ell_i\pm1}\sum_{L_{i'}J_{i'}} R^2_{\ell_i,\ell_i\pm1}\tilde{g}(x_{\ell_i,\ell_i\pm1}) + \sum_{\ell_f\pm1}\sum_{L_{f'}J_{f'}} R^2_{\ell_f,\ell_f\pm1}\tilde{g}(x_{\ell_f,\ell_f\pm1}) + \left(\sum_{i'} R^2_{ii'}\right)_{\Delta n\neq 0} g(x_{n_i,n_i+1}) + \left(\sum_{f'} R^2_{ff'}\right)_{\Delta n\neq 0} g(x_{n_f,n_f+1})\right\} \quad (1)$$

where the initial level is denoted with i, the final one with f, $R^2_{\ell_k,\ell_{k'}}, k = i,f$ is the square of the coordinate operator $\hat{r}$ matrix element, and

$$\left(\sum_{k'} R^2_{kk'}\right)_{\Delta n\neq 0} = \left(\frac{3n^*_k}{2Z}\right)^2 \frac{1}{9}(n^{*2}_k + 3\ell^2_k + 3\ell_k + 11) \quad (2)$$

(in Coulomb approximation).

In Eq. (1)

$$x_{l_k,l_{k'}} = \frac{E}{\Delta E_{l_k,l_{k'}}}, k = i,f$$

where $E = \frac{3}{2}kT$ is the electron kinetic energy and $\Delta E_{l_k,l_{k'}} = |E_{l_k} - E_{l_{k'}}|$, is the energy difference between levels l_k and $l_k \pm 1$ (k = i, f),

$$x_{n_k,n_k+1} \approx \frac{E}{\Delta E_{n_k,n_k+1}},$$

where for $\Delta n \neq 0$ the energy difference between energy levels with n_k and $n_k + 1$, $\Delta E_{n_k,n_k+1}$, is estimated as $\Delta E_{n_k,n_k+1} \approx 2Z^2E_{\mathrm{H}}/n^{*3}_k$, $n^*_k = [E_{\mathrm{H}}Z^2/(E_{\mathrm{ion}} - E_k)]^{1/2}$ is the effective principal quantum number, Z is the residual ionic charge, for example $Z = 1$ for neutral atoms and E_{ion} is the appropriate spectral series limit.

In Eqs. (1 and 2) N and T are electron density and temperature, respectively, while with $g(x)$ (Griem, 1968) and $\tilde{g}(x)$ (Dimitrijević and Konjević, 1980) are denoted the corresponding Gaunt factors for width, respectively.

In comparison with the semiclassical perturbation approach (Sahal-Bréchot, 1969a,b; Dimitrijević et al., 1991), the modified semiempirical approach needs a considerably smaller number of atomic data. In fact, if there are no perturbing levels strongly violating the assumed approximation, for e.g. the line width calculations, we need only the energy levels with $\Delta n = 0$ and $\ell_{if} = \ell_{if} \pm 1$, since all perturbing levels with $\Delta n \neq 0$, needed for a full semiclassical investigation are lumped together and approximately estimated. The modified semiempirical method is used here, since we do not have a sufficiently complete set of published experimental Cu III, Zn III and Se III energy levels for an adequate semiclassical treatment.

We will use results obtained to investigate the influence of Stark broadening on the considered line profiles in stellar atmospheres. In order to do so, we will compare the thermal Doppler and Stark widths as a function of optical depth. Let us take the direction of gravity as the z-direction in dealing here with a stellar atmosphere. If the atmosphere is in macroscopic mechanical equilibrium and with ρ denoting gas density, the optical depth is

$$\tau_\nu = \int_z^\infty k_\nu \rho \, \mathrm{d}z,$$

where k_ν is the absorption coefficient at a frequency ν. Let us introduce an independent variable, a mean optical depth

$$\tau_{\mathrm{Ross}} = \int_z^\infty k_{\mathrm{Ross}} \rho \, \mathrm{d}z,$$

For this Rosseland mean optical depth τ_{Ross}, k_{Ross} is defined as

$$\frac{1}{k_{\mathrm{Ross}}}\int_0^\infty \frac{\mathrm{d}B_\nu}{\mathrm{d}T}\,\mathrm{d}\nu = \int_0^\infty \frac{1}{k_\nu}\frac{\mathrm{d}B_\nu}{\mathrm{d}T}\,\mathrm{d}\nu,$$

where

$$B_\nu(T) = \frac{2h\nu^3}{c^2}(\mathrm{e}^{h\nu/kT} - 1)^{-1}.$$

For stellar plasma considerations, instead of the direction toward the observer, it is often more convenient to determine optical depth along the stellar radius r, or for a plane-parallel layer, along the geometrical depth x toward the stellar center as in Kuruczs (1979) and Wickramasinghe (1972). The connection between the two systems is $\mathrm{d}x = -\cos\theta \mathrm{d}z$, where θ is the angle between the geometrical depth direction and the direction toward the observer.

3. Results and discussions

Atomic energy levels needed for calculation of Cu III Stark line widths were taken from Sugar and Musgrove (1990), for Zn III from Sugar and Musgrove (1995) and ones for Se III from Moore (1971).

The results obtained within the modified semiempirical method (Dimitrijević and Konjević, 1980, see also the review of inovations and applications in Dimitrijević and Popović, 2001) for the Stark widths (full width at half maximum) due to electron-impacts, for six Cu III, six Zn III and three Se III transitions are shown in Tables 1–3, respectively, for perturber density of 10^{17} cm^{-3} and temperatures from 10,000 K up to 300,000 K.

Table 1
This table presents Cu III electron-impact broadening parameters (full width at half maximum W) obtained by the modified semiempirical method (Dimitrijević and Konjević, 1980) for perturber density of 10^{17} cm^{-3} and temperatures from 10,000 up to 300,000 K

Transition	T (K)	Width (Å)	Transition	T (K)	Width (Å)
4s ^{4}F–4p ^{4}F^o 1601.6Å	10,000	0.206E−01	4s ^{2}F–4p ^{2}D^o 1676.2Å	10,000	0.235E−01
	20,000	0.146E−01		20,000	0.166E−01
	50,000	0.921E−02		50,000	0.105E−01
	100,000	0.651E−02		100,000	0.742E−02
	200,000	0.497E−02		200,000	0.571E−02
	300,000	0.444E−02		300,000	0.513E−02
4s ^{4}F–4p ^{4}G^o 1667.7Å	10,000	0.220E−01	4s ^{2}F–4p ^{2}F^o 1673.0Å	10,000	0.235E−01
	20,000	0.156E−01		20,000	0.166E−01
	50,000	0.984E−02		50,000	0.105E−01
	100,000	0.696E−02		100,000	0.743E−02
	200,000	0.533E−02		200,000	0.572E−02
	300,000	0.476E−02		300,000	0.514E−02
4s ^{4}F–4p ^{4}D^o 1716.8Å	10,000	0.232E−01	4s ^{2}F–4p ^{2}G^o 1774.4Å	10,000	0.262E−01
	20,000	0.164E−01		20,000	0.185E−01
	50,000	0.104E−01		50,000	0.117E−01
	100,000	0.732E−02		100,000	0.828E−02
	200,000	0.562E−02		200,000	0.639E−02
	300,000	0.502E−02		300,000	0.574E−02

Table 2
This table presents Zn III electron-impact broadening parameters (full width at half maximum W) obtained by the modified semiempirical method (Dimitrijević and Konjević, 1980) for perturber density of 10^{17} cm^{-3} and temperatures from 10,000 up to 300,000 K

Transition	T (K)	Width (Å)	Transition	T (K)	Width (Å)
4s ^{1}D–4p ^{1}D^o 1619.6Å	10,000	0.824E−02	4s ^{3}D–4p ^{3}D^o 1472.8Å	10,000	0.713E−02
	20,000	0.583E−02		20,000	0.504E−02
	50,000	0.369E−02		50,000	0.319E−02
	100,000	0.261E−02		100,000	0.226E−02
	200,000	0.187E−02		200,000	0.163E−02
	300,000	0.160E−02		300,000	0.140E−02
4s ^{1}D–4p ^{1}F^o 1639.3Å	10,000	0.835E−02	4s ^{3}D–4p ^{3}F^o 1604.1Å	10,000	0.780E−02
	20,000	0.590E−02		20,000	0.551E−02
	50,000	0.373E−02		50,000	0.349E−02
	100,000	0.264E−02		100,000	0.247E−02
	200,000	0.189E−02		200,000	0.177E−02
	300,000	0.161E−02		300,000	0.150E−02
4s ^{1}D–4p ^{1}F^o 1562.5Å	10,000	0.580E−02	4s ^{3}D–4p ^{3}P^o 1667.9Å	10,000	0.630E−02
	20,000	0.410E−02		20,000	0.446E−02
	50,000	0.260E−02		50,000	0.282E−02
	100,000	0.183E−02		100,000	0.199E−02
	200,000	0.130E−02		200,000	0.141E−02
	300,000	0.108E−02		300,000	0.115E−02

For A type stars, where, as it has been shown several times see Dimitrijević et al., 2003; Simić et al., 2005; Popović et al., 2001, that Stark broadening may be significant particularly in deeper layers, our temperatures correspond to the photospheric and also, to subphotospheric layers. We note here that Seaton (1987) draw attention on the importance of Stark broadening for their modelling and investigation. For a Doppler-broadened spectral line, the intensity distribution is not Lorentzian as for electron-impact broadening but Gaussian, whose full half width of the spectral line may be determined by the equation

$$W_{\mathrm{D}}[\text{Å}] = 7.16 \times 10^{-7} \lambda[\text{Å}]) \sqrt{T(\mathrm{K}) M_{\mathrm{Se}}^{-1}},$$

where atomic weight for selenium is $M_{\mathrm{Se}} = 78.96$ a.u. Consequently, in Fig. 1 are compared Se III 4p5s ^{3}P^o–5p ^{3}D ($\lambda = 3815.5$ Å) line widths due to Stark and thermal Doppler broadening mechanisms as functions of Rosseland optical depth corresponding to 10,000–30,000 K temperature range, for an A type star atmosphere model with $T_{\mathrm{eff}} =$ 10,000 K and $\log g = 4.5$ (Kuruczs, 1979). One can see in Fig. 1, that in subphotosheric layers, for $\log g > 1.7$, Stark width becomes larger than Doppler one. One should take into account that due to differences between Lorentz (Stark) and Gauss (Doppler) line intensity distributions, Stark broadening may be more important on line wings in comparison with the thermal Doppler one, even when

Table 3
This table presents Se III electron-impact broadening parameters (full width at half maximum W) obtained by the modified semiempirical method (Dimitrijević and Konjević, 1980) for perturber density of 10^{17} cm^{-3} and temperatures from 10,000 up to 300,000 K

Transition	T (K)	Width (Å)	Transition	T (K)	Width (Å)
5s ^{3}P^o–5p ^{3}D 3815.5Å	10,000	0.377	5s ^{3}P^o–5p ^{3}S 3271.0Å	10,000	0.273
	20,000	0.267		20,000	0.193
	50,000	0.169		50,000	0.122
	100,000	0.134		100,000	0.958E−01
	200,000	0.119		200,000	0.857E−01
	300,000	0.116		300,000	0.831E−01
5s ^{3}P^o–5p ^{3}P 3534.1Å	10000	0.321			
	20,000	0.227			
	50,000	0.144			
	100,000	0.113			
	200,000	0.101			
	300,000	0.981E−01			

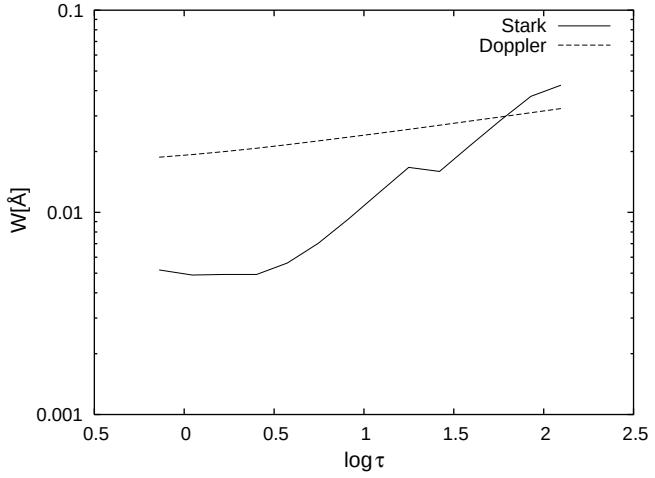

Fig. 1. Thermal Doppler and Stark widths for Se III spectral lines 4p5s ^{3}P^o–5p ^{3}D ($\lambda = 3815.5$ Å), for an A type star atmosphere model with $T_{\rm eff} = 10{,}000$ K and $\log g = 4.5$, as a function of the Rosseland optical depth.

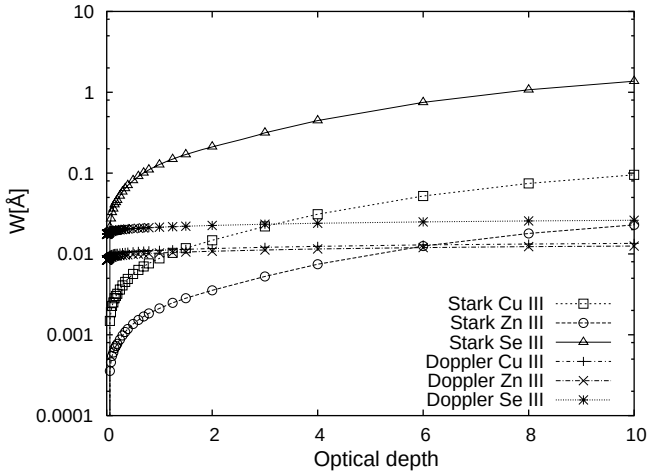

Fig. 2. Thermal Doppler and Stark widths for Cu III, Zn III and Se III spectral lines 4s ^{2}F–4p ^{2}G^o ($\lambda = 1774.4$ Å), 4s ^{3}D–4p ^{3}P^o ($\lambda = 1667.9$ Å) and 4p5s ^{3}P^o–5p ^{3}D ($\lambda = 3815.5$ Å) for a DB white dwarf atmosphere model with $T_{\rm eff} = 15{,}000$ K and $\log g = 7$, as a function of optical depth τ_{5150}.

it is smaller in the central part. Consequently, Stark broadening is significant for the considered line in a more wider layer and may be of interest in far line wings for the whole considered range of optical depths.

The influence of the Stark broadening on Cu III, Zn III and Se III spectral lines for DB white dwarf plasma conditions was investigated for 4s ^{2}F–4p ^{2}G^o ($\lambda = 1774.4$ Å), 4s ^{3}D–4p ^{3}P^o ($\lambda = 1667.9$ Å) and 4p5s ^{3}P^o–5p ^{3}D ($\lambda = 3815.5$ Å) by using the corresponding model with $T_{\rm eff} = 15{,}000$ K and $\log g = 7$ (Wickramasinghe, 1972). For the considered model atmosphere of the DB white dwarfs, the prechosen optical depth points at the standard wavelength $\lambda_s = 5150$ Å(τ_{5150}) are used in Wickramasinghe (1972) and here, as the difference to the A type star model (Kuruczs, 1979), the Rosseland optical depth scale ($\tau_{\rm Ross}$) was taken. As one can see in Fig. 2, for the DB white dwarf atmosphere plasma conditions, thermal Doppler broadening has much less importance in comparison with the Stark broadening mechanism than in A-type stellar atmospheres. For example, Stark width of the considered Se III 3815.5 Å line is larger than Doppler one up to two orders of magnitude within the considered range of optical depths. Much larger Stark widths in DB white dwarf atmosphere are the consequence of larger electron densities due to much larger $\log g$ and larger $T_{\rm eff}$, so that electron-impact (Stark) broadening mechanism is more effective. The different behaviour of Stark widths versus optical depths for A type stars and DB white dwarfs is conditioned by differences in electron density distribution with the height in stellar atmosphere.

The Stark broadening parameters obtained here, contribute also to the creation of a set of such data for as large as possible number of spectral lines, of significance for a number of problems in astrophysical, laboratory and technological plasma research. We note also that there are not other published theoretical or experimental data for the investigated ions.

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References

Adelman, S.J., 1994. MNRAS 271, 355.
Cowley, C.R., Ryabchikova, T., Kupka, F., Bord, D.J., Mathys, G., Bidelman, W.P., 2000. MNRAS 317, 299.
Chayer, P., Vennes, S., Dupuis, J., Kruk, J.W., 2005a. JRASC 99, 128.
Chayer, P., Vennes, S., Dupuis, J., Kruk, J.W., 2005b. ApJ 630, 169.
Dimitrijević, M.S., Konjević, N., 1980. JQSRT 24, 451.
Dimitrijević, M.S., Popović, L.Č., 2001. Zh. P. S. 68, 685.
Dimitrijević, M.S., Djurić, Z., Mihajlov, A.A., 1994. J. Phys. D: Appl. Phys. 27, 247.
Dimitrijević, M.S., Sahal-Bréchot, S., Bommier, V., 1991. A&A S 89, 581.
Dimitrijević, M.S., Ryabchikova, T., Popović, L.Č., Shylyak, D., Tsymbal, V., 2003. A& A 404, 1099.
Gayasov, R.R., Ryabtsev, A.N., 1992. PhyS 45, 322.
Griem, H.R., 1968. PhRv 165, 258.
Jacobs, J.M., Dworetsky, M.M., 1981. In: Proceedings of the 23rd Liege Ap. Colloquium, Star Main Sequence Cp Stars, Liege, p. 153.
Kuruczs, R.L., 1979. ApJS 40, 1.
Moore, C.E., 1971Atomic Energy Levels, vol. II. U. S. Department of Commerce, NBS, Government Printing Office, Washington, DC.
Piskunov, N., Kupka, F., 2001. ApJ 547, 1040.
Popović, L.Č., Simić, S., Milovanović, N., Dimitrijević, M.S., 2001. ApJS 135, 109.
Rasheig, S.C., Marshall, R.H.J., 1978. J. Appl. Phys. 49, 2540.
Ryabchikova, T.A., Savanov, I.S., Hatzes, A.P., Weiss, W.W., Handler, G., 2000. A& A 357, 981.
Sahal-Bréchot, S., 1969a. A&A 1, 91.
Sahal-Bréchot, S., 1969b. A&A 2, 322.
Seaton, M.J., 1987. J. Phys. B20, 6363.
Simić, Z., Dimitrijević, M.S., Milovanović, N., Sahal-Bréchot, S., 2005. A&A 441, 391.
Sugar, J., Musgrove, A., 1990. J. Phys. Chem. Ref. Data 19, 527.
Sugar, J., Musgrove, A., 1995. J. Phys. Chem. Ref. Data 24, 1803.
Wickramasinghe, D.T., 1972. Mem. R. Astron. Soc. 76, 129.

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Rate coefficients for the chemi-ionization processes in sodium- and other alkali-metal geocosmical plasmas

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Abstract

The chemi-ionization processes in thermal and sub-thermal collisions of excited alkali atoms with atoms in ground and excited states were considered, with a particular accent to the applications for geocosmical plasma research. An improved version of semi-classical method for the rate coefficients calculation is presented. The method is applied to the cases of excited alkali atoms with the principal quantum numbers $5 \leqslant n \leqslant 25$. The results of calculation of the considered chemi-ionization processes rate coefficients are compared to the existing experimental data. Their good agreement recommends to use the rate coefficients obtained for analysis of geocosmical plasma processes.
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1. Introduction

Elementary processes involving ions, atoms and molecules in geocosmical plasmas, traditionally attract researchers attention for a longer time (see e.g. Herbst and Klemperer, 1973). Among these processes, those involving highly excited Rydberg atoms are also of interest for stellar atmospheres of late spectral classes, interstellar H II clouds where Rydberg atoms form as a result of electron–proton recombination processes, as well as in other astrophysical plasmas. Recently was reported in Harth et al. (2004) that Rydberg molecules of atmospheric gases influence even on terrestrial biosphere. At first, our attention will be paid here on a group of ionization processes in Rydberg atom collisions with ground state parent atoms, known in literature as chemi-ionization processes, namely

$$RA(n) + A \Rightarrow \mathrm{e} + A_2^+ \quad (\mathrm{AI}), \tag{1a}$$

$$RA(n) + A \Rightarrow \mathrm{e} + A + A^+ \quad (\mathrm{PI}), \tag{1b}$$

where A, A^+ are atoms and their positive ions in their ground states, $RA(n)$ an atom in a highly excited (Rydberg) state with the principal quantum number $n \gg 1$, A_2^+ corresponding molecular ions in ground electronic states, and e a free electron, AI – associative ionization, PI – Penning-like ionization. Besides, we will consider shortly on the ionization processes in collisions of atoms in the weakly excited states.

The processes (1) with participation of alkaline atoms are studied for a long time experimentally (Devdariani et al., 1978; Boulmer et al., 1983; Zagrebin and Samson, 1985; Weiner and Boulmer, 1986), as well as theoretically (Janev and Mihajlov, 1980; Mihajlov and Janev, 1981; Duman and Shmatov, 1980). In all just mentioned papers, the processes (1) were treated exclusively in the laboratory conditions. In the hydrogen and helium cases however, the (1) processes later were considered in the conditions of stellar photospheres by Mihajlov et al. (1997), Mihajlov et al. (2003a). However, the processes (1) involving alkali atoms continued to be studied exclusively from the laboratory aspect. But for a longer time were collected data on the possible significant presence of alkali atoms, especially of sodium atoms, in some moons and planet atmospheres, as well as in comet tails and brown dwarfs and cooler star atmospheres (Mekler et al., 1976; Coroniti et al., 1976; Combi et al., 1997; Jonson, 2000; Takahashi et al., 2000; Burrows and Volobuyev, 2003; Schaefer and Fegley, 2005; Dalgarno and Block, 1976; Bezuglov et al., 1997b).

Chemi-ionization processes, leading to formation of molecular ions, can play an essential role in the sequence of ion-molecular reactions on surfaces of solid particles or in associative processes of the binary collisions leading to surprising variety of molecular formations in interstellar gas (Dalgarno and Block, 1976).

From above mentioned it follows that it became interesting to consider the processes (1) where A is an alkali metal atom, because such results begin now to enter as a subject of the astronomical data's publications (Bezuglov et al., 1997b). In this paper, we will consider the most significant case when $A \equiv$ Na.

The considered processes are interesting from two points of view: first, they could be quite effective sources of the charged particles generation in the optically excited gaseous media; second, they could be studied as a prototype of the elementary process of the radiation energy transformation into electrical one, which is of interest for the physics of geocosmos.

We will continue on the example of the hydrogen-like alkali metal atoms, so that the obtained results should directly correlate with analogous conclusions for hydrogen – the most spread and the most abundant component of the Universe.

It is well known from solar photospheric and planet absorption spectrum, chemical analysis of asteroid fragments, meteorites and cosmic dust that alkali metals, especially such as Na and K, are present in large number of studied cosmic objects including solar system (Burrows and Volobuyev, 2003; Schaefer and Fegley, 2005). In spite of the fact that alkali metals are not so wide spread compared to hydrogen, the logarithm of sodium abundance, for example, is 6.31 in meteorites and 6.30 in Solar photosphere (hydrogen – 12.00 in both cases).

It is known also that for particular astrophysical objects abundances of elements from the Mendeleyev periodic table could be 4–6 orders of magnitude larger than its averaged cosmic abundance (Aslanov et al., 1973). In such a way, alkali metal cosmic plasma can be the subject of direct astrophysical investigations. For example sodium plasma clouds are found in the atmosphere of the Jovian satellite Io. Apart of that, alkali plasma became and the object of astrophysically inspired laboratory experiments for the modeling of processes in geocosmos (D'Angelo et al., 1966).

At the end, on the approach of astrophysics and new sophisticated technologies, projects of the alkali metal photoplasma application in devices for direct conversion of Solar energy into the electrical one are known (Palmer, 1977).

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A certain interest for the processes of aerosol forming in conditions of geocosmos can represent and the effect of solid particles of micron size forming in collisions of optically excited alkali atoms with hydrogen (Tam et al., 1977).

The rate of the collisional ionization processes in an absorbing gaseous medium depends on the characteristics of the medium itself which are determined by its possibility to absorb and, then, to reemit radiation. As a result of joint investigations carried out in the Pisa and St. Petersburg Universities, analytical methods for solving a wide class of integro-differential equations, describing both the processes of radiation transfer in optically dense media (Bezuglov et al., 1995a, 1999b) and the processes of the valence electron transition in the set of quasi-continuous energy levels, were developed (Bezuglov et al., 1997b). Here, we will consider only the second-collisional-aspect of the general problem of energy transfer in an optically excited medium, which leads to its ionization.

Investigations of elementary ionization processes in the thermal and subthermal energy ranges have a direct relation to investigations of low-temperature photoplasma creation via optical excitation (Klucharev and Vujnović, 1990). Any sophisticated set of equations describing a plasma medium has the right to exist only under the condition of knowledge of accurate values of the cross sections of elementary collisional processes occurring in it.

In the literature, the following gradation of temperature ranges of atomic collisions is commonly used: thermal ($T = 10^2$–10^3 K), subthermal or cold ($10^{-3} < T < 10^2$ K), and ultracold ($T \ll 10^{-3}$ K) collisions. Experimental investigation of ultracold collisions requires the use of special equipment for laser cooling and trapping of the particles. At the same time, the conditions for subthermal collisions can be rather easily realized in effusive atomic beams owing to the specific features of the relative velocity distribution of atoms. The existence of directed fluxes of matter in the gaseous phase, as e.g. due to effects of particle explosive vaporization provoked by radiation, is quite typical in the conditions of geocosmos.

Under the situation when the sum of the excitation energies of atoms-partners is smaller than the ionization potential of the individual atom and of thermal or subthermal energies of collisions, two main processes are known that lead to a considerable energy transfer, namely, AI and energy pooling (EP):

$$A^* + A^* \Rightarrow \mathrm{e} + A_2^+ \quad (\mathrm{AI}), \tag{2}$$

$$A^* + A^* \Rightarrow RA + A \quad (\mathrm{EP}). \tag{3}$$

In process (2), practically the whole internal energy of two colliding particles is transferred to one of them. The EP-process itself is not ionization process, but it leads to the appearance of new ionization channels due to the formation of highly excited atoms. Two above-mentioned cases, (1b) and (2), imply the interaction between discrete strongly coupled atomic states (2) or between discrete states and the electron continuum (1b). Other situation can appear in the case of the AI-process occurring via an intermediate stage – a Rydberg quasi-molecule (RM):

$$RA + A \Rightarrow (RM + A) \Rightarrow \mathrm{e} + (A, A^+). \tag{4}$$

The RM-system with one Rydberg electron and the other strongly bound inner electron may be represented as a real model of a nonlinear system.

2. Chemi-ionization in binary collisions of atoms in low-lying excited states

2.1. Rate coefficients for binary collisions of alkali-metal atoms in the first excited resonant states

In low-temperature plasma physics, chemi-ionization processes are traditionally regarded as providing an effective channel for the production of molecular ions. This refers in the first instance to studies involving inert-gas and alkali-metal atoms in the lowest of all the possible (resonance) excited states because of their extensive applications in science and technology. Two possibilities are then found to arise.

$$\sum E^* > U_\mathrm{i} \tag{5}$$

$$\sum E^* < U_\mathrm{i} \tag{6}$$

where $\sum E^*$ is the total excitation energy, U_i is the ionization potential of an individual atom.

Case (5) includes the ionization of the hydrogen atoms, inert gases, the halogens, nitrogen, and oxygen, whereas case (6) includes the ionization of alkali-metals, rare-earth elements, uranium, etc.

Table 1 lists experimental results included for the first time in Saint-Petersburg University for the gas-cell conditions in 1975–1977s (Dobrolege et al., 1975; Klucharev and Ryazanov, 1971). When the activation energy $\Delta U > 0$ the expression for the reaction rate contains the factor $\exp(-\Delta U/kT)$, which largely determines the temperature $k(T)$ function. The strong dependence on temperature of the reaction rate for the chemi-ionization (associative ionization) must be taken into account in any real condition. From the data's analysis it can be seen, that the efficacy of threshold (AI) processes depends significantly on the shape of the particle velocity distribution (Bezuglov et al., 1984). When the conditions are different, the data must be re-examined and this can only be done if we know the corresponding terms of the quasi-molecules and molecular ion. One needs the temperature dependence of the AI cross-section too.

For example, on the one hand, sodium is the most abundant of alkalis; whilst, on the other hand, newly published data are not entirely free from internal contradiction. This is so-called the ''sodium paradox''.

The data in the tables are obtained without identification of the total moment values for fine structure components of $^2P_{1/2,3/2}$ term. According to Carre et al. (1981), depending on values of quantum numbers $J = 1/2, 3/2$, colliding atoms AI rate constant can change 2.5 times. We

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Table 1
AI rate coefficients for the process $Na(3^2P) + Na(3^2P) \Rightarrow e + Na_2^+$

Experimental conditions	Beam source temperature	Original value K (10^{-11} cm^3 s^{-1})	Corrected value (Bezuglov et al., 1984)	Reference
Gas cell, resonant lamp	550 K	3.8 (±20%)	3.8	Klucharev et al. (1977)
Single beam, laser	580 K	0.015 (factor 2)	0.03	De Iong and van der Valk (1979)
Gas cell, laser	650 K	0.56 (±40%)	1.1	Huennekens and Gallager (1983)
Beams crossing at 90°, laser	520 K	0.34 (±50%)		Carre et al. (1984)
Uncollimated single beam, laser	570 K	1.8 (±40%)	3.4	Bonanno et al. (1983)
Single beam, laser	"Effective temperature" 60×10^{-3} K	$6.3 + 1.8$		Thorsheim et al. (1989)
Optical trap	0.75×10^{-3} K	$11 + 1.3$		Gould et al. (1988)

shall not discuss here the influence of polarizing effects on reaction rate coefficients since this is not so essential for the corresponding estimations in space plasma.

Note that the unexpectedly large value of K in cold collisions ($T \sim 10^{-3}$ K) may be explained in terms of the increased de Broglie wavelength at such conditions (Weiner et al., 1989).

The interesting aspect of very cold collisions between two resonantly-excited sodium atoms was discussed in Gallager (1991). It is suggested that the production of Na_2^+ ions at low light intensities can be considered as the following many stage process:

$$h\nu_1 + Na + Na \Rightarrow Na^* + Na. \quad (7)$$

The particle pair moves in the attractive potential of quasi-molecule with the simultaneous absorption of the photon $h\nu_2$ and the associated production of a pair of resonantly excited atoms

$$h\nu_2 + Na^* + Na \Rightarrow Na^* + Na^*. \quad (8)$$

The two excited atoms interact and produce the molecular ion, namely

$$Na^* + Na^* \Rightarrow e + Na_2^+. \quad (9)$$

2.2. Ionization in binary collisions of low-lying excited atoms in states higher than the resonant one

The collisional ionization (10) in effusive beams with the participation of alkali atoms in low-lying excited states was successfully studied by the methods of high-resolution electron spectrometry (Dengel et al., 1993).

$$\begin{aligned} &A^*(n_1, l_1) + A^*(n_2, l_2) \Rightarrow e + A^*(n', l') + A^+, \\ &A^*(n_1, l_1) + A^*(n_2, l_2) \Rightarrow e + A_2^+, \\ &n_1 \geqslant 3, \quad n_2 \leqslant 5, \quad l_1 \geqslant 0, \quad l_2 \leqslant 2, \quad n' = 3, \ l' = 0, 1. \end{aligned} \quad (10)$$

The effect of inter-configuration interaction on the efficiency of processes (10) can be neglected for the 4d4p, 4p4s, 5s5p, 5s4p, 4s4s, and 3p3d initial configurations. In Table 2 are presented the calculation data of the total ionization cross-section σ_i for reaction (10) for four of the above-mentioned configurations; the calculation was performed within the framework of the first-order approximation of the dipole–dipole interatomic interaction. The effect of the Cooper minimum in the photo-ionization cross sections of excited atoms on the probability of allowed dipole transitions leads to a decrease in the values for 4p4s and 5s5p configurations. The similar effect, relative to the corresponding values of the spectral line strength, results in a decrease of the magnitude of σ_i for the 5s4p states. As the limiting case, Table 2 also gives the value of σ_i calculated with the allowance made for the phenomenon of twisting. The comparison with experimental data proved to be possible only for the case of 3p3d initial configuration (Dengel et al., 1993; $\sigma_i = 0{,}5 \times 10^{-13}$ cm^2 – theory, and $\sigma_i = 10^{-13}$ cm^2 – experiment) because the results of measuring the cross section by electron spectroscopy methods do not give, as a rule, their absolute values. In the general case, the line strength S increasing leads to an increase in the efficiency of channel, accompanied by the appearance of slow electrons and by the population of the excited states close to the initial one.

Table 2
Calculated data on ionization in binary collisions of low excited sodium atoms, $E = 0.28 \times 10^{-3}$ eV (Bezuglov et al., 1999a)

Configuration	σ_i (a.u.)	σ_i (a.u.), in the channel S-state creation	σ_i (a.u.), in the channel P-state creation
3p3d	1687	1687	
4p4s	13	13	
5s5p	135		135
5s4p	875	24	851

3. Collision ionization with RA participation: symmetrical case

3.1. Ionization in Rydberg-atom–atom collisions

3.1.1. The resonant mechanism

Recently, in connection with development of basic researches in the field of interaction of radiation with the

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single atoms and molecules the circle of problems in which RA play the main role was significantly enlarged. Here it is necessary to name first of all such fundamental and applied researches as laser cooling of atoms and Bose–Einstein condensation, management of the single atom states, new prospects in creation of logic devices of quantum computers, quantum teleportation, etc. All this increases interest to experimental and theoretical researches with RA participation, including the processes leading to their ionization in atom collisions. Let us note that the first results in this area have been received in 1978 (experiment Devdariani et al., 1978) and 1980 (the theory Janev and Mihajlov, 1980; Mihajlov and Janev, 1981; Duman and Shmatov, 1980) years.

Present experimental facilities on laser excitation allow to achieve the highly excited RA population compared with the normal one. Under primary selective excitation resonant atomic states the energy pooling processes may provide the RA effective population. So the high selectivity of the optical excitation in the experimental investigation with excited atoms in many cases may be treated as a "nice blue idea". The ionization over new opened Rydberg channels takes the part on such channels.

Two ionization channels are possible in binary collisions such as (1). The first series of quantitative measurements of the rate coefficients K for (1) started in 1978 for group one elements (Devdariani et al., 1978).

Due to the interest in chemi-ionization processes, several methods of rate coefficients calculations were presented within short time. The methods developed in Janev and Mihajlov (1980), Mihajlov and Janev (1981) treated the considered RA-atom systems within the semi-classical approach, while in Duman and Shmatov (1980) an attempt at quantum-mechanical description of the internuclear motion was made. All these methods were based on the same resonant mechanism of quasi-resonant energy exchange within the electronic component of the RA-atom system. This mechanism was introduced in Smirnov and Mihajlov (1971) in connection with some inelastic processes in slow $RA + A$ collisions.

The resonant mechanism of the considered inelastic processes is effective in region of internuclear distances

$$R \ll r_n, \tag{11}$$

where $r_n \sim n^2$ is the mean radius of atom RA, as illustrated in Fig. 1. In this region the system $RA + A$ is taken in the form $(A^+ + A) + e_n$, where A^+ and e_n are the core and the outer electron of RA. The inelastic processes are treated as a result of the interaction of the outer electron e_n with the dipole momentum of the subsystem $A^+ + A$. Atomic units are used in further.

The electronic state of $A^+ + A$ subsystem during the collision is described as a group of adiabatic electronic states of the molecular ion A_2^+, adiabatically correlated with the electronic states of this sub-system at $R = \infty$. In the case when A is an atom with one or two s-electrons outside closed shells (A = H, He, Li, Na, etc.), only two Σ^+-states

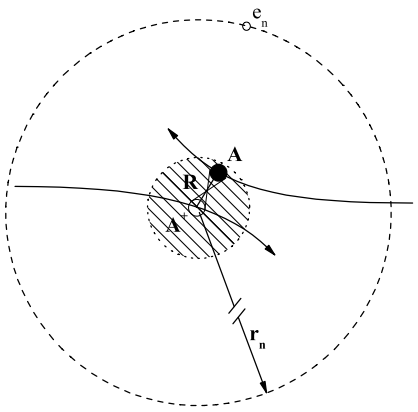

Fig. 1. Schematic illustration of $RA + A$ collision (the region of R where the outer electron is collectivized is shaded; Ignjatović and Mihajlov, 2005).

of A_2^+, the ground and the first excited states, compose such a group. When A is an alkali atom they are Σ_g^+ - and Σ_u^+ states, respectively.

It is assumed that in the region of R where the considered inelastic process takes place the optical electron of the atom A is collectivized within the $A^+ + A$ subsystem (see Fig. 1). The ranges of R where the energy exchange between the outer electron e_n and the electron component of the $A^+ + A$ sub-system has an almost resonant character give the main contribution to the considered inelastic process. Such ranges represent the neighborhoods of crossing-points of the potential curves for different Λ_u and Λ_g states of $RA + A$ quasi-molecular system, which is illustrated by Fig. 2.

Until now, this resonant mechanism was used in three different approximations: two semi-classical and one quantum mechanical. The first semi-classical one, used already in Smirnov and Mihajlov (1971), understands that the relative nuclear motion occurs in some average effective

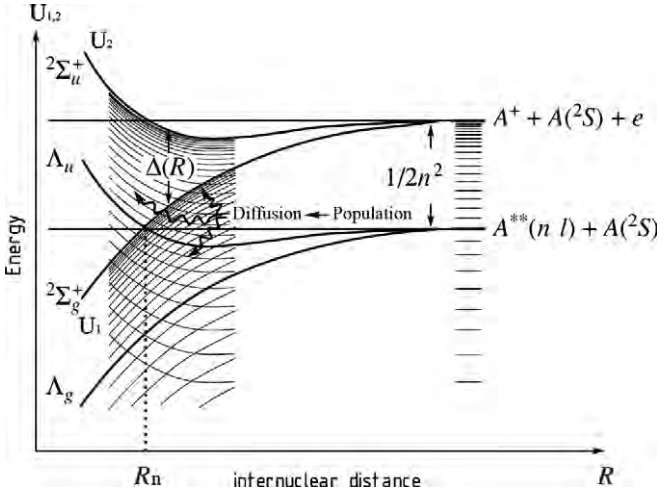

Fig. 2. Illustration of the mechanism of the $RA + A$ collision process. $^2\Sigma_u^+$, $^2\Sigma_g^+$ – the ionic states, Λ_u, Λ_g – the initial quasi-molecular states. The Λ_u state crosses the ionic state at $R = R_n$.

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potential along the unique trajectory. In Smirnov and Mihajlov (1971) it was shown that in such a case the dipole moment $D(R)$ of $A^+ + A$ sub-system can be represented as a known function of the time, namely

$$D(R(t)) = \frac{R(t)}{2}\cos\left[\int_{-\infty}^{t}\Delta E(R(\tau))\,\mathrm{d}\tau\right], \quad (12)$$

where $R(t)$ is the internuclear distance in the moment of time t, $\Delta E(R)$ is the splitting term

$$\Delta E(R) = U_2(R) - U_1(R), \quad (13)$$

and $U_1(R)$ and $U_2(R)$ are the adiabatic potentials of the ground and the first excited electronic states of the molecular ion A_2^+. In this case the behavior of outer electron e_n is described by means of time dependent Schrödinger equation, where the perturbation is known function of the time. This approach was applied in the case of ionization processes in symmetric atom-Rydberg atom collisions in Devdariani et al. (1978).

The other semi-classical approach, developed in Janev and Mihajlov (1980), Mihajlov and Janev (1981), understands that the relative nuclear motion occurs with the probability 1/2 along the trajectory which corresponds to the potential $U_1(R)$, and with the same probability 1/2 – along the trajectory which corresponds to the potential $U_2(R)$. Consequently, such semi-classical approach should be treated as the approximation of two classical trajectories. In the case of ionization processes the initial electronic state of the sub-system $A^+ + A$ is the first excited $^2\Sigma_u^+$- state. Accordingly, the trajectory which corresponds to the potential $U_2(R)$ is relevant in this case, and the ionization process is treated as the result of the transition of the sub-system $A^+ + A$ from $^2\Sigma_u^+$ to $^2\Sigma_g^+$-state together with the transition of outer electron e_n from the considered Rydberg state to continuum.

The third approach, applied in Duman and Shmatov (1980), understands that the relative nuclear motion is treated in quantum mechanical way, by means of superposition of two adiabatic nuclear wave functions which describe the motion in the potentials $U_1(R)$ and $U_2(R)$, separately. The ionization process is treated similarly as in the second semi-classical approximation.

Authors (Duman and Shmatov, 1980) represent unique attempt to describe processes (1) along with the quantum-mechanical treatment of the internuclear motion with an additional assumption about the possibility of smearing ro-vibrational spectrum of molecular ion A_2^+. Here we will not discuss this method because it was applied only to the processes (1) with $A = Cs$. The first theoretical results obtained within the framework of semi-classical method (Janev and Mihajlov, 1980; Mihajlov and Janev, 1981) and quantum mechanical one (Duman and Shmatov, 1980) was in a good agreement with the experiment.

The theoretical results based on two last approaches (Janev and Mihajlov, 1980; Mihajlov and Janev, 1981; Duman and Shmatov, 1980) are called in the literature as the DSMJ model (the abbreviation consists of the first letters of the author names). The further development and improvement of the theory was connected to the hydrogen and helium atom cases and their application in astrophysics (see e.g. Mihajlov et al., 1992, 1996, 1997, 1999, 2003a,b). However there was a permanent interest in the processes (1) involving atoms of alkali metals (Boulmer et al., 1983; Zagrebin and Samson, 1985; Weiner and Boulmer, 1986; Bezuglov et al., 1997b).

The experimental and theoretical results obtained in the world laboratories till today concerning AI and PI processes including RA have been discussed in the literature repeatedly ever since. For example effect of decay of the initial electronic state during $A^{**}(n) + A$ collision, using of approximate analytical expressions for the adiabatic potential curves $U_1(R)$ and $U_2(R)$, see Fig. 3; decoupling the RE motion from the internuclear one, and correctness of the unique straight line approximation to the particles motion, were discussed. For that reasons it was necessary to return again to the chemi-ionization in the alkali atoms case.

Now will be considered the results obtained with authors participation in last time (Ignjatović and Mihajlov, 2005; Miculis et al., 2005; Beterov et al., 2005) namely the chemi-ionization rate coefficients obtained taking into account results for the RA for principal quantum numbers $5 \leqslant n \leqslant 25$, where there is no crossing of the systems $A^{**}(n) + A$ and $A^+ + A^-$, where A^- denotes a stable negative ion.

3.1.2. The stochastic dynamics approach: the unique trajectory model

The first results on the investigation of chemi-ionization in RA-atom collisions are summarized in Klucharev and Lazarenko (1980). The more substantial disadvantage of such work was the neglecting of the large number of crossings of the initial ion term U_2. In the case of multiple crossing of terms, the attempt to take into account each particular crossing in theoretical approaches traditional

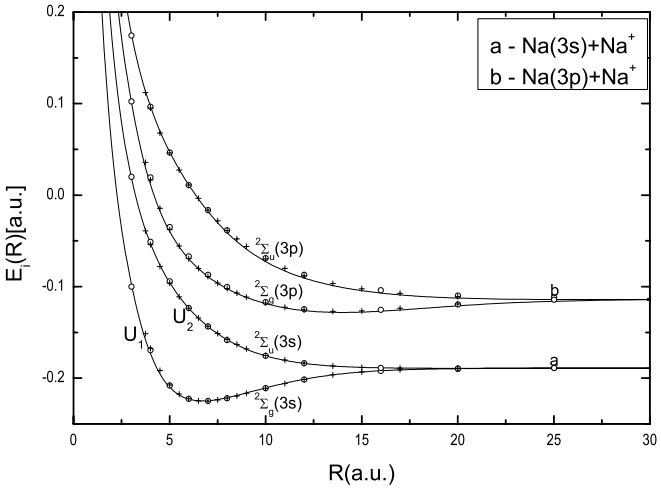

Fig. 3. The adiabatic potential curves of molecular ion Na_2^+ (Ignjatović and Mihajlov, 2005): (a) $Na(3s) + Na^+$, (b) $Na(3p) + Na^+$.

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for atom collision physics does not lead to any kind of general results. Namely, the Rydberg electron (RE) energy change occurring for each of the multiple crossing of the terms is $\delta E \leqslant 1/n^3$, so that $\delta E/E_n \sim 1/n \ll 1$, where $E_n = 0.5/n_2$ is the binding energy of RA. This lead to the idea of the possibility of a diffusion approach to solution of the atomic collisions problem with RA participation, having in mind diffusion over the energy states of the quasi-molecule in one collision event (Devdariani et al., 1988). Unfortunately, the proposed model was largely qualitative: no actual physic process causing the RE to diffuse was suggested.

Note that the idea that the RE diffuses over the discrete energy spectrum of RA was successfully used earlier in Delone et al. (1983) to interpret anomalously high photo-ionization cross sections in experiments on laser irradiation of gases (see also Koch and Leeuwen, 1995). This logically suggests that for the ionization of the considered RA, the quasi-monochromatic electric field formed by charge transfer can also cause RE to diffuse over the discrete electronic spectrum, a process that can result in the "smearing" of the position of point R_i.

The latest stochastic version of chemi-ionization on RA-atom collisions extends the treatments of the DSMJ model by taking into account redistribution of population over a range of Rydberg states prior to ionization. That redistribution is modelled as diffusion of the RE in the Rydberg energy spectrum using a Fokker–Plank–Kolmogorov type equation (FPK).

The first obtained results give the reasons to believe that, during a single slow collision, the motion of the RE experiences the action of internal nonlinear dynamic resonances that arise due to the coincidence of the overtones of the RE motion over the Keplerian orbit with the frequency of the inner electron transfer. As a result, the motion of the RE becomes unstable. In this case, the transitions of the RE acquire the character of random walks over the network of crossing potential energy curves, thereby admitting a kinetic description of the time evolution of the distribution $f(n,t)$ of the RE.

The process of l-mixing of Rydberg states at large internuclear distances and twisting of the collision trajectories on attractive potential $U_2(R)$ have been taken into account too (Ignjatović and Mihajlov, 2005; Miculis et al., 2005; Beterov et al., 2005).

3.1.2.1. Model of stochastic diffusion. Stochastic dynamics describe the random walk of RE within the hydrogen like discrete energy spectrum caused by the coupling of RE with internal electrical field ($E(t)$). The initial covalent Λ_u state crosses the ionic $^2\Sigma_g^+$ state at $R = R_n$, becoming auto-ionizing for $R = R_n$.

3.1.2.1.1. Characteristic times

(1) Inter-nuclear distance $R(t)$ depends on time according to collision dynamics of the system.
(2) Factorization of FPK (with respect to R and n) means introduction of an "effective time" t_{eff}.
(3) Total effective time t_{tot} for the collision event with fixed ρ means time spent while $R(t)$ goes from $R = \infty$ to turning point R_{turn}.
(4) Average effective diffusion time $\langle t_{eff} \rangle$: the average time $t_{diff}(n_0, \rho)$ for the RE to diffuse from n_0^* level to the ionization limit determined from steady-state solution of FPK.

3.1.2.1.2. Diffusion equation. RE perturbation by internal electrical field $E(t)$ causes appearance of auto-ionization width $W(n_{eff}, R)$ of terms and can lead to dynamics chaos regime of classic trajectories. Stochastic motion of RE in energy space is described by (FPK) diffusion equation for the distribution function $f(n_{eff}, t)$:

3.1.2.1.3. Area of dynamics chaos regime. Stochastic diffusion of RE in energy space is based on Chirikov criteria (Chirikov, 1979) with Kepler mapping.

(1) Restrictions on the random motion ("lower limit"): The diffusion is forbidden in the energy region $n_{eff} < N_{min}(R)$, because energy difference between the neighboring levels becomes too large.
(2) Restriction on random motion ("upper limit"): Chirikov criteria for global chaos onset breaks down.

The ionization occurs whenever RE enters levels $n_{eff} > N_{max}(R)$ where the direct quantum photo-ionization channel becomes open and the corresponding auto-ionization width $W(n_{eff}, R)$ is expressed via the photo-ionization cross-section σ_{ph}. Important key-point for the stochastic diffusion processes: long collision times. It makes the model suitable for future application to treat collisions between cold atoms.

3.1.3. The decay approximation: the two-trajectories model

The processes (1) are treated here as a result of decay of the initial electronic state of the system $A^{**} + A$, caused by the resonant mechanism along a part of the relevant trajectory determined in the potential $U_2(R)$ by the impact-parameter ρ and the impact-energy E. In Janev and Mihajlov (1980) it was shown that the corresponding decay rate is given by expression

$$W_n(R) = \frac{4}{3\sqrt{3}n_{eff}^5} D_{12}^2(R) G_{nk}, \tag{14}$$

where $D_{12}(R)$ is module of the dipole matrix element for the electronic transition from the ground to the first excited state of the molecular ion Na_2^+, and G_{nk} denotes the generalized Gaunt factor, defined by the expression

$$G_{nk} = \frac{\sigma_{ph}(n,k)}{\sigma_{ph}^{Kr}(n,k)}, \tag{15}$$

where $\sigma_{ph}(n,k)$ is the photo-ionization cross section of the atom $A^{**}(n)$ with transition of the outer electron to the state with the energy ϵ_k, and $\sigma_{ph}^{Kr}(n,k)$ denotes the same photo-ionization cross section in Kramers's approximation.

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According to (Janev and Mihajlov, 1980), the chemi-ionization processes at given ρ and E can be characterized by the ionization probability $P_{ci}(t,n,\rho,E) = (1/2)P_d(t,n,\rho,E)$, where the probability $P_d(t)$ is defined as the solution of the equation

$$\frac{dP_d(t)}{dt} = [1 - P_d(t)] \cdot W_n(R(t)), \quad P_d(t = t_{in}) = 0 \tag{16}$$

namely

$$P_d(t) = 1 - \exp\left[-\int_{t_{in}^{(n)}}^{t} W_n(R(t'))\, dt'\right], \tag{17}$$

where t_{in} is the moment, when the distance R between Na^+ and Na becomes smaller than R_n.

In Mihajlov and Janev (1981) it was taken that the factor $[1 - P_d(t)]$ in (16) may be replaced by 1, so that the decay of the initial electronic state of the atom-Rydberg atom system observed during the collision was neglected. This approximation was justified in the case of chemi-ionization processes (1) with $A = H$ and He. However, in the case of alkali metal atoms the mentioned decay had to be taken into account. Because of that, in Mihajlov and Janev (1981) was necessary to make a posteriori calculation. It required an additional parameter which could not be properly determined within the method used in Mihajlov and Janev (1981). For that reason we shall follow the basic work in Janev and Mihajlov (1980), and use (16) here without the above simplification.

Using the probability $P_{ci}(t = t_{fin,n,\rho,E})$, where t_{fin} is the moment, when the distance R between Na^+ and Na becomes lager than R_n, one determines the cross sections for the chemi-ionization processes (1)

$$\sigma_{ci}(n,E) = 2\pi \int_0^{\rho_{max}(E)} P_{ci}(t_{fin},n,\rho,E)\rho\, d\rho, \tag{18}$$

where $\rho_{max}(E)$ is the upper limit of values ρ at which the corresponding region R is reached for a given E. Rate coefficients for processes (1) are determined thereafter by the expressions

$$K_{ci}(n,T) = \int_{E_{min}(n)}^{\infty} \sigma_{ci}(n,E)F(v_c;T)\, dv_c, \tag{19}$$

where v_c is the impact velocity, corresponding to the given E, $E_{min}(n) = 0$ if $U_2(R_n) \leqslant 0$, and $E_{min}(n) = U_2(R_n)$ if $U_2(R_n) > 0$, $F(v_c,T)$ is the velocity distribution function at a given temperature T which is different in cells, single beams and crossed beams cases (see e.g. Bezuglov et al., 1987; Wang and Weiner, 1987; Bezuglov et al., 1989 and Fig. 4). Finally, taking $K_{ci}(n,T)$, in the form

$$K_{ci}(n,T) = K_{ci}^{(a)}(n,T) + K_{ci}^{(b)}(n,T), \tag{20}$$

where $K^{(a)}$ and $K^{(b)}$ are partial rate coefficients for the processes (1), we will also characterize these processes by the branch coefficients

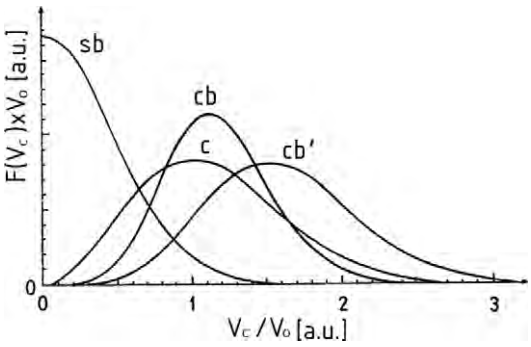

Fig. 4. Distribution function $F(v_c,T)$ of relative velocity v_c of short-living excited and normal atoms of the same mass M in a crossed beam (cb), counter beam (cb′) and gas cell (c); $T_{sb} = T_{cb} = T_{cb'} = T_c$, T – represent the gas temperature in the beam sources and cell. The characteristic thermal velocity is $v_0 = \sqrt{kT/M}$ (Klucharev and Vujnović, 1990).

$$X^{(a,b)}(n,T) = \frac{K_{ci}^{(a,b)}(n,T)}{K_{ci}(n,T)}, \quad X^{(a)}(n,T) + X^{(b)}(n,T) \equiv 1. \tag{21}$$

The determination of the partial rate coefficients $K_{ci}^{(a,b)}(n,T)$ is made in a similar way as $K_{ci}(n,T)$, i.e. by Eqs. (16)–(19), with the corresponding initial conditions (see Ignjatović and Mihajlov, 2005).

3.1.4. The comparison of the experimental and theoretical results

In the recent works (Ignjatović and Mihajlov, 2005; Miculis et al., 2005; Beterov et al., 2005), the results of the systematic experimental and theoretical studies of chemi-ionization of sodium RA in n^2S, n^2P, n^2D states with $n_{eff} = 5$–25 in symmetrical collisions with ground-state atoms have been presented.

The shapes of experimental dependencies of AI rate coefficients on the effective quantum number exhibit a broad maximum near $n_{eff} \approx 10$. Note that such peculiar $K(n_{eff})$ dependence was observed in the first work of such kind for RA (n^2P)–A collisions (Klucharev and Vujnović, 1990) (See Figs. 5–12).

The experimental absolute values of the rate coefficients are close to the theoretical calculation results for ^2P and ^2D states, but not for ^2S states (see Fig. 9).

From (Miculis et al., 2005; Beterov et al., 2005) comparison with experimental results it follows that stochastic diffusion model requires a further development in order to account for possible correlation effects between electronic and nuclear degrees of freedom in slow atomic collisions.

Strictly speaking in the experimental crossed beams conditions the resulting Na_2^+ signal is described by a sum of the respective AI rate constants

$$K_{AI}^{(\Sigma)} = K_{AI}^{(sb)} + K_{AI}^{(cb)} \tag{22}$$

with considerably different relative collision velocity distribution. In this relation K_{AI}^{cb} is the pure crossed beam AI rate constant which describes only the collisions between atoms

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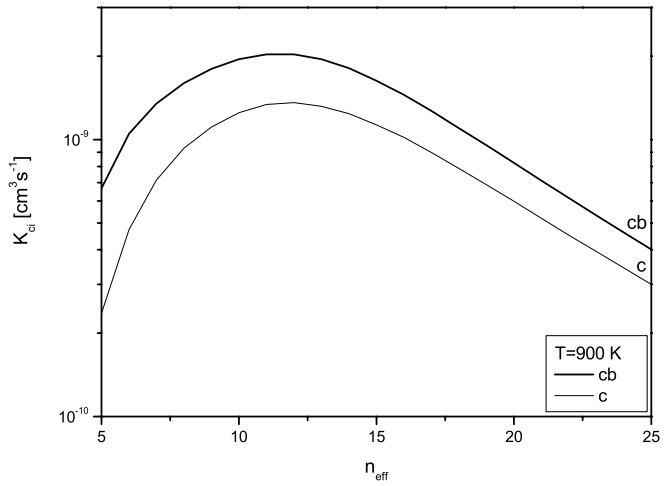

Fig. 5. The total rate coefficients K_{ci} for chemi-ionization in $Na^*(n_{eff}{}^2P) + Na$ collision theory, within the semi-classical approach (Ignjatović and Mihajlov, 2005). The curves K_{ci} correspond to the crossing beams (cb) and the cell conditions (c), T – the beam sources or the gas cell temperature respectively, $T = 900$ K.

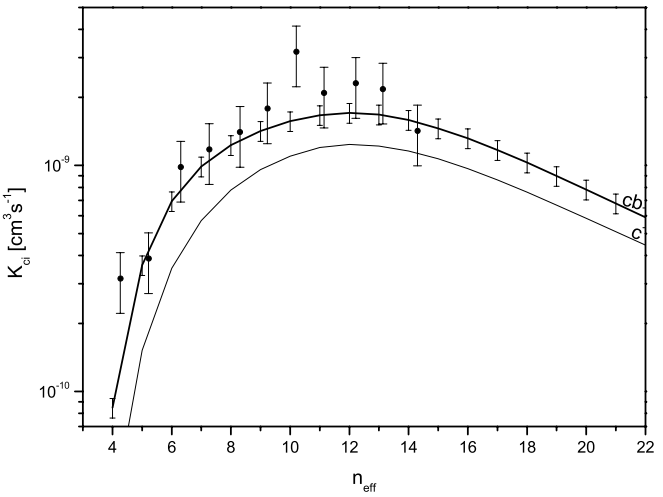

Fig. 7. The associative ionization rate coefficients for chemi-ionization in $Na^*(n_{eff}{}^2P) + Na$ collisions; dots: cb-conditions, $T = 600$ K, associative ionization experiment (Boulmer et al., 1983) the full curve: cb ($T = 600$ K), c = cell ($T = 720$ K), theory (Ignjatović and Mihajlov, 2005).

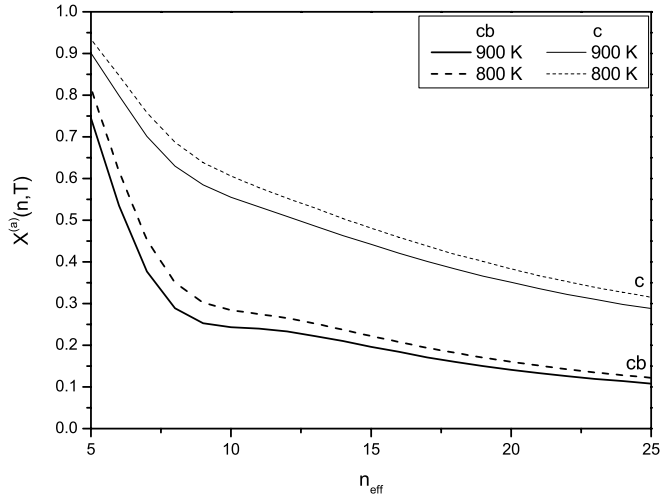

Fig. 6. The branch coefficients $X^{(a)}(n_{eff}, T)$ for chemi-ionization in $Na^*(n_{eff}{}^2P) + Na$ collisions. The main designations are the same as on the previous figure, $T = 900$ K, the dotted line, $T = 800$ K (Ignjatović and Mihajlov, 2005).

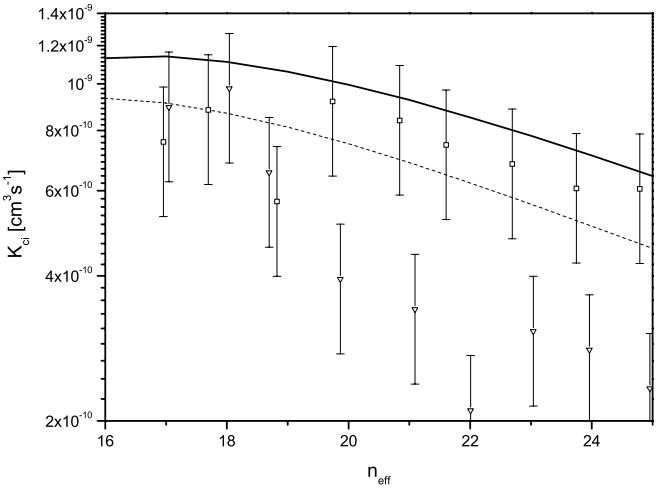

Fig. 8. The K_{ci} rate coefficients for chemi-ionization in $Na^*(n_{eff}, l) + Na$ single beam's collisions at $T = 1000$ K. The full and broken curves are the semi-classical theory results for $l = 0$ and $l = 2, 3$, respectively (Ignjatović and Mihajlov, 2005); open square – experiment, associative ionization, for $l = 0$; open triangle – experiment, associative ionization, for $l = 2$ (Weiner and Boulmer, 1986).

belonging to different beams and K_{AI}^{sb} applies to collisions with atoms from the same beam. The extraction of pure crossed beam rate constant K_{AI}^{cb} was performed in Beterov et al. (2005) for n^2S and n^2D states.

The experimental dependencies of K_{AI}^{Σ} and K_{AI}^{cb} on n_{eff} from (Beterov et al., 2005) are presented in Fig. 11 ($8 < n_{eff} < 18$). They have similar shapes but the absolute values of K_{AI}^{Σ} are about two time larger than K_{AI}^{cb}. These dependencies have a wide maximum at $n_{eff} = 8$–16 and a more narrow one at $n_{eff} = 11$–14 for n^2S states. The figure presents the results of theoretical ionization model. Note that in the widely known publication (Boulmer et al., 1983) cited above, the total K_{AI}^{Σ} was only presented. Fig. 12 shows the comparison of the experimental values $K_{AI}^{\Sigma}(l, n_{eff})$ in crossed beams for n^2S, n^2P and n^2D states.

Note that experimental K_{AI} dependencies on n_{eff} in two ranges of n_{eff}: $8 < n_{eff} < 18$ (crossed beam Boulmer et al., 1983) and $n_{eff} > 18$ (single beam Weiner and Boulmer, 1986) for n^2S and n^2D states are turned out on their absolute values. That unexpected results require a further elaboration.

3.2. Ionization in binary Rydberg-atom collisions

Let us briefly look at the ionization processes in two *RA* collisions.

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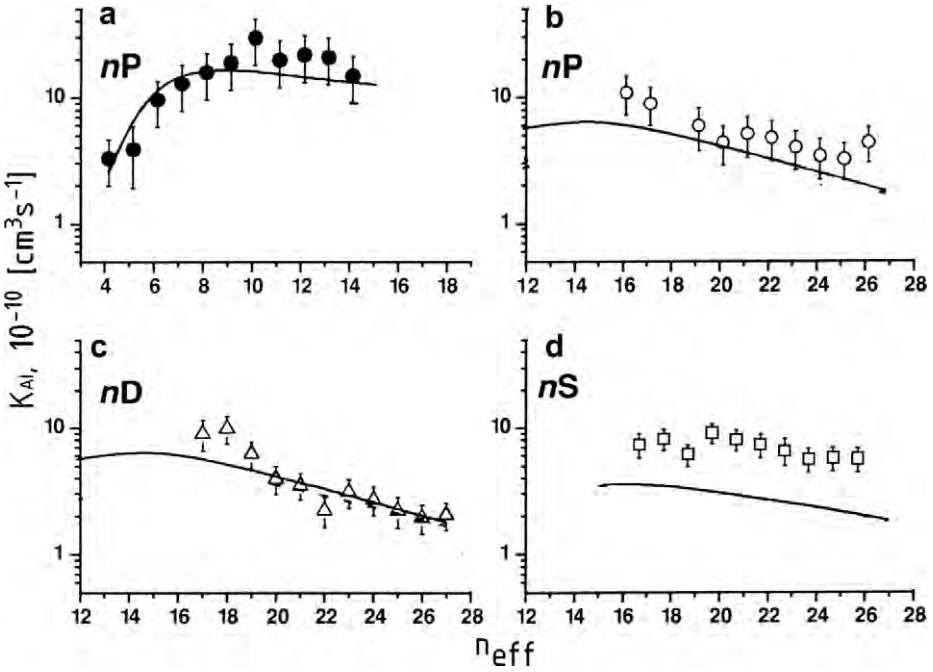

Fig. 9. Experimental and theoretical $Na^*(n_{eff}, l) + Na$ AI rate coefficients. (a) dots – cb conditions, $l = 1$, $T = 600$ K (Boulmer et al., 1983); (b) open circle, sb-conditions, $l = 1$, $T = 1000$ K (Weiner and Boulmer, 1986); (c) open triangle, sb-conditions, $l = 2$, $T = 1000$ K (Weiner and Boulmer, 1986); (d) open square, sb-conditions, $l = 0$, $T = 1000$ K (Weiner and Boulmer, 1986) full curves – theory, stochastic theory results (Miculis et al., 2005).

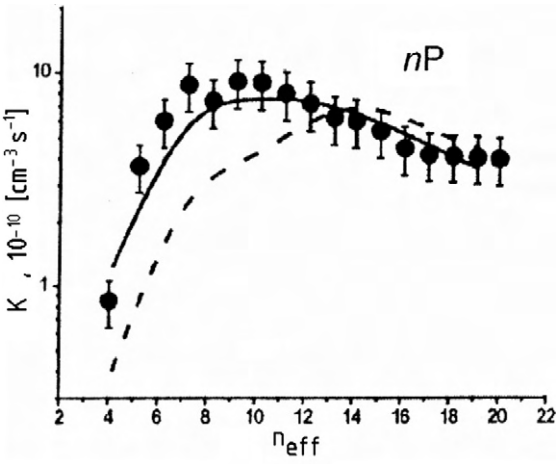

Fig. 10. Experimental and theoretical chemi-ionization rate coefficients in sb-conditions: dots – the experimental results (Zagrebin and Samson, 1985) obtained under non-accurate quantitative spectrometric identification of the ions mass and possibly poor atom collimation (Miculis et al., 2005), broken curve – AI stochastic model results, obtained with non-corrected (Zagrebin and Samson, 1985) collision velocity distribution; full curve – AI stochastic model results with velocity distribution correction (Miculis et al., 2005).

$$RA + RA \Rightarrow e + A + A^+, \tag{23a}$$

$$RA + RA \Rightarrow e + A_2^+, \tag{23b}$$

$$RA + RA \Rightarrow A^+ + A^-. \tag{23c}$$

In such processes, the total energy of two RA exceeds the ionization potential U_i of the individual atom. Therefore, as a result of binary RA collisions, the ionization-stable covalent atomic configurations (RA, RA) are converted into the Σ, Π, Δ, etc. auto-ionization states of the quasi-molecule which may decay into the positive ion A^+ and the excited atom A^* with a transition to low-lying states whose excitation energy is smaller than the energy of the initial RA state. Unfortunately, ionization in collisions of two Rydberg atoms is still the insufficiently studied field of atomic collision physics.

As a result of the non-adiabatic interaction of the initial RA–RA configuration with the neighboring ones, including unstable configurations, additional ionization channels are opened, such as the ionization through intermediate states and the formation of a pair consisting of the excited negative ion (A^*) in the auto-ionization state and the positive ion A^+; in addition, the initial states can also change without ionization. Despite the fact that stable negative ions A^- were experimentally detected in the output channel of the reactions, the process (23) is the main ionization channel (Olson, 1979).

In calculating the total auto-ionization width, of a Rydberg quasi-molecule with respect to PI channels in Bezuglov et al. (1995b), was used the first-order perturbation theory of the interatomic dipole–dipole interaction and the straight-line trajectory approximation. The role of this long-range interaction noticeably increases in the range of cold velocities. The above-mentioned conditions imply that the collisions with the impact parameters, larger than the sum of the Bohr radii of the colliding particles (equal to $4n^2$), make the main contribution to the ionization. In the case of alkali atoms, the presence of the quantum defect significantly influences the value of σ_i because it leads to a

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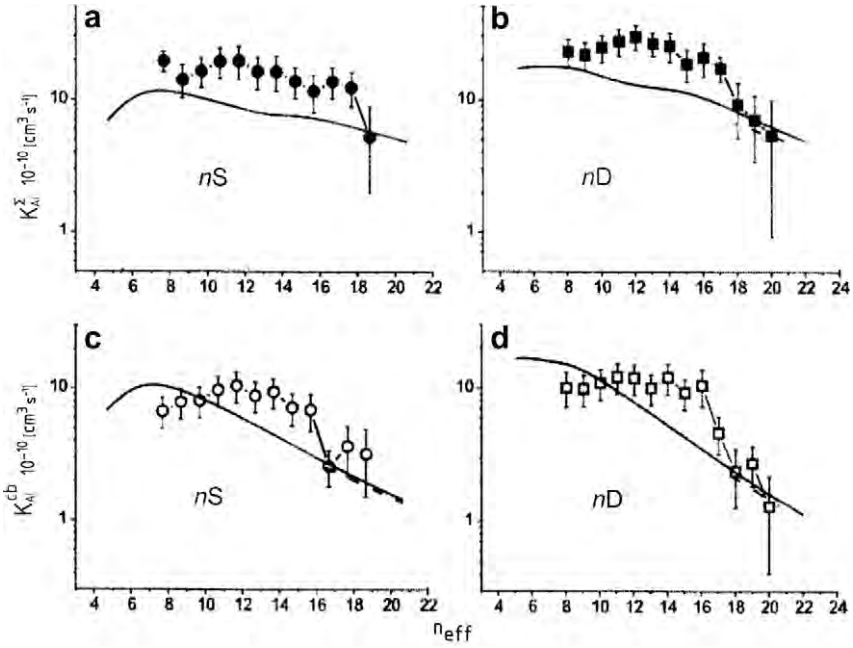

Fig. 11. Experimental and theoretical $Na^*(n_{eff}, l) + Na$ AI rate coefficients $8 \leqslant n_{eff} \leqslant 18$ for cb conditions, $T = 600$ K. Dots, open circle, open and full square experiment, full curves – stochastic theory results (Beterov et al., 2005). (a) K^{Σ}_{Al}, $l = 0$; (b) K^{Σ}_{Al}, $l = 2$; (c) K^{cb}_{Al}, $l = 0$; (d) K^{cb}_{Al}, $l = 2$.

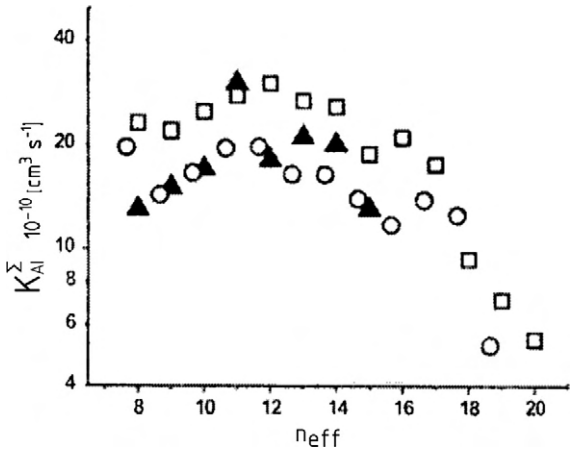

Fig. 12. Comparison of AI rate coefficients K^{Σ}_{Al} for n^2S (open circles) n^2D (open squares) states measured in cb-conditions $8 \leqslant n_{eff} \leqslant 18$, $T = 600$ K (Beterov et al., 2005) with the experimental results for n^2P states (solid triangles) obtained in Boulmer et al. (1983).

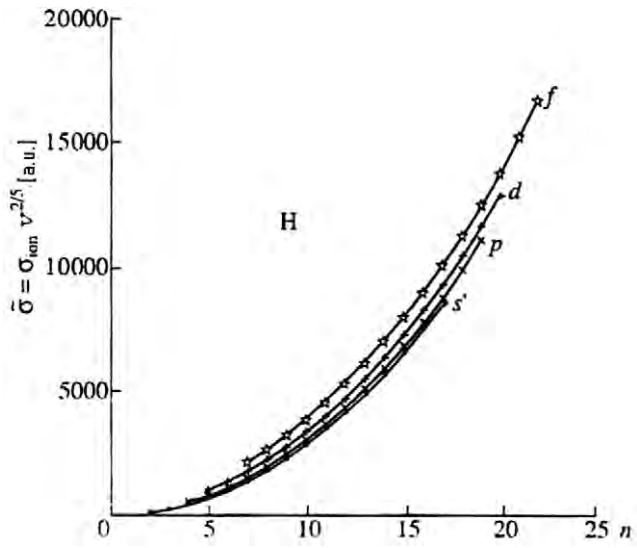

Fig. 13. PI ionization cross-section in the pair collisions of Rydberg hydrogen atom in the s, p, d and f states vs. principal quantum number (calculation) (Bezuglov et al., 1995b).

difference of the electrostatic field close to the ion core from the pure Coulomb field. Within the framework of the model in Bezuglov et al. (1995b) have been calculated the cross sections of process for symmetric collisions of the first-group atoms H, Li, Rb (Figs. 13–15). The expression for σ_i averaged over the values of the orbital angular momentum $L < n$ and integrated over all the low states $n''A^*$ with $n'' < n/\sqrt{2}$ has the form:

$$\sigma_i = 23.6 v^{-\frac{2}{5}} n^{-\frac{8}{5}}. \quad (24)$$

Because of the mixing of the nearest atomic configuration in the *PI* process, the population of the states can occur with violation of the selection rules for optically allowed transitions. So, even in the case of the initial selective population of two highly excited n^2P states, the population of the lower-lying n'^2P states ($n' < n$) via the intermediate $(S + S)$ configuration is also possible (Bezuglov et al., 1997a).

In McGeoch et al. (1988) *RA* Penning-type ionization in $Li^{**} + Li^*$ collisions was considered in another way using a classical trajectory Monte-Carlo method (CTMC). It has been noted that at low collision velocities CTMC method greatly overestimated the cross sections (Olson, 1979).

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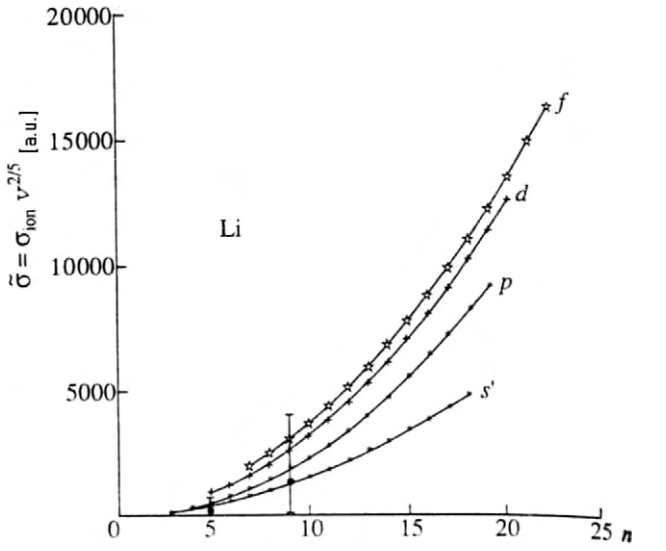

Fig. 14. The same as in Fig. 13, but for the lithium atoms (Borodin et al., 1995). The experimental point corresponds to the cb conditions with the n^2P states, $T = 1090$ K and molecular channel of the ionization (McGeoch et al., 1988).

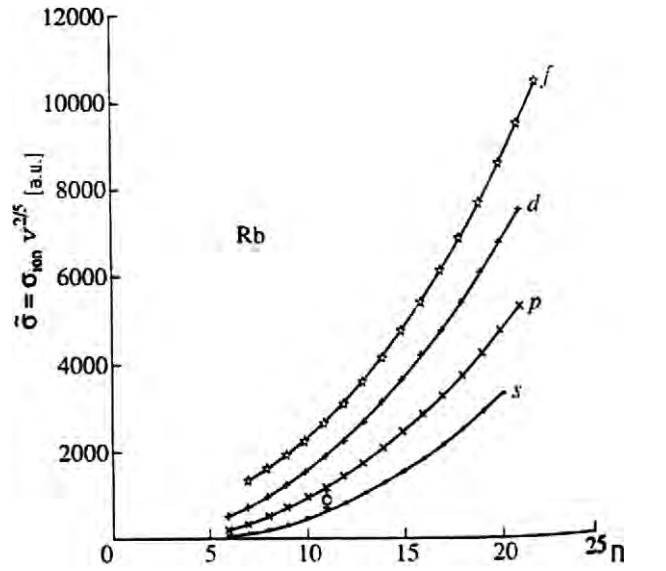

Fig. 15. The same as in Fig. 12, but for the rubidium atoms. The experimental point corresponds to the single beam experiment with the n^2P states $T = 380$ K and Rb_2^+ creation (Borodin et al., 1995).

4. Collision ionization with Rydberg atom participation (non-symmetrical collision)

4.1. Rydberg atom collisions with molecules

Note that it would expect high enrichment of alkali and halogen elements in volcanic gases on Io, so that the abundances of Na and Cl in Io's atmosphere may be compared (Schaefer and Fegley, 2005). Appreciable cross section (10^{-14}–10^{-15} cm^2) for thermal collisions between a metal atom (M) and a homo-nuclear (X_2) or hetero-nuclear (XY) halogen molecule was first noted in 1930s.

Chemi-ionization processes in atom-molecule collisions are usually multi-channel phenomena:

$$M + XY \Rightarrow M + XY^-, \tag{25a}$$

$$M + XY \Rightarrow M + X + Y^-, \tag{25b}$$

$$M + XY \Rightarrow M + X^- + Y, \tag{25c}$$

The cross section for the production of an ion pair depends on the degree of excitation of halogen-containing molecules and alkali metal atoms. For halogen-containing molecules, characterized by high rate coefficients ($K \approx 10^{-7}$ cm^3 s^{-1}, SF_6), the negative-ion yield in thermal collisions with RA is determined by the RE attachment probability. This follows from the theory and is confirmed by measurements of the ionization rate constants for RA with $n = 20$–100 in collisions with halogenides.

Table 3 lists the ionization rate coefficients and cross sections for collisions between $4^2D_{5/2}$ ($E_I^* = 0.86$ eV) or $5^2S_{1/2}$ ($E_I^* = 1.02$ eV) sodium atoms, and halogen containing molecules for sodium beam-source temperature $T = 600$ K.

The cross section for the production of an ion pair was found in Moutinho et al. (1971) to be a function of the degree of vibrational excitation of halogen-containing molecules colliding with alkali-metal atoms. For the $RA + SF_6 \Rightarrow A^+ + SF_6^-$ reaction, the cross section is inversely proportional to the orbital velocity of the electron in its highly excited state: $\sigma(v) = (4.2 \pm 1.0) \times 10^{-7}/v$. Since the Rydberg states of all atoms are similar, an analogous result is also obtained for xenon RA. As the principal quantum number is varied in the range $n = 23$–106, the RA chemi-ionization rate constant for collisions with SF_6 is found to lie in the range 4×10^{-7}–4.5×10^{-7} cm^3 s^{-1} and is practically independent of n.

In Beterov et al. (1987) it was found that the ionization data of n^2P Rydberg atoms of sodium ($n = 24$–32) in collisions with SF_6 molecules have a reasonable agreement with previously published data for Xe(nF) ($n = 25$–40), Rb(nS) ($n = 49$–62), and $Rb(n$D) ($n = 38$–106). An interesting new result is that there is a systematic discrepancy between the rate constants measured in experiments on the attachment of slow electrons to molecules, on the one hand, and the chemi-ionization measurements on RA, on the other. For other complex molecules, K either increases with increasing n (CCl_4, CCl_3F, CH_3I) or decreases (C_7F_{14}). The detailed dependence of σ on n is determined by the properties of the scattering of ultra-slow RE by molecules. Associative and Penning ionization in collisions between potassium atoms in metastable autoionizing states and D_2, NO, N_2, CO, CO_2, N_2O, H_2O, and H_2S molecules was investigated semi-quantitatively in Moutinho et al. (1971). According to these data, the Penning ionization cross sections are of the order of 10^{-15} cm^2.

The published data clearly illustrate the basic difficulties encountered when attempts are made to construct universal models of chemi-ionization in a wide range of values of n

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Table 3
Rate coefficients for chemi-ionization at thermal energies in collision of sodium atoms in $4^2D_{5/2}$ or $5^2S_{1/2}$ states and halogen-containing molecules, $T = 600$ K (Beterov et al., 1982, 1983)

	Atom, molecule	K (10^{-10} cm^3 s^{-1})	σ (10^{-13} cm^2)	Resulting negative ions
1	$Na(4^2D), SF_6$	2.8 ± 0.8	$1.6^{(*)}$, 4.6	SF_6^-
2	$Na(4^2D), CH_3Br$	0.35 ± 0.1	8.4, 2.5	Br^-
3	$Na(4^2D), CCl_2F_2$	0.54 ± 0.2	2.84	$23\%Cl_2^- + 77\%$ Cl^- or F_2^-
4	$Na(4^2D), C_6F_6$	0.08 ± 0.03	1.2×10^{-4}	$C_6F_6^-$
5	$Na(4^2D), C_6F_5H$	0.18 ± 0.06	2.7×10^{-4}	
6	$Na(4^2D), CH_3I$	2.1 ± 0.6		I^-
7	$Na(5^2S), O_2$	0.13 ± 0.04		O_2^-
8	$Na(5^2S), SF_6$	0.16 ± 0.05		SF_6^-

(*) Reactions 1–4 and 7 are endothermic so that the value is based on E_a used in the analysis of measured reaction rates.

even for a given atom. The high rate constants for the production of the SF_6^- ions are due to the fact that this ion appears in a long-lived excited state with lifetime $\tau > 0.001$ s. A different situation arises for the intermediate states in collisions between the alkali metals and O_2 molecules: the lifetime of the resulting $(O_2^-)^*$ ion is very short ($t_{eff} \sim 10^{-9}$ s) and, in the absence of a stabilizing mechanism, we have electron autodetachment (Walter et al., 1986). The interaction with the ion core of the Rydberg atom can serve as a stabilizing factor. If stabilization is less effective for smaller n, then, in contrast to, the above case of collisions with SF_6, the rate constant K for O_2 should decrease with n. This may be the explanation of the low value of K (10^{-12} cm^3 s^{-1}) and the reduction in K with increasing n ($8 \leqslant n \leqslant 12$) reported in Dunning and Stebbings (1983).

Ionization cross section for RA colliding with dipolar molecules such as H_2O, NH_3, SO_2, C_2H_5OH, and CH_3NO_2 are given in Dunning and Stebbings (1983) and Smirnov (1982). For $n > 30$, the corresponding rate constants tend to their asymptotic limit (10^{-6} cm^3 s^{-1}, H_2O, NH_3).

4.2. Non-symmetrical atom–atom chemi-ionization processes

In Klucharev and Lazarenko (1980), under the optical excitation of the excited potassium vapors, ionization with n^2P excited sodium atoms $4 \leqslant n \leqslant 7$ has been registered. Sodium was presented in potassium vapor as a slight admixture less than one per cent. Excited n^2P sodium states with $n = 5$ are situated beyond the potassium ionization threshold. That makes it possible to assume the non-symmetrical ionization process:

$$\begin{aligned} &Na^* + K \Rightarrow e + NaK^+, \\ &Na^* + K \Rightarrow e + Na + K^+, \end{aligned} \tag{26}$$

$$\begin{aligned} &Rb^*(n) + K \Rightarrow e + RbK^+, \quad 6 \leqslant n \leqslant 8 \\ &Rb^*(n) + K \Rightarrow e + Rb + K^+ \end{aligned} \tag{27}$$

exceeds 10^{-10} cm^3 s^{-1}.

In Harth et al. (1986), AI cross-sections during $Ne^*(nS, nD) + He$ collisions yielding $HeNe^+$ ions have been measured. In the cross-sections maximum closes to $n_{eff} \sim 10$ the AI cross-section in the case $Ne^* + He$ collisions about twenty times smaller than in the symmetrical $Ne^* + Ne$ one.

At last in Jonnson et al. (1988) non-direct experimental estimations have been performed to evaluate the production rate of homo- and heteronuclear molecular ions Na_2^+ – K_1 and NaLi – K_2 in AI reactions:

$$\begin{aligned} &Na^*(n^2P) + Na \Rightarrow e + Na_2^+, \\ &Na^*(n^2P) + Li \Rightarrow e + NaLi^+, \quad 8 \leqslant n \leqslant 14. \end{aligned} \tag{28}$$

The obtained result shows that the ratio K_1/K_2 is less than unity.

It appears as the immediate task to work up on the theoretical models for very important in the weakly ionized gas media's conditions, non-symmetrical chemi-ionization processes involving two different atoms.

5. Photoplasma

The investigation of elementary processes at slow particle energies is closely related to the investigation of low temperature plasmas (LTP). A sophisticated system of equations describing such plasma states is useful only with the accurate knowledge of the rate coefficients of the elementary processes. Many scientific and technological today problems have promising solution in LTP with alkali atoms.

For instance, the optically stimulated alkali plasma is one of the promising tools for the development of ecologically clean devices for direct transformation of light energy to electric one in upper atmosphere (Palmer, 1977).

Chemi-ionization processes are responsible for the formation of LPT when an absorbing medium is optically excited by the light of an intensity which is neither sufficient for the multi-photon transitions neither for stimulated radiation, nor has photons capable to ionize the medium in a direct photo-ionization process. In the first experiment to report a new physical phenomenon so called "photoplasma" or "photoresonant plasma" a quasistationary plasma was observed with $N_e = 10^{12}$ cm^{-3} after cesium vapor was illuminated with light from alkali gas discharged lamp (Morgulis et al., 1967).

Calculations show that for alkali-metal vapor with $10^{15} \leqslant No \leqslant 10^{17}$ cm^{-3} and light illumination of $10^5 \leqslant I \leqslant 10^6$ W cm^{-2} (line width about 0.05 nm), AI is the dominant source of primary electrons in Na.

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Scheme (see Fig. 16) illustrates possible mechanisms for the evolution of photoplasma during absorption of resonant radiation. Here are included 1 – optical excitation of the resonant atomic states, 2 – energy pooling processes, 3 – *AI* in binary resonant excited atom collisions, 4 – collisional production of negative and positive ion pair, 5, 6 – *AI* and *PI* processes with *RA*, correspondingly, 7 – the collisions leading to the fast electron formation, 8 – excitation and 9 – subsequent ionization with the fast electrons participation.

It is useful to note that optical (laser) experiments concerned with ionization phenomena for $I \geqslant 10^5\ \mathrm{W\,cm^{-2}}$ have not revealed any saturation effects in the charged-particle current. However, optical-signal saturation, i.e., resonant fluorescence, is seen for much lower illumination power densities (see, for example, Weiner and Polak-Dingels, 1981). This means that the dynamics of the colliding atoms system may change significantly in the laser radiation field, and laser-induced associative and Penning ionization processes may come into play. The measured cross section for such processes with $I \approx 10^6\ \mathrm{W\,cm^{-2}}$ are $3 \times 10^{-19}\ \mathrm{cm^2}$ for Na and is in reasonable agreement with calculations (Geltman, 1988) (Fig. 17). When the exciting laser pulse length is comparable with the lifetime of the excited states, one begins to see the effects of the photo-dissociation of molecular ions produced in *AI* channels. Thus, in crossed-beam experiments using sodium beams ($N_0 = 10^9\ \mathrm{cm^{-3}}$), the Na_2^+ ions for $10^5\ \mathrm{W\,cm^{-2}}$ undergo partial photo-dissociation during the laser pulse. Since molecular ions produced in dimmer *AI* and photo-ionization channels have different vibrational excitation, the photo-dissociation cross sections are correspondingly different (Roussel et al., 1983).

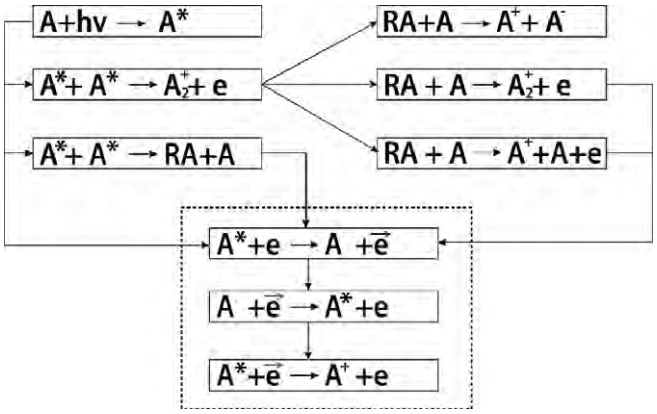

Fig. 16. Photoplasma steps creation.

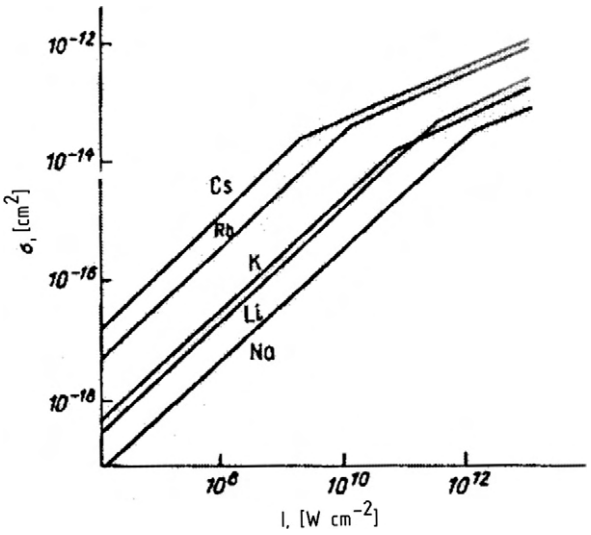

Fig. 17. Cross sections for Penning ionization stimulated by radiation (Geltman, 1988).

6. Conclusion

The efficiency of collision-induced ionization of chemi-ionization type at thermal ($E > 10^2\ \mathrm{K}$) and subthermal ($E < 10^2\ \mathrm{K}$) collisions involving excited atoms was examined. In contrast to the rate constants for ultracold ($E < 10^{-3}\ \mathrm{K}$) collisions, which need special theoretical approaches because the motion of the nuclei cannot be treated here as classical, the rate constants for subthermal and thermal collisions are modeled essentially in the same way.

The results obtained show that the theoretical models proposed for collision-induced ionization are adequate in a wide range of principal quantum numbers of the excited hydrogen-like atoms. It was established that for slow collisions, in systems with few degrees of freedom, the stochastic dynamics processes occurring during the single collision may be observed.

Above considered models of the chemi-ionization processes with alkaline atoms are equally applicable to ionized gas and gas dynamics media as well as to atomic beams (thermal and subthermal conditions). This opens up prospects for consideration of the alkali metals, first of all sodium, present significantly in a number of cosmic objects, which is of interest from the astrophysical aspect.

Recently, in connection with development of basic researches in the field of interaction of radiation with single atoms and molecules the circle of problems in which highly excited atoms play the leading part was essentially extended. Laser cooled atoms, Bose–Einstein condensation, and management of the single atom conditions, new prospects in creation of logic devices of quantum computers, quantum teleportation etc. concern to them. All this increases interest to experimental and theoretical researches with participation of excited and, first of all, highly excited atoms, including the processes of their atomic collision ionization.

The classical model describing the ionization process in collisions of Rydberg atom with ground-state one (Ignjatović and Mihajlov, 2005) was supplemented in Miculis et al. (2005) and Beterov et al. (2005). The most substantial modification was the modeling of the quasi-molecular manifold of Rydberg states using the stochastic dynamics

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of the Rydberg electrons. The results presented above may be recommended for the interpretation of the hydrogen-like excited atom species in the weakly ionized astrophysical formations of alkalis, specifically in volcanic gases on Io.

We note that this work is not envisaged as a particular one, but as a basis for planned modelling of sodium formations in Io atmosphere, representing the most impressive object where the sodium problem is actual. Namely, results of this work provide part of kinetics for the modelling of sodium formations in Io atmosphere, not investigated before. The other needed processes are well known and could be easily included in the model. One should take into account that the atmosphere of Io is not calm, and that processes there are in the presence of numerous powerful electric discharges. Consequently, one could assume that sodium vapor is there under strong influence of UV radiation and discharge products, so that the processes investigated here are present and presented results could be useful.

Acknowledgements

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References

Aslanov, I.A., Hieldebrandt, G., Khokhlova, V.L., Shoneich, W., 1973. Astrophys. Space. Sci. 21, 447.
Beterov, I.M., Fateev, N.V., 1983. Abstracts of Papers Presented to the Sixth All-Union Conference on the Physics of Low-Temperature Plasmas, Leningrad, p. 31 (in Russian).
Beterov, I.M., Kurochkin, V.L., Fateev, N.V., 1982. Khim. Fizika 1, 95.
Beterov, I., Vasilenko, G., Smirnov, B., Fateev, N., 1987. Sov. Phys. JETP 66, 17.
Beterov, I., Tretyakov, D., Ryabtsev, I., Bezuglov, N., Miculis, K., Ekers, A., Klucharev, A., 2005. J. Phys. B 38, 4349.
Bezuglov, N., Klucharev, A., Sheverev, V., 1984. J. Phys. B 17, L449.
Bezuglov, N., Klucharev, A., Sheverev, V., 1987. J. Phys. B 20, 2495.
Bezuglov, N., Vujnovic, V., Klucharev, A., Sheverev, V., 1989. Opt. Spectrosc. 66, 721.
Bezuglov, N., Klucharev, A., Stacevicz, T., Taratin, B., Molish, A., Allegrini, M., 1995a. Opt. Commun. 120, 249.
Bezuglov, N.N., Borodin, V.M., Klyucharev, A.N., Allegrini, M., 1995b. Opt. Spectrosc. 79 (1), 680.
Bezuglov, N.N., Borodin, V.M., Klyucharev, A.N., Fuso, F., Allegrini, M., 1997a. Opt. Spectrosc. 83, 338–344.
Bezuglov, N.N., Borodin, V.M., Klyucharev, A.N., Orlovskii, K.V., Allegrini, M., 1997b. Opt. Spectrosc. 82 (3), 334–337.
Bezuglov, N.N., Borodin, V.M., Klyucharev, A.N., Fuso, F., Allegrini, M., Janson, M.L., Orlovskii, C.V., 1999a. Opt. Spectrosc. 86, 824.
Bezuglov, N., Molish, A., Klucharev, A., Fuso, F., Allegrini, M., 1999b. Phys. Rev. A 59, 4340.
Bonanno, R., Boulmer, J., Weiner, J., 1983. Phys. Rev. A 28, 604.
Borodin, V.M., Dobrolezh, B.V., Klucharev, A.N., Tsyganov, A., 1995. Opt. Spectrosc. 78, 15.
Boulmer, J., Bonano, R., Weiner, J., 1983. J. Phys. B 16, 3015.
Burrows, A., Volobuyev, M., 2003. Astrophys. J. 583, 985.
Carre, B., Roussel, F., Breger, P., Spiss, G., 1981. J. Phys. B 14, 4271.
Carre, B., Spiss, G., Bizau, J.M., Dhez, P., et al., 1984. Opt. Commun. 52, 19.
Chirikov, B.V., 1979. Phys. Rep. 52, 265.
Combi, M., DiSanti, M., Func, U., 1997. Icarus 130, 336.
Coroniti, F., Eviater, A., Mekler, Y., 1976. Astrophys. J. 205, 622.
Dalgarno, A., Block, J., 1976. Rep. Prog. Phys. 39, 573.
D'Angelo, N., Goeler, S., Ohe, T., 1966. Appl. Phys. 37, 2519.
De Iong, A., van der Valk, F., 1979. J. Phys. B 12, L561.
Delone, N., Krainov, V., Shepelyansky, D., 1983. Sov. Phys. Usp. 26, 551.
Dengel, H., Ruf, M., Hotop, H., 1993. Europhys. Lett. 23, 567.
Devdariani, A.Z., Klyucharev, A.N., Lazarenko, A.B., Sheverev, V.A., 1978. Pis'ma Zh. Tekh. Fiz. 4, 1013–1016.
Devdariani, A.Z., Klyucharev, A.N., Penkin, N.P., Sebyakin, Y.N., 1988. Opt. Spektrosk. 64, 706–709.
Dobrolege, B., Klucharev, A., Sepman, V., 1975. Opt. Spektrosk. 38, 1090.
Duman, E.L., Shmatov, I.P., 1980. JETP 51, 1061.
Dunning, F.B., Stebbings, R.F., 1983. Rydberg States of Atoms and Molecules. Cambridge University Press, Cambridge.
Gallager, A., 1991. Phys. Rev. A 44, 4249.
Geltman, S., 1988. J. Phys. B 21, L735.
Gould, P.L., Jett, D., Julienn, P.S., Phillips, W.D., et al., 1988. Phys. Rev. Lett. 60, 788.
Harth, K., Hotop, H., Ruf, M.W., 1986. In: International Seminar on Highly Excited States of Atoms and Molecules, Fuji-Yoshida, Japan, p. 117.
Harth, K., Hotop, H., Ruf, M.W., 2004. In: Book of Abstracts of International Conference on Problems of Geocosmos, St. Petersburg, Russia, p. 4.
Herbst, E., Klemperer, W., 1973. Astrophys. J. 185, 505.
Huennekens, J., Gallager, A., 1983. Phys. Rev. A 28, 1276.
Ignjatović, L., Mihajlov, A.A., 2005. Phys. Rev. A 72, 022715.
Janev, R.K., Mihajlov, A.A., 1980. Phys. Rev. A 21, 819–826.
Jonnson, B.C., Wang, M.X., Weiner, J., 1988. J. Phys. B 52, 19.
Jonson, R., 2000. Icarus 143, 429.
Klucharev, A.N., Lazarenko, A.V., 1980. Opt. Spektrosk. 48, 412.
Klucharev, A.N., Ryazanov, N.S., 1971. Opt. Spektrosk. 31, 347.
Klucharev, A.N., Vujnović, V., 1990. Phys. Rep. 185 (2), 55–81.
Klucharev, A.N., Sepman, V.Yu., Vujnović, V., 1977. J. Phys. B 10, 715.
Koch, P.M., Leeuwen, K.A.H., 1995. Phys. Rep. 255, 289.
McGeoch, M.W., Shlier, R.E., Chawla, G., 1988. Phys. Rev. Lett. 61, 2088.
Mekler, Y., Eviatar, A., Coroniti, F., 1976. Astrophys. Space Sci. 40, 63.
Miculis, K., Beterov, I., Bezuglov, N., Ryabtsev, I., Tretyakov, D., Ekers, A., Klucharev, A., 2005. J. Phys. B 38, 1811.
Mihajlov, A.A., Janev, R.K., 1981. J. Phys. B 14, 1639.
Mihajlov, A.A., Ljepojević, N.N., Dimitrijević, M.S., 1992. J. Phys. B 25, 5121.
Mihajlov, A.A., Dimitrijević, M.S., Djurić, Z., 1996. Phys. Scr. 53, 159–166.
Mihajlov, A.A., Ignjatovic, L.M., Vasilijević, M.M., Dimitrijević, M.S., 1997. Astron. Astrophys. 324, 1206.
Mihajlov, A.A., Dimitrijević, M.S., Ignjatović, L.M., Vasilijević, M.M., 1999. Astron. Astrophys. Trans. 18, 145–149.
Mihajlov, A.A., Ignjatović, L.M., Dimitrijević, M.S., Djurić, Z., 2003a. Astrophys. J. Suppl. Ser. 147, 369–377.
Mihajlov, A.A., Jevremović, D., Hauschildt, P., Dimitrijević, M.S., Ignjatović, L.M., Alard, F., 2003b. Astron. Astrophys. 403, 787–791.
Morgulis, N.D., Korchevoi, Y.P., Przhonskii, A.M., 1967. Zh. Eksp. Teor. Fiz. 53, 417.
Moutinho, A.M.C., Aten, I.A., Los, A., 1971. Physica 53, 471.
Olson, R.E., 1979. Phys. Rev. Lett. 43, 126.

Author's personal copy

Palmer, A., 1977. Research Report 513. Hughes Research Laboratories, Malibu, p. 16.
Roussel, F., Carre, B., Breger, P., Spiess, G., 1983. J. Phys. B 16, 1749.
Schaefer, L., Fegley, B., 2005. Icarus 173, 454.
Smirnov, B.M., 1982. Vozbuzhdennye atomy (Excited Atoms). Energoatomizdat, Moscow.
Smirnov, V.M., Mihajlov, A.A., 1971. Opt. Spektrosk. 30, 984.
Takahashi, S., Misawa, H., Nozava, H., Morioka, A., Sood, R., Okano, S., Yumoto, K., 2000. Adv. Space Res. 26 (10), 1529.
Tam, A., Happer, W., Siano, D., 1977. Chem. Phys. Lett. 49, 320.
Thorsheim, H.R., Wang, Y., Weiner, J., 1989 (unpublished).
Walter, C.W., Zollars, B.C., Jonson, C., 1986. Phys. Rev. A 34, 4431.
Wang, M.X., Weiner, J., 1987. J. Phys. B 21, L15.
Weiner, J., Boulmer, J., 1986. J. Phys. B 19, 599.
Weiner, J., Polak-Dingels, P., 1981. J. Chem. Phys. 74, 508.
Weiner, J., Masnou-Seeuws, F., Giusti-Suzor, A., 1989. Adv. Atom. Mol. Opt. Phys. 26, 209.
Zagrebin, S.B., Samson, A.V., 1985. J. Phys. B 18, L217.

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Rate coefficients for the chemi-ionization processes in sodium- and other alkali-metal geocosmical plasmas

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Abstract

The chemi-ionization processes in thermal and sub-thermal collisions of excited alkali atoms with atoms in ground and excited states were considered, with a particular accent to the applications for geocosmical plasma research. An improved version of semi-classical method for the rate coefficients calculation is presented. The method is applied to the cases of excited alkali atoms with the principal quantum numbers $5 \leqslant n \leqslant 25$. The results of calculation of the considered chemi-ionization processes rate coefficients are compared to the existing experimental data. Their good agreement recommends to use the rate coefficients obtained for analysis of geocosmical plasma processes.
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1. Introduction

Elementary processes involving ions, atoms and molecules in geocosmical plasmas, traditionally attract researchers attention for a longer time (see e.g. Herbst and Klemperer, 1973). Among these processes, those involving highly excited Rydberg atoms are also of interest for stellar atmospheres of late spectral classes, interstellar H II clouds where Rydberg atoms form as a result of electron–proton recombination processes, as well as in other astrophysical plasmas. Recently was reported in Harth et al. (2004) that Rydberg molecules of atmospheric gases influence even on terrestrial biosphere. At first, our attention will be paid here on a group of ionization processes in Rydberg atom collisions with ground state parent atoms, known in literature as chemi-ionization processes, namely

$$RA(n) + A \Rightarrow \mathrm{e} + A_2^+ \quad (\mathrm{AI}), \tag{1a}$$

$$RA(n) + A \Rightarrow \mathrm{e} + A + A^+ \quad (\mathrm{PI}), \tag{1b}$$

where A, A^+ are atoms and their positive ions in their ground states, $RA(n)$ an atom in a highly excited (Rydberg) state with the principal quantum number $n \gg 1$, A_2^+ corresponding molecular ions in ground electronic states, and e a free electron, AI – associative ionization, PI – Penning-like ionization. Besides, we will consider shortly on the ionization processes in collisions of atoms in the weakly excited states.

The processes (1) with participation of alkaline atoms are studied for a long time experimentally (Devdariani et al., 1978; Boulmer et al., 1983; Zagrebin and Samson, 1985; Weiner and Boulmer, 1986), as well as theoretically (Janev and Mihajlov, 1980; Mihajlov and Janev, 1981; Duman and Shmatov, 1980). In all just mentioned papers, the processes (1) were treated exclusively in the laboratory conditions. In the hydrogen and helium cases however, the (1) processes later were considered in the conditions of stellar photospheres by Mihajlov et al. (1997), Mihajlov et al. (2003a). However, the processes (1) involving alkali atoms continued to be studied exclusively from the laboratory aspect. But for a longer time were collected data on the possible significant presence of alkali atoms, especially of sodium atoms, in some moons and planet atmospheres, as well as in comet tails and brown dwarfs and cooler star atmospheres (Mekler et al., 1976; Coroniti et al., 1976; Combi et al., 1997; Jonson, 2000; Takahashi et al., 2000; Burrows and Volobuyev, 2003; Schaefer and Fegley, 2005; Dalgarno and Block, 1976; Bezuglov et al., 1997b).

Chemi-ionization processes, leading to formation of molecular ions, can play an essential role in the sequence of ion-molecular reactions on surfaces of solid particles or in associative processes of the binary collisions leading to surprising variety of molecular formations in interstellar gas (Dalgarno and Block, 1976).

From above mentioned it follows that it became interesting to consider the processes (1) where A is an alkali metal atom, because such results begin now to enter as a subject of the astronomical data's publications (Bezuglov et al., 1997b). In this paper, we will consider the most significant case when $A \equiv$ Na.

The considered processes are interesting from two points of view: first, they could be quite effective sources of the charged particles generation in the optically excited gaseous media; second, they could be studied as a prototype of the elementary process of the radiation energy transformation into electrical one, which is of interest for the physics of geocosmos.

We will continue on the example of the hydrogen-like alkali metal atoms, so that the obtained results should directly correlate with analogous conclusions for hydrogen – the most spread and the most abundant component of the Universe.

It is well known from solar photospheric and planet absorption spectrum, chemical analysis of asteroid fragments, meteorites and cosmic dust that alkali metals, especially such as Na and K, are present in large number of studied cosmic objects including solar system (Burrows and Volobuyev, 2003; Schaefer and Fegley, 2005). In spite of the fact that alkali metals are not so wide spread compared to hydrogen, the logarithm of sodium abundance, for example, is 6.31 in meteorites and 6.30 in Solar photosphere (hydrogen – 12.00 in both cases).

It is known also that for particular astrophysical objects abundances of elements from the Mendeleyev periodic table could be 4–6 orders of magnitude larger than its averaged cosmic abundance (Aslanov et al., 1973). In such a way, alkali metal cosmic plasma can be the subject of direct astrophysical investigations. For example sodium plasma clouds are found in the atmosphere of the Jovian satellite Io. Apart of that, alkali plasma became and the object of astrophysically inspired laboratory experiments for the modeling of processes in geocosmos (D'Angelo et al., 1966).

At the end, on the approach of astrophysics and new sophisticated technologies, projects of the alkali metal photoplasma application in devices for direct conversion of Solar energy into the electrical one are known (Palmer, 1977).

A certain interest for the processes of aerosol forming in conditions of geocosmos can represent and the effect of solid particles of micron size forming in collisions of optically excited alkali atoms with hydrogen (Tam et al., 1977).

The rate of the collisional ionization processes in an absorbing gaseous medium depends on the characteristics of the medium itself which are determined by its possibility to absorb and, then, to reemit radiation. As a result of joint investigations carried out in the Pisa and St. Petersburg Universities, analytical methods for solving a wide class of integro-differential equations, describing both the processes of radiation transfer in optically dense media (Bezuglov et al., 1995a, 1999b) and the processes of the valence electron transition in the set of quasi-continuous energy levels, were developed (Bezuglov et al., 1997b). Here, we will consider only the second-collisional-aspect of the general problem of energy transfer in an optically excited medium, which leads to its ionization.

Investigations of elementary ionization processes in the thermal and subthermal energy ranges have a direct relation to investigations of low-temperature photoplasma creation via optical excitation (Klucharev and Vujnović, 1990). Any sophisticated set of equations describing a plasma medium has the right to exist only under the condition of knowledge of accurate values of the cross sections of elementary collisional processes occurring in it.

In the literature, the following gradation of temperature ranges of atomic collisions is commonly used: thermal ($T = 10^2$–10^3 K), subthermal or cold ($10^{-3} < T < 10^2$ K), and ultracold ($T \ll 10^{-3}$ K) collisions. Experimental investigation of ultracold collisions requires the use of special equipment for laser cooling and trapping of the particles. At the same time, the conditions for subthermal collisions can be rather easily realized in effusive atomic beams owing to the specific features of the relative velocity distribution of atoms. The existence of directed fluxes of matter in the gaseous phase, as e.g. due to effects of particle explosive vaporization provoked by radiation, is quite typical in the conditions of geocosmos.

Under the situation when the sum of the excitation energies of atoms-partners is smaller than the ionization potential of the individual atom and of thermal or subthermal energies of collisions, two main processes are known that lead to a considerable energy transfer, namely, AI and energy pooling (EP):

$$A^* + A^* \Rightarrow \mathrm{e} + A_2^+ \quad (\mathrm{AI}), \tag{2}$$

$$A^* + A^* \Rightarrow RA + A \quad (\mathrm{EP}). \tag{3}$$

In process (2), practically the whole internal energy of two colliding particles is transferred to one of them. The EP-process itself is not ionization process, but it leads to the appearance of new ionization channels due to the formation of highly excited atoms. Two abovementioned cases, (1b) and (2), imply the interaction between discrete strongly coupled atomic states (2) or between discrete states and the electron continuum (1b). Other situation can appear in the case of the AI-process occurring via an intermediate stage – a Rydberg quasi-molecule (RM):

$$RA + A \Rightarrow (RM + A) \Rightarrow \mathrm{e} + (A, A^+). \tag{4}$$

The RM-system with one Rydberg electron and the other strongly bound inner electron may be represented as a real model of a nonlinear system.

2. Chemi-ionization in binary collisions of atoms in low-lying excited states

2.1. Rate coefficients for binary collisions of alkali-metal atoms in the first excited resonant states

In low-temperature plasma physics, chemi-ionization processes are traditionally regarded as providing an effective channel for the production of molecular ions. This refers in the first instance to studies involving inert-gas and alkali-metal atoms in the lowest of all the possible (resonance) excited states because of their extensive applications in science and technology. Two possibilities are then found to arise.

$$\sum E^* > U_\mathrm{i} \tag{5}$$

$$\sum E^* < U_\mathrm{i} \tag{6}$$

where $\sum E^*$ is the total excitation energy, U_i is the ionization potential of an individual atom.

Case (5) includes the ionization of the hydrogen atoms, inert gases, the halogens, nitrogen, and oxygen, whereas case (6) includes the ionization of alkali-metals, rare-earth elements, uranium, etc.

Table 1 lists experimental results included for the first time in Saint-Petersburg University for the gas-cell conditions in 1975–1977s (Dobrolege et al., 1975; Klucharev and Ryazanov, 1971). When the activation energy $\Delta U > 0$ the expression for the reaction rate contains the factor $\exp(-\Delta U/kT)$, which largely determines the temperature $k(T)$ function. The strong dependence on temperature of the reaction rate for the chemi-ionization (associative ionization) must be taken into account in any real condition. From the data's analysis it can be seen, that the efficacy of threshold (AI) processes depends significantly on the shape of the particle velocity distribution (Bezuglov et al., 1984). When the conditions are different, the data must be re-examined and this can only be done if we know the corresponding terms of the quasi-molecules and molecular ion. One needs the temperature dependence of the AI cross-section too.

For example, on the one hand, sodium is the most abundant of alkalis; whilst, on the other hand, newly published data are not entirely free from internal contradiction. This is so-called the "sodium paradox".

The data in the tables are obtained without identification of the total moment values for fine structure components of $^2P_{1/2,3/2}$ term. According to Carre et al. (1981), depending on values of quantum numbers $J = 1/2, 3/2$, colliding atoms AI rate constant can change 2.5 times. We

Table 1
AI rate coefficients for the process $Na(3^2P) + Na(3^2P) \Rightarrow e + Na_2^+$

Experimental conditions	Beam source temperature	Original value K (10^{-11} cm^3 s^{-1})	Corrected value (Bezuglov et al., 1984)	Reference
Gas cell, resonant lamp	550 K	3.8 (±20%)	3.8	Klucharev et al. (1977)
Single beam, laser	580 K	0.015 (factor 2)	0.03	De Iong and van der Valk (1979)
Gas cell, laser	650 K	0.56 (±40%)	1.1	Huennekens and Gallager (1983)
Beams crossing at 90°, laser	520 K	0.34 (±50%)		Carre et al. (1984)
Uncollimated single beam, laser	570 K	1.8 (±40%)	3.4	Bonanno et al. (1983)
Single beam, laser	"Effective temperature" 60×10^{-3} K	6.3 + 1.8		Thorsheim et al. (1989)
Optical trap	0.75×10^{-3} K	11 + 1.3		Gould et al. (1988)

shall not discuss here the influence of polarizing effects on reaction rate coefficients since this is not so essential for the corresponding estimations in space plasma.

Note that the unexpectedly large value of K in cold collisions ($T \sim 10^{-3}$ K) may be explained in terms of the increased de Broglie wavelength at such conditions (Weiner et al., 1989).

The interesting aspect of very cold collisions between two resonantly-excited sodium atoms was discussed in Gallager (1991). It is suggested that the production of Na_2^+ ions at low light intensities can be considered as the following many stage process:

$$h\nu_1 + Na + Na \Rightarrow Na^* + Na. \quad (7)$$

The particle pair moves in the attractive potential of quasi-molecule with the simultaneous absorption of the photon $h\nu_2$ and the associated production of a pair of resonantly excited atoms

$$h\nu_2 + Na^* + Na \Rightarrow Na^* + Na^*. \quad (8)$$

The two excited atoms interact and produce the molecular ion, namely

$$Na^* + Na^* \Rightarrow e + Na_2^+. \quad (9)$$

2.2. Ionization in binary collisions of low-lying excited atoms in states higher than the resonant one

The collisional ionization (10) in effusive beams with the participation of alkali atoms in low-lying excited states was successfully studied by the methods of high-resolution electron spectrometry (Dengel et al., 1993).

$$A^*(n_1, l_1) + A^*(n_2, l_2) \Rightarrow e + A^*(n', l') + A^+,$$
$$A^*(n_1, l_1) + A^*(n_2, l_2) \Rightarrow e + A_2^+,$$
$$n_1 \geqslant 3, \quad n_2 \leqslant 5, \quad l_1 \geqslant 0, \quad l_2 \leqslant 2, \quad n' = 3, \ l' = 0, 1. \quad (10)$$

The effect of inter-configuration interaction on the efficiency of processes (10) can be neglected for the 4d4p, 4p4s, 5s5p, 5s4p, 4s4s, and 3p3d initial configurations. In Table 2 are presented the calculation data of the total ionization cross-section σ_i for reaction (10) for four of the above-mentioned configurations; the calculation was performed within the framework of the first-order approximation of the dipole–dipole interatomic interaction. The effect of the Cooper minimum in the photo-ionization cross sections of excited atoms on the probability of allowed dipole transitions leads to a decrease in the values for 4p4s and 5s5p configurations. The similar effect, relative to the corresponding values of the spectral line strength, results in a decrease of the magnitude of σ_i for the 5s4p states. As the limiting case, Table 2 also gives the value of σ_i calculated with the allowance made for the phenomenon of twisting. The comparison with experimental data proved to be possible only for the case of 3p3d initial configuration (Dengel et al., 1993; $\sigma_i = 0{,}5 \times 10^{-13}$ cm^2 – theory, and $\sigma_i = 10^{-13}$ cm^2 – experiment) because the results of measuring the cross section by electron spectroscopy methods do not give, as a rule, their absolute values. In the general case, the line strength S increasing leads to an increase in the efficiency of channel, accompanied by the appearance of slow electrons and by the population of the excited states close to the initial one.

Table 2
Calculated data on ionization in binary collisions of low excited sodium atoms, $E = 0.28 \times 10^{-3}$ eV (Bezuglov et al., 1999a)

Configuration	σ_i (a.u.)	σ_i (a.u.), in the channel S-state creation	σ_i (a.u.), in the channel P-state creation
3p3d	1687	1687	
4p4s	13	13	
5s5p	135		135
5s4p	875	24	851

3. Collision ionization with RA participation: symmetrical case

3.1. Ionization in Rydberg-atom–atom collisions

3.1.1. The resonant mechanism

Recently, in connection with development of basic researches in the field of interaction of radiation with the

single atoms and molecules the circle of problems in which RA play the main role was significantly enlarged. Here it is necessary to name first of all such fundamental and applied researches as laser cooling of atoms and Bose–Einstein condensation, management of the single atom states, new prospects in creation of logic devices of quantum computers, quantum teleportation, etc. All this increases interest to experimental and theoretical researches with RA participation, including the processes leading to their ionization in atom collisions. Let us note that the first results in this area have been received in 1978 (experiment Devdariani et al., 1978) and 1980 (the theory Janev and Mihajlov, 1980; Mihajlov and Janev, 1981; Duman and Shmatov, 1980) years.

Present experimental facilities on laser excitation allow to achieve the highly excited RA population compared with the normal one. Under primary selective excitation resonant atomic states the energy pooling processes may provide the RA effective population. So the high selectivity of the optical excitation in the experimental investigation with excited atoms in many cases may be treated as a "nice blue idea". The ionization over new opened Rydberg channels takes the part on such channels.

Two ionization channels are possible in binary collisions such as (1). The first series of quantitative measurements of the rate coefficients K for (1) started in 1978 for group one elements (Devdariani et al., 1978).

Due to the interest in chemi-ionization processes, several methods of rate coefficients calculations were presented within short time. The methods developed in Janev and Mihajlov (1980), Mihajlov and Janev (1981) treated the considered RA-atom systems within the semi-classical approach, while in Duman and Shmatov (1980) an attempt at quantum-mechanical description of the internuclear motion was made. All these methods were based on the same resonant mechanism of quasi-resonant energy exchange within the electronic component of the RA-atom system. This mechanism was introduced in Smirnov and Mihajlov (1971) in connection with some inelastic processes in slow $RA + A$ collisions.

The resonant mechanism of the considered inelastic processes is effective in region of internuclear distances

$$R \ll r_n, \tag{11}$$

where $r_n \sim n^2$ is the mean radius of atom RA, as illustrated in Fig. 1. In this region the system $RA + A$ is taken in the form $(A^+ + A) + e_n$, where A^+ and e_n are the core and the outer electron of RA. The inelastic processes are treated as a result of the interaction of the outer electron e_n with the dipole momentum of the subsystem $A^+ + A$. Atomic units are used in further.

The electronic state of $A^+ + A$ subsystem during the collision is described as a group of adiabatic electronic states of the molecular ion A_2^+, adiabatically correlated with the electronic states of this sub-system at $R = \infty$. In the case when A is an atom with one or two s-electrons outside closed shells (A = H, He, Li, Na, etc.), only two Σ^+-states

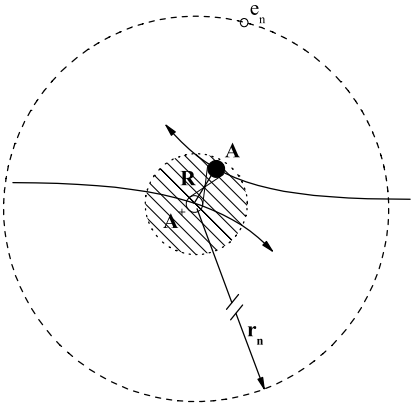

Fig. 1. Schematic illustration of $RA + A$ collision (the region of R where the outer electron is collectivized is shaded; Ignjatović and Mihajlov, 2005).

of A_2^+, the ground and the first excited states, compose such a group. When A is an alkali atom they are Σ_g^+ - and Σ_u^+ states, respectively.

It is assumed that in the region of R where the considered inelastic process takes place the optical electron of the atom A is collectivized within the $A^+ + A$ subsystem (see Fig. 1). The ranges of R where the energy exchange between the outer electron e_n and the electron component of the $A^+ + A$ sub-system has an almost resonant character give the main contribution to the considered inelastic process. Such ranges represent the neighborhoods of crossing-points of the potential curves for different Λ_u and Λ_g states of $RA + A$ quasi-molecular system, which is illustrated by Fig. 2.

Until now, this resonant mechanism was used in three different approximations: two semi-classical and one quantum mechanical. The first semi-classical one, used already in Smirnov and Mihajlov (1971), understands that the relative nuclear motion occurs in some average effective

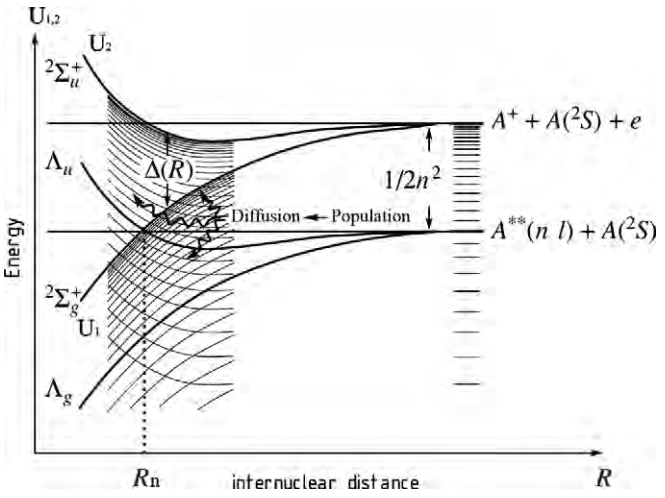

Fig. 2. Illustration of the mechanism of the $RA + A$ collision process. $^2\Sigma_u^+$, $^2\Sigma_g^+$ – the ionic states, Λ_u, Λ_g – the initial quasi-molecular states. The Λ_u state crosses the ionic state at $R = R_n$.

potential along the unique trajectory. In Smirnov and Mihajlov (1971) it was shown that in such a case the dipole moment $D(R)$ of $A^+ + A$ sub-system can be represented as a known function of the time, namely

$$D(R(t)) = \frac{R(t)}{2}\cos\left[\int_{-\infty}^{t}\Delta E(R(\tau))\,\mathrm{d}\tau\right], \tag{12}$$

where $R(t)$ is the internuclear distance in the moment of time t, $\Delta E(R)$ is the splitting term

$$\Delta E(R) = U_2(R) - U_1(R), \tag{13}$$

and $U_1(R)$ and $U_2(R)$ are the adiabatic potentials of the ground and the first excited electronic states of the molecular ion A_2^+. In this case the behavior of outer electron e_n is described by means of time dependent Schrödinger equation, where the perturbation is known function of the time. This approach was applied in the case of ionization processes in symmetric atom-Rydberg atom collisions in Devdariani et al. (1978).

The other semi-classical approach, developed in Janev and Mihajlov (1980), Mihajlov and Janev (1981), understands that the relative nuclear motion occurs with the probability 1/2 along the trajectory which corresponds to the potential $U_1(R)$, and with the same probability 1/2 – along the trajectory which corresponds to the potential $U_2(R)$. Consequently, such semi-classical approach should be treated as the approximation of two classical trajectories. In the case of ionization processes the initial electronic state of the sub-system $A^+ + A$ is the first excited $^2\Sigma_u^+$- state. Accordingly, the trajectory which corresponds to the potential $U_2(R)$ is relevant in this case, and the ionization process is treated as the result of the transition of the sub-system $A^+ + A$ from $^2\Sigma_u^+$ to $^2\Sigma_g^+$-state together with the transition of outer electron e_n from the considered Rydberg state to continuum.

The third approach, applied in Duman and Shmatov (1980), understands that the relative nuclear motion is treated in quantum mechanical way, by means of superposition of two adiabatic nuclear wave functions which describe the motion in the potentials $U_1(R)$ and $U_2(R)$, separately. The ionization process is treated similarly as in the second semi-classical approximation.

Authors (Duman and Shmatov, 1980) represent unique attempt to describe processes (1) along with the quantum-mechanical treatment of the internuclear motion with an additional assumption about the possibility of smearing ro-vibrational spectrum of molecular ion A_2^+. Here we will not discuss this method because it was applied only to the processes (1) with $A = Cs$. The first theoretical results obtained within the framework of semi-classical method (Janev and Mihajlov, 1980; Mihajlov and Janev, 1981) and quantum mechanical one (Duman and Shmatov, 1980) was in a good agreement with the experiment.

The theoretical results based on two last approaches (Janev and Mihajlov, 1980; Mihajlov and Janev, 1981; Duman and Shmatov, 1980) are called in the literature as the DSMJ model (the abbreviation consists of the first letters of the author names). The further development and improvement of the theory was connected to the hydrogen and helium atom cases and their application in astrophysics (see e.g. Mihajlov et al., 1992, 1996, 1997, 1999, 2003a,b). However there was a permanent interest in the processes (1) involving atoms of alkali metals (Boulmer et al., 1983; Zagrebin and Samson, 1985; Weiner and Boulmer, 1986; Bezuglov et al., 1997b).

The experimental and theoretical results obtained in the world laboratories till today concerning AI and PI processes including *RA* have been discussed in the literature repeatedly ever since. For example effect of decay of the initial electronic state during $A^{**}(n) + A$ collision, using of approximate analytical expressions for the adiabatic potential curves $U_1(R)$ and $U_2(R)$, see Fig. 3; decoupling the *RE* motion from the internuclear one, and correctness of the unique straight line approximation to the particles motion, were discussed. For that reasons it was necessary to return again to the chemi-ionization in the alkali atoms case.

Now will be considered the results obtained with authors participation in last time (Ignjatović and Mihajlov, 2005; Miculis et al., 2005; Beterov et al., 2005) namely the chemi-ionization rate coefficients obtained taking into account results for the *RA* for principal quantum numbers $5 \leqslant n \leqslant 25$, where there is no crossing of the systems $A^{**}(n) + A$ and $A^+ + A^-$, where A^- denotes a stable negative ion.

3.1.2. The stochastic dynamics approach: the unique trajectory model

The first results on the investigation of chemi-ionization in *RA*-atom collisions are summarized in Klucharev and Lazarenko (1980). The more substantial disadvantage of such work was the neglecting of the large number of crossings of the initial ion term U_2. In the case of multiple crossing of terms, the attempt to take into account each particular crossing in theoretical approaches traditional

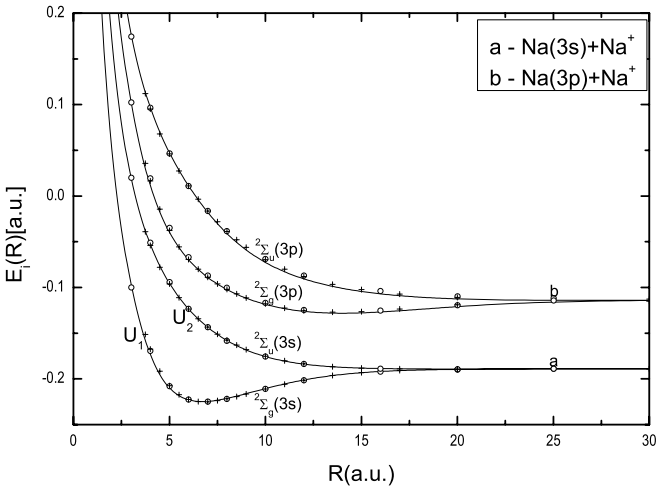

Fig. 3. The adiabatic potential curves of molecular ion Na_2^+ (Ignjatović and Mihajlov, 2005): (a) $Na(3s) + Na^+$, (b) $Na(3p) + Na^+$.

for atom collision physics does not lead to any kind of general results. Namely, the Rydberg electron (*RE*) energy change occurring for each of the multiple crossing of the terms is $\delta E \leqslant 1/n^3$, so that $\delta E/E_n \sim 1/n \ll 1$, where $E_n = 0.5/n_2$ is the binding energy of *RA*. This lead to the idea of the possibility of a diffusion approach to solution of the atomic collisions problem with *RA* participation, having in mind diffusion over the energy states of the quasi-molecule in one collision event (Devdariani et al., 1988). Unfortunately, the proposed model was largely qualitative: no actual physic process causing the RE to diffuse was suggested.

Note that the idea that the *RE* diffuses over the discrete energy spectrum of *RA* was successfully used earlier in Delone et al. (1983) to interpret anomalously high photo-ionization cross sections in experiments on laser irradiation of gases (see also Koch and Leeuwen, 1995). This logically suggests that for the ionization of the considered *RA*, the quasi-monochromatic electric field formed by charge transfer can also cause *RE* to diffuse over the discrete electronic spectrum, a process that can result in the "smearing" of the position of point R_i.

The latest stochastic version of chemi-ionization on *RA*-atom collisions extends the treatments of the DSMJ model by taking into account redistribution of population over a range of Rydberg states prior to ionization. That redistribution is modelled as diffusion of the *RE* in the Rydberg energy spectrum using a Fokker–Plank–Kolmogorov type equation (FPK).

The first obtained results give the reasons to believe that, during a single slow collision, the motion of the *RE* experiences the action of internal nonlinear dynamic resonances that arise due to the coincidence of the overtones of the *RE* motion over the Keplerian orbit with the frequency of the inner electron transfer. As a result, the motion of the *RE* becomes unstable. In this case, the transitions of the *RE* acquire the character of random walks over the network of crossing potential energy curves, thereby admitting a kinetic description of the time evolution of the distribution $f(n,t)$ of the *RE*.

The process of *l*-mixing of Rydberg states at large internuclear distances and twisting of the collision trajectories on attractive potential $U_2(R)$ have been taken into account too (Ignjatović and Mihajlov, 2005; Miculis et al., 2005; Beterov et al., 2005).

3.1.2.1. Model of stochastic diffusion. Stochastic dynamics describe the random walk of *RE* within the hydrogen like discrete energy spectrum caused by the coupling of *RE* with internal electrical field ($E(t)$). The initial covalent Λ_u state crosses the ionic $^2\Sigma_g^+$ state at $R = R_n$, becoming auto-ionizing for $R = R_n$.

3.1.2.1.1. Characteristic times

(1) Inter-nuclear distance $R(t)$ depends on time according to collision dynamics of the system.
(2) Factorization of FPK (with respect to R and n) means introduction of an "effective time" t_{eff}.
(3) Total effective time t_{tot} for the collision event with fixed ρ means time spent while $R(t)$ goes from $R = \infty$ to turning point R_{turn}.
(4) Average effective diffusion time $\langle t_{\text{eff}} \rangle$: the average time $t_{\text{diff}}(n_0, \rho)$ for the *RE* to diffuse from n_0^* level to the ionization limit determined from steady-state solution of FPK.

3.1.2.1.2. Diffusion equation. *RE* perturbation by internal electrical field $E(t)$ causes appearance of auto-ionization width $W(n_{\text{eff}}, R)$ of terms and can lead to dynamics chaos regime of classic trajectories. Stochastic motion of RE in energy space is described by (FPK) diffusion equation for the distribution function $f(n_{\text{eff}}, t)$:

3.1.2.1.3. Area of dynamics chaos regime. Stochastic diffusion of RE in energy space is based on Chirikov criteria (Chirikov, 1979) with Kepler mapping.

(1) Restrictions on the random motion ("lower limit"): The diffusion is forbidden in the energy region $n_{\text{eff}} < N_{\min}(R)$, because energy difference between the neighboring levels becomes too large.
(2) Restriction on random motion ("upper limit"): Chirikov criteria for global chaos onset breaks down.

The ionization occurs whenever *RE* enters levels $n_{\text{eff}} > N_{\max}(R)$ where the direct quantum photo-ionization channel becomes open and the corresponding auto-ionization width $W(n_{\text{eff}}, R)$ is expressed via the photo-ionization cross-section σ_{ph}. Important key-point for the stochastic diffusion processes: long collision times. It makes the model suitable for future application to treat collisions between cold atoms.

3.1.3. The decay approximation: the two-trajectories model

The processes (1) are treated here as a result of decay of the initial electronic state of the system $A^{**} + A$, caused by the resonant mechanism along a part of the relevant trajectory determined in the potential $U_2(R)$ by the impact-parameter ρ and the impact-energy E. In Janev and Mihajlov (1980) it was shown that the corresponding decay rate is given by expression

$$W_n(R) = \frac{4}{3\sqrt{3}n_{\text{eff}}^5} D_{12}^2(R) G_{nk}, \tag{14}$$

where $D_{12}(R)$ is module of the dipole matrix element for the electronic transition from the ground to the first excited state of the molecular ion Na_2^+, and G_{nk} denotes the generalized Gaunt factor, defined by the expression

$$G_{nk} = \frac{\sigma_{\text{ph}}(n,k)}{\sigma_{\text{ph}}^{\text{Kr}}(n,k)}, \tag{15}$$

where $\sigma_{\text{ph}}(n,k)$ is the photo-ionization cross section of the atom $A^{**}(n)$ with transition of the outer electron to the state with the energy ϵ_k, and $\sigma_{\text{ph}}^{\text{Kr}}(n,k)$ denotes the same photo-ionization cross section in Kramers's approximation.

According to (Janev and Mihajlov, 1980), the chemi-ionization processes at given ρ and E can be characterized by the ionization probability $P_{ci}(t,n,\rho,E) = (1/2)P_d(t,n,\rho,E)$, where the probability $P_d(t)$ is defined as the solution of the equation

$$\frac{dP_d(t)}{dt} = [1 - P_d(t)] \cdot W_n(R(t)), \quad P_d(t = t_{in}) = 0 \tag{16}$$

namely

$$P_d(t) = 1 - \exp\left[-\int_{t_{in}^{(n)}}^{t} W_n(R(t'))\, dt'\right], \tag{17}$$

where t_{in} is the moment, when the distance R between Na^+ and Na becomes smaller than R_n.

In Mihajlov and Janev (1981) it was taken that the factor $[1 - P_d(t)]$ in (16) may be replaced by 1, so that the decay of the initial electronic state of the atom-Rydberg atom system observed during the collision was neglected. This approximation was justified in the case of chemi-ionization processes (1) with $A = H$ and He. However, in the case of alkali metal atoms the mentioned decay had to be taken into account. Because of that, in Mihajlov and Janev (1981) was necessary to make a posteriori calculation. It required an additional parameter which could not be properly determined within the method used in Mihajlov and Janev (1981). For that reason we shall follow the basic work in Janev and Mihajlov (1980), and use (16) here without the above simplification.

Using the probability $P_{ci}(t = t_{fin,n,\rho,E})$, where t_{fin} is the moment, when the distance R between Na^+ and Na becomes lager than R_n, one determines the cross sections for the chemi-ionization processes (1)

$$\sigma_{ci}(n,E) = 2\pi \int_0^{\rho_{max}(E)} P_{ci}(t_{fin},n,\rho,E)\rho\, d\rho, \tag{18}$$

where $\rho_{max}(E)$ is the upper limit of values ρ at which the corresponding region R is reached for a given E. Rate coefficients for processes (1) are determined thereafter by the expressions

$$K_{ci}(n,T) = \int_{E_{min}(n)}^{\infty} \sigma_{ci}(n,E)F(v_c;T)\, dv_c, \tag{19}$$

where v_c is the impact velocity, corresponding to the given E, $E_{min}(n) = 0$ if $U_2(R_n) \leqslant 0$, and $E_{min}(n) = U_2(R_n)$ if $U_2(R_n) > 0$, $F(v_c,T)$ is the velocity distribution function at a given temperature T which is different in cells, single beams and crossed beams cases (see e.g. Bezuglov et al., 1987; Wang and Weiner, 1987; Bezuglov et al., 1989 and Fig. 4). Finally, taking $K_{ci}(n,T)$, in the form

$$K_{ci}(n,T) = K_{ci}^{(a)}(n,T) + K_{ci}^{(b)}(n,T), \tag{20}$$

where $K^{(a)}$ and $K^{(b)}$ are partial rate coefficients for the processes (1), we will also characterize these processes by the branch coefficients

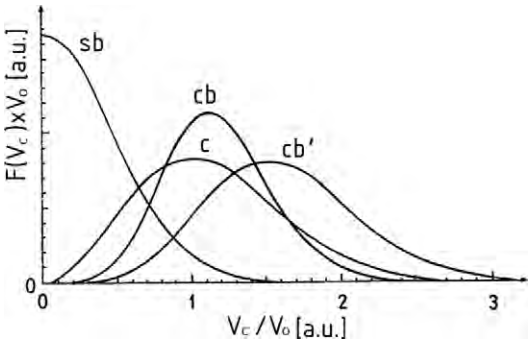

Fig. 4. Distribution function $F(v_c,T)$ of relative velocity v_c of short-living excited and normal atoms of the same mass M in a crossed beam (cb), counter beam (cb′) and gas cell (c); $T_{sb} = T_{cb} = T_{cb'} = T_c$, T – represent the gas temperature in the beam sources and cell. The characteristic thermal velocity is $v_0 = \sqrt{kT/M}$ (Klucharev and Vujnović, 1990).

$$X^{(a,b)}(n,T) = \frac{K_{ci}^{(a,b)}(n,T)}{K_{ci}(n,T)}, \quad X^{(a)}(n,T) + X^{(b)}(n,T) \equiv 1. \tag{21}$$

The determination of the partial rate coefficients $K_{ci}^{(a,b)}(n,T)$ is made in a similar way as $K_{ci}(n,T)$, i.e. by Eqs. (16)–(19), with the corresponding initial conditions (see Ignjatović and Mihajlov, 2005).

3.1.4. The comparison of the experimental and theoretical results

In the recent works (Ignjatović and Mihajlov, 2005; Miculis et al., 2005; Beterov et al., 2005), the results of the systematic experimental and theoretical studies of chemi-ionization of sodium RA in n^2S, n^2P, n^2D states with $n_{eff} = 5$–25 in symmetrical collisions with ground-state atoms have been presented.

The shapes of experimental dependencies of AI rate coefficients on the effective quantum number exhibit a broad maximum near $n_{eff} \approx 10$. Note that such peculiar $K(n_{eff})$ dependence was observed in the first work of such kind for RA (n^2P)–A collisions (Klucharev and Vujnović, 1990) (See Figs. 5–12).

The experimental absolute values of the rate coefficients are close to the theoretical calculation results for ^2P and ^2D states, but not for ^2S states (see Fig. 9).

From (Miculis et al., 2005; Beterov et al., 2005) comparison with experimental results it follows that stochastic diffusion model requires a further development in order to account for possible correlation effects between electronic and nuclear degrees of freedom in slow atomic collisions.

Strictly speaking in the experimental crossed beams conditions the resulting Na_2^+ signal is described by a sum of the respective AI rate constants

$$K_{AI}^{(\Sigma)} = K_{AI}^{(sb)} + K_{AI}^{(cb)} \tag{22}$$

with considerably different relative collision velocity distribution. In this relation K_{AI}^{cb} is the pure crossed beam AI rate constant which describes only the collisions between atoms

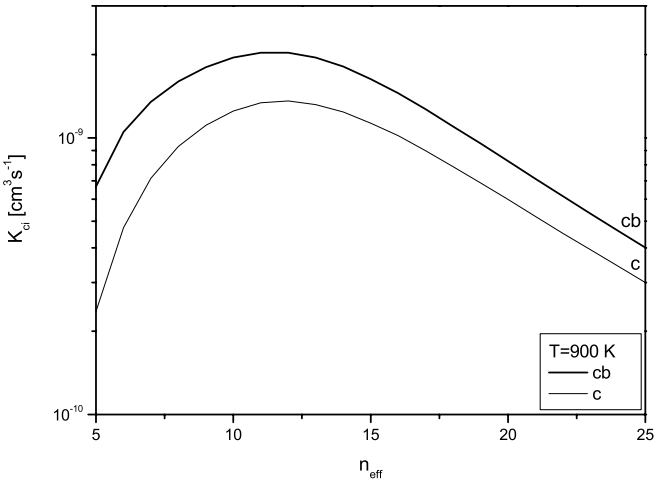

Fig. 5. The total rate coefficients K_{ci} for chemi-ionization in $Na^*(n_{eff}{}^2P) + Na$ collision theory, within the semi-classical approach (Ignjatović and Mihajlov, 2005). The curves K_{ci} correspond to the crossing beams (cb) and the cell conditions (c), T – the beam sources or the gas cell temperature respectively, $T = 900$ K.

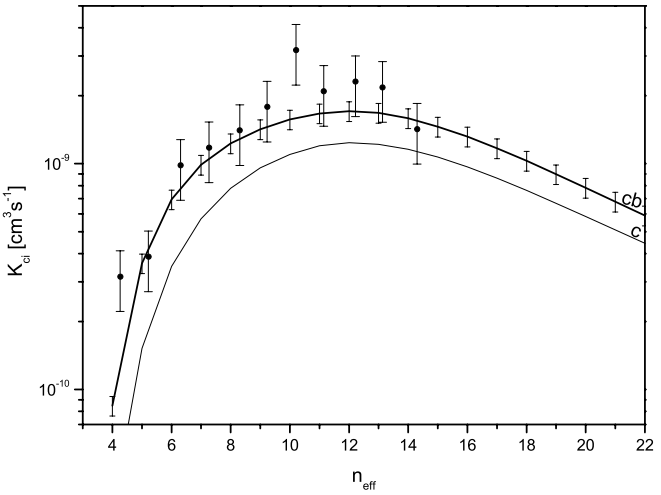

Fig. 7. The associative ionization rate coefficients for chemi-ionization in $Na^*(n_{eff}{}^2P) + Na$ collisions; dots: cb-conditions, $T = 600$ K, associative ionization experiment (Boulmer et al., 1983) the full curve: cb ($T = 600$ K), c = cell ($T = 720$ K), theory (Ignjatović and Mihajlov, 2005).

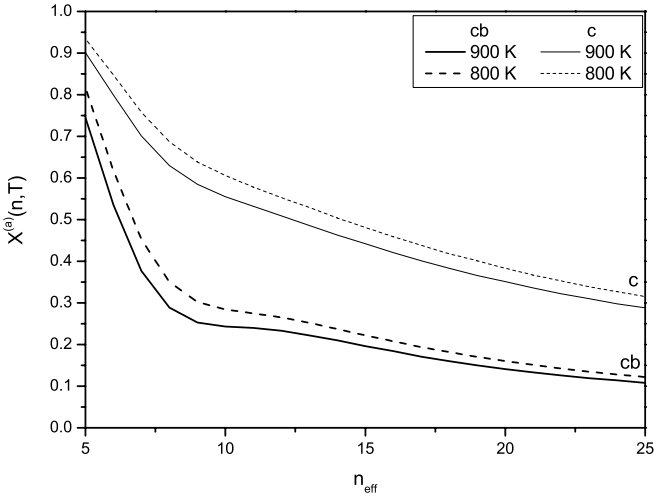

Fig. 6. The branch coefficients $X^{(a)}(n_{eff}, T)$ for chemi-ionization in $Na^*(n_{eff}{}^2P) + Na$ collisions. The main designations are the same as on the previous figure, $T = 900$ K, the dotted line, $T = 800$ K (Ignjatović and Mihajlov, 2005).

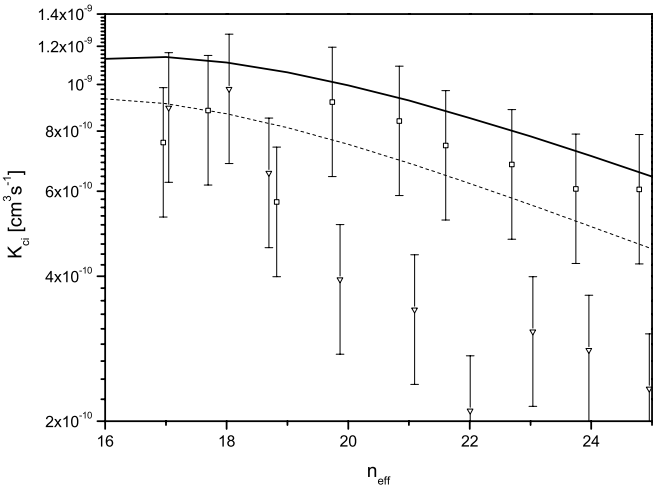

Fig. 8. The K_{ci} rate coefficients for chemi-ionization in $Na^*(n_{eff}, l) + Na$ single beam's collisions at $T = 1000$ K. The full and broken curves are the semi-classical theory results for $l = 0$ and $l = 2, 3$, respectively (Ignjatović and Mihajlov, 2005); open square – experiment, associative ionization, for $l = 0$; open triangle – experiment, associative ionization, for $l = 2$ (Weiner and Boulmer, 1986).

belonging to different beams and K_{AI}^{sb} applies to collisions with atoms from the same beam. The extraction of pure crossed beam rate constant K_{AI}^{cb} was performed in Beterov et al. (2005) for n^2S and n^2D states.

The experimental dependencies of K_{AI}^{Σ} and K_{AI}^{cb} on n_{eff} from (Beterov et al., 2005) are presented in Fig. 11 ($8 < n_{eff} < 18$). They have similar shapes but the absolute values of K_{AI}^{Σ} are about two time larger than K_{AI}^{cb}. These dependencies have a wide maximum at $n_{eff} = 8$–16 and a more narrow one at $n_{eff} = 11$–14 for n^2S states. The figure presents the results of theoretical ionization model. Note that in the widely known publication (Boulmer et al., 1983) cited above, the total K_{AI}^{Σ} was only presented. Fig. 12 shows the comparison of the experimental values $K_{AI}^{\Sigma}(l, n_{eff})$ in crossed beams for n^2S, n^2P and n^2D states.

Note that experimental K_{AI} dependencies on n_{eff} in two ranges of n_{eff}: $8 < n_{eff} < 18$ (crossed beam Boulmer et al., 1983) and $n_{eff} > 18$ (single beam Weiner and Boulmer, 1986) for n^2S and n^2D states are turned out on their absolute values. That unexpected results require a further elaboration.

3.2. Ionization in binary Rydberg-atom collisions

Let us briefly look at the ionization processes in two *RA* collisions.

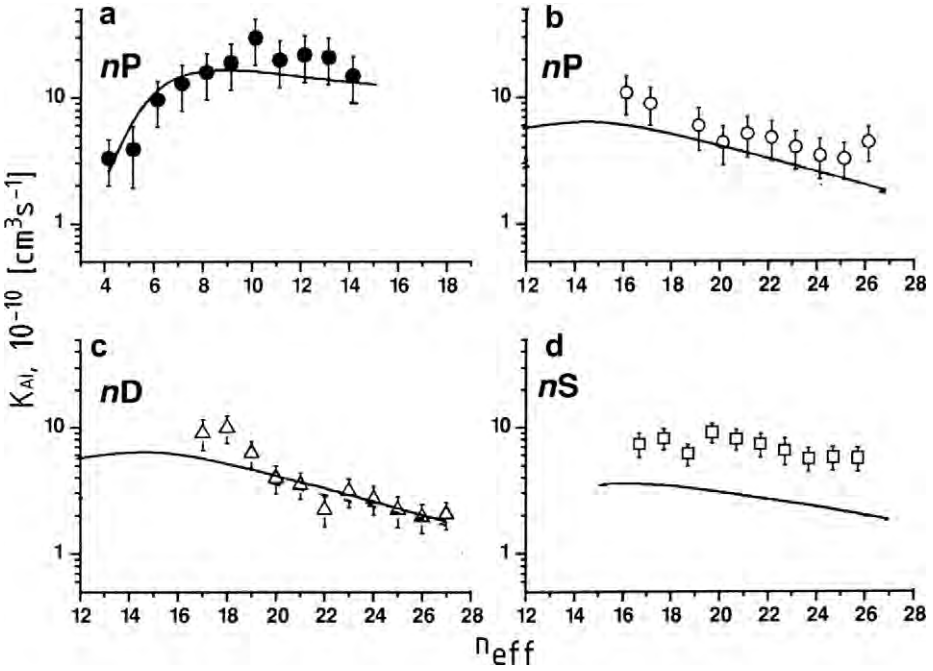

Fig. 9. Experimental and theoretical $Na^*(n_{eff}, l) + Na$ AI rate coefficients. (a) dots – cb conditions, $l = 1$, $T = 600$ K (Boulmer et al., 1983); (b) open circle, sb-conditions, $l = 1$, $T = 1000$ K (Weiner and Boulmer, 1986); (c) open triangle, sb-conditions, $l = 2$, $T = 1000$ K (Weiner and Boulmer, 1986); (d) open square, sb-conditions, $l = 0$, $T = 1000$ K (Weiner and Boulmer, 1986) full curves – theory, stochastic theory results (Miculis et al., 2005).

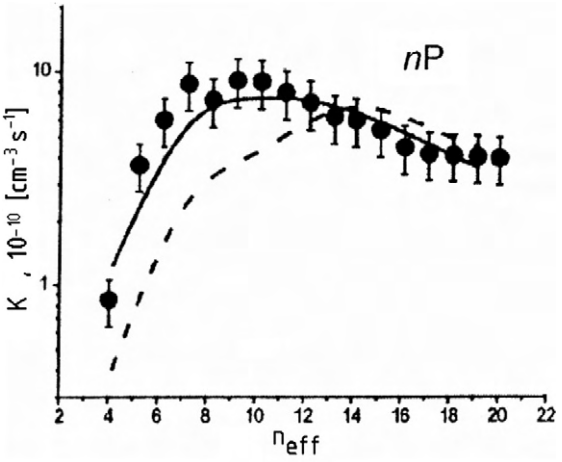

Fig. 10. Experimental and theoretical chemi-ionization rate coefficients in sb-conditions: dots – the experimental results (Zagrebin and Samson, 1985) obtained under non-accurate quantitative spectrometric identification of the ions mass and possibly poor atom collimation (Miculis et al., 2005), broken curve – AI stochastic model results, obtained with non-corrected (Zagrebin and Samson, 1985) collision velocity distribution; full curve – AI stochastic model results with velocity distribution correction (Miculis et al., 2005).

$$RA + RA \Rightarrow e + A + A^+, \tag{23a}$$

$$RA + RA \Rightarrow e + A_2^+, \tag{23b}$$

$$RA + RA \Rightarrow A^+ + A^-. \tag{23c}$$

In such processes, the total energy of two RA exceeds the ionization potential U_i of the individual atom. Therefore, as a result of binary RA collisions, the ionization-stable covalent atomic configurations (RA, RA) are converted into the Σ, Π, Δ, etc. auto-ionization states of the quasi-molecule which may decay into the positive ion A^+ and the excited atom A^* with a transition to low-lying states whose excitation energy is smaller than the energy of the initial RA state. Unfortunately, ionization in collisions of two Rydberg atoms is still the insufficiently studied field of atomic collision physics.

As a result of the non-adiabatic interaction of the initial RA–RA configuration with the neighboring ones, including unstable configurations, additional ionization channels are opened, such as the ionization through intermediate states and the formation of a pair consisting of the excited negative ion (A^*) in the auto-ionization state and the positive ion A^+; in addition, the initial states can also change without ionization. Despite the fact that stable negative ions A^- were experimentally detected in the output channel of the reactions, the process (23) is the main ionization channel (Olson, 1979).

In calculating the total auto-ionization width, of a Rydberg quasi-molecule with respect to PI channels in Bezuglov et al. (1995b), was used the first-order perturbation theory of the interatomic dipole–dipole interaction and the straight-line trajectory approximation. The role of this long-range interaction noticeably increases in the range of cold velocities. The above-mentioned conditions imply that the collisions with the impact parameters, larger than the sum of the Bohr radii of the colliding particles (equal to $4n^2$), make the main contribution to the ionization. In the case of alkali atoms, the presence of the quantum defect significantly influences the value of σ_i because it leads to a

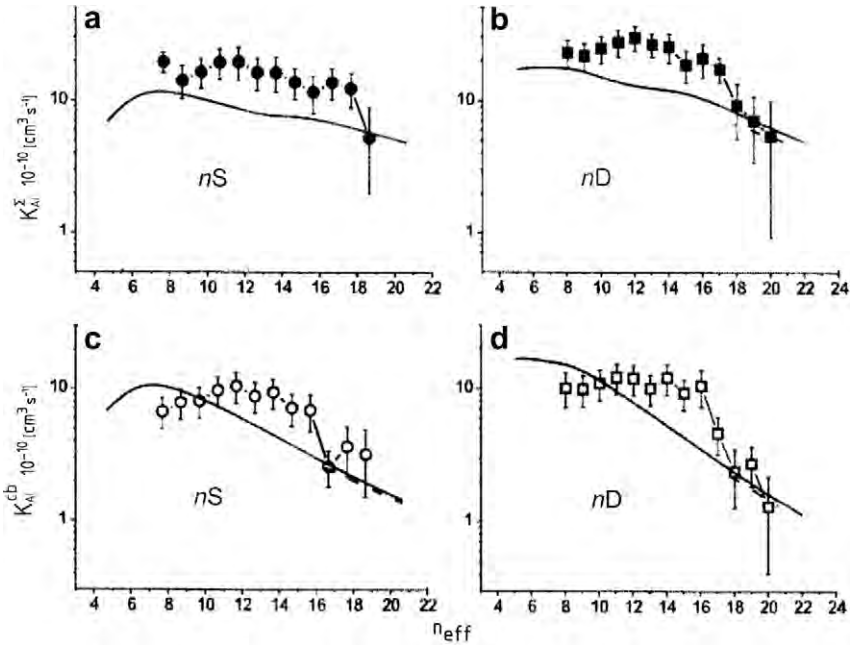

Fig. 11. Experimental and theoretical $Na^*(n_{eff}, l) + Na$ AI rate coefficients $8 \leqslant n_{eff} \leqslant 18$ for cb conditions, $T = 600$ K. Dots, open circle, open and full square experiment, full curves – stochastic theory results (Beterov et al., 2005). (a) K^{Σ}_{AI}, $l = 0$; (b) K^{Σ}_{AI}, $l = 2$; (c) K^{cb}_{AI}, $l = 0$; (d) K^{cb}_{AI}, $l = 2$.

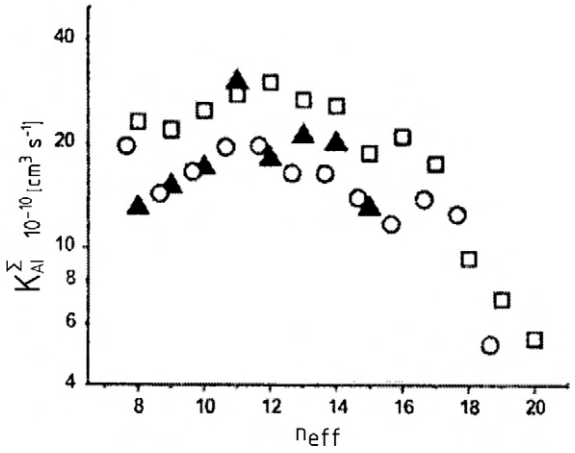

Fig. 12. Comparison of AI rate coefficients K^{Σ}_{AI} for n^2S (open circles) n^2D (open squares) states measured in cb-conditions $8 \leqslant n_{eff} \leqslant 18$, $T = 600$ K (Beterov et al., 2005) with the experimental results for n^2P states (solid triangles) obtained in Boulmer et al. (1983).

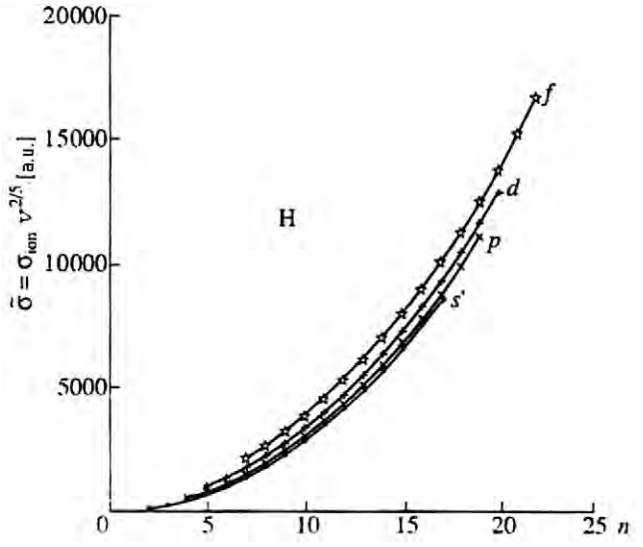

Fig. 13. PI ionization cross-section in the pair collisions of Rydberg hydrogen atom in the s, p, d and f states vs. principal quantum number (calculation) (Bezuglov et al., 1995b).

difference of the electrostatic field close to the ion core from the pure Coulomb field. Within the framework of the model in Bezuglov et al. (1995b) have been calculated the cross sections of process for symmetric collisions of the first-group atoms H, Li, Rb (Figs. 13–15). The expression for σ_i averaged over the values of the orbital angular momentum $L < n$ and integrated over all the low states $n''A^*$ with $n'' < n/\sqrt{2}$ has the form:

$$\sigma_i = 23.6 v^{-\frac{2}{5}} n^{-\frac{8}{5}}. \quad (24)$$

Because of the mixing of the nearest atomic configuration in the *PI* process, the population of the states can occur with violation of the selection rules for optically allowed transitions. So, even in the case of the initial selective population of two highly excited n^2P states, the population of the lower-lying n'^2P states ($n' < n$) via the intermediate ($S + S$) configuration is also possible (Bezuglov et al., 1997a).

In McGeoch et al. (1988) *RA* Penning-type ionization in $Li^{**} + Li^*$ collisions was considered in another way using a classical trajectory Monte-Carlo method (CTMC). It has been noted that at low collision velocities CTMC method greatly overestimated the cross sections (Olson, 1979).

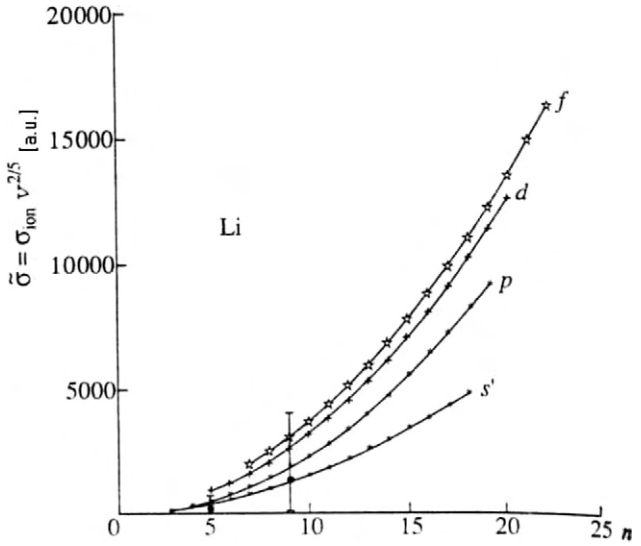

Fig. 14. The same as in Fig. 13, but for the lithium atoms (Borodin et al., 1995). The experimental point corresponds to the cb conditions with the n^2P states, $T = 1090$ K and molecular channel of the ionization (McGeoch et al., 1988).

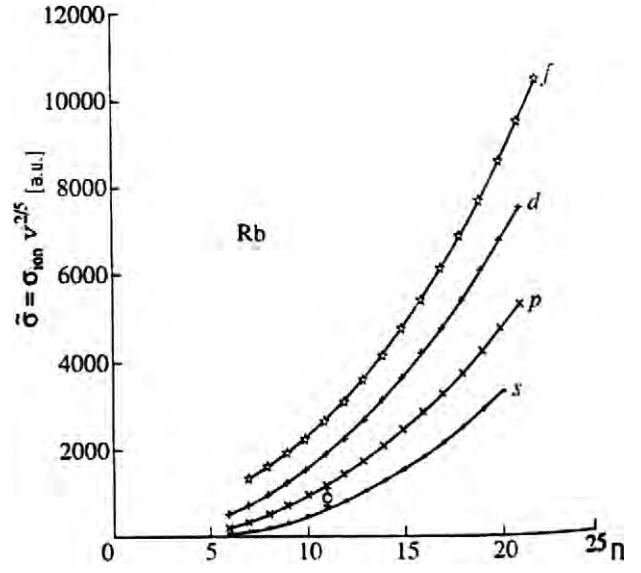

Fig. 15. The same as in Fig. 12, but for the rubidium atoms. The experimental point corresponds to the single beam experiment with the n^2P states $T = 380$ K and Rb_2^+ creation (Borodin et al., 1995).

4. Collision ionization with Rydberg atom participation (non-symmetrical collision)

4.1. Rydberg atom collisions with molecules

Note that it would expect high enrichment of alkali and halogen elements in volcanic gases on Io, so that the abundances of Na and Cl in Io's atmosphere may be compared (Schaefer and Fegley, 2005). Appreciable cross section (10^{-14}–10^{-15} cm^2) for thermal collisions between a metal atom (M) and a homo-nuclear (X_2) or hetero-nuclear (XY) halogen molecule was first noted in 1930s.

Chemi-ionization processes in atom-molecule collisions are usually multi-channel phenomena:

$$M + XY \Rightarrow M + XY^-, \tag{25a}$$

$$M + XY \Rightarrow M + X + Y^-, \tag{25b}$$

$$M + XY \Rightarrow M + X^- + Y, \tag{25c}$$

The cross section for the production of an ion pair depends on the degree of excitation of halogen-containing molecules and alkali metal atoms. For halogen-containing molecules, characterized by high rate coefficients ($K \approx 10^{-7}$ cm^3 s^{-1}, SF_6), the negative-ion yield in thermal collisions with RA is determined by the RE attachment probability. This follows from the theory and is confirmed by measurements of the ionization rate constants for RA with $n = 20$–100 in collisions with halogenides.

Table 3 lists the ionization rate coefficients and cross sections for collisions between $4^2D_{5/2}$ ($E_I^* = 0.86$ eV) or $5^2S_{1/2}$ ($E_I^* = 1.02$ eV) sodium atoms, and halogen containing molecules for sodium beam-source temperature $T = 600$ K.

The cross section for the production of an ion pair was found in Moutinho et al. (1971) to be a function of the degree of vibrational excitation of halogen-containing molecules colliding with alkali-metal atoms. For the $RA + SF_6 \Rightarrow A^+ + SF_6^-$ reaction, the cross section is inversely proportional to the orbital velocity of the electron in its highly excited state: $\sigma(v) = (4.2 \pm 1.0) \times 10^{-7}/v$. Since the Rydberg states of all atoms are similar, an analogous result is also obtained for xenon RA. As the principal quantum number is varied in the range $n = 23$–106, the RA chemi-ionization rate constant for collisions with SF_6 is found to lie in the range 4×10^{-7}–4.5×10^{-7} cm^3 s^{-1} and is practically independent of n.

In Beterov et al. (1987) it was found that the ionization data of n^2P Rydberg atoms of sodium ($n = 24$–32) in collisions with SF_6 molecules have a reasonable agreement with previously published data for Xe(nF) ($n = 25$–40), Rb(nS) ($n = 49$–62), and $Rb(nD)$ ($n = 38$–106). An interesting new result is that there is a systematic discrepancy between the rate constants measured in experiments on the attachment of slow electrons to molecules, on the one hand, and the chemi-ionization measurements on RA, on the other. For other complex molecules, K either increases with increasing n (CCl_4, CCl_3F, CH_3I) or decreases (C_7F_{14}). The detailed dependence of σ on n is determined by the properties of the scattering of ultra-slow RE by molecules. Associative and Penning ionization in collisions between potassium atoms in metastable autoionizing states and D_2, NO, N_2, CO, CO_2, N_2O, H_2O, and H_2S molecules was investigated semi-quantitatively in Moutinho et al. (1971). According to these data, the Penning ionization cross sections are of the order of 10^{-15} cm^2.

The published data clearly illustrate the basic difficulties encountered when attempts are made to construct universal models of chemi-ionization in a wide range of values of n

Table 3
Rate coefficients for chemi-ionization at thermal energies in collision of sodium atoms in $4^2D_{5/2}$ or $5^2S_{1/2}$ states and halogen-containing molecules, $T = 600$ K (Beterov et al., 1982, 1983)

	Atom, molecule	K (10^{-10} cm^3 s^{-1})	σ (10^{-13} cm^2)	Resulting negative ions
1	$Na(4^2D), SF_6$	2.8 ± 0.8	$1.6^{(*)}$, 4.6	SF_6^-
2	$Na(4^2D), CH_3Br$	0.35 ± 0.1	8.4, 2.5	Br^-
3	$Na(4^2D), CCl_2F_2$	0.54 ± 0.2	2.84	$23\%Cl_2^- + 77\%$ Cl^- or F_2^-
4	$Na(4^2D), C_6F_6$	0.08 ± 0.03	1.2×10^{-4}	$C_6F_6^-$
5	$Na(4^2D), C_6F_5H$	0.18 ± 0.06	2.7×10^{-4}	
6	$Na(4^2D), CH_3I$	2.1 ± 0.6		I^-
7	$Na(5^2S), O_2$	0.13 ± 0.04		O_2^-
8	$Na(5^2S), SF_6$	0.16 ± 0.05		SF_6^-

(*) Reactions 1–4 and 7 are endothermic so that the value is based on E_a used in the analysis of measured reaction rates.

even for a given atom. The high rate constants for the production of the SF_6^- ions are due to the fact that this ion appears in a long-lived excited state with lifetime $\tau > 0.001$ s. A different situation arises for the intermediate states in collisions between the alkali metals and O_2 molecules: the lifetime of the resulting $(O_2^-)^*$ ion is very short ($t_{eff} \sim 10^{-9}$ s) and, in the absence of a stabilizing mechanism, we have electron autodetachment (Walter et al., 1986). The interaction with the ion core of the Rydberg atom can serve as a stabilizing factor. If stabilization is less effective for smaller n, then, in contrast to, the above case of collisions with SF_6, the rate constant K for O_2 should decrease with n. This may be the explanation of the low value of K (10^{-12} cm^3 s^{-1}) and the reduction in K with increasing n ($8 \leqslant n \leqslant 12$) reported in Dunning and Stebbings (1983).

Ionization cross section for RA colliding with dipolar molecules such as H_2O, NH_3, SO_2, C_2H_5OH, and CH_3NO_2 are given in Dunning and Stebbings (1983) and Smirnov (1982). For $n > 30$, the corresponding rate constants tend to their asymptotic limit (10^{-6} cm^3 s^{-1}, H_2O, NH_3).

4.2. Non-symmetrical atom–atom chemi-ionization processes

In Klucharev and Lazarenko (1980), under the optical excitation of the excited potassium vapors, ionization with n^2P excited sodium atoms $4 \leqslant n \leqslant 7$ has been registered. Sodium was presented in potassium vapor as a slight admixture less than one per cent. Excited n^2P sodium states with $n = 5$ are situated beyond the potassium ionization threshold. That makes it possible to assume the non-symmetrical ionization process:

$$\begin{aligned} &Na^* + K \Rightarrow e + NaK^+, \\ &Na^* + K \Rightarrow e + Na + K^+, \end{aligned} \qquad (26)$$

$$\begin{aligned} &Rb^*(n) + K \Rightarrow e + RbK^+, \quad 6 \leqslant n \leqslant 8 \\ &Rb^*(n) + K \Rightarrow e + Rb + K^+ \end{aligned} \qquad (27)$$

exceeds 10^{-10} cm^3 s^{-1}.

In Harth et al. (1986), AI cross-sections during $Ne^*(nS, nD) + He$ collisions yielding $HeNe^+$ ions have been measured. In the cross-sections maximum closes to $n_{eff} \sim 10$ the AI cross-section in the case $Ne^* + He$ collisions about twenty times smaller than in the symmetrical $Ne^* + Ne$ one.

At last in Jonnson et al. (1988) non-direct experimental estimations have been performed to evaluate the production rate of homo- and heteronuclear molecular ions Na_2^+ – K_1 and NaLi – K_2 in AI reactions:

$$\begin{aligned} &Na^*(n^2P) + Na \Rightarrow e + Na_2^+, \\ &Na^*(n^2P) + Li \Rightarrow e + NaLi^+, \quad 8 \leqslant n \leqslant 14. \end{aligned} \qquad (28)$$

The obtained result shows that the ratio K_1/K_2 is less than unity.

It appears as the immediate task to work up on the theoretical models for very important in the weakly ionized gas media's conditions, non-symmetrical chemi-ionization processes involving two different atoms.

5. Photoplasma

The investigation of elementary processes at slow particle energies is closely related to the investigation of low temperature plasmas (LTP). A sophisticated system of equations describing such plasma states is useful only with the accurate knowledge of the rate coefficients of the elementary processes. Many scientific and technological today problems have promising solution in LTP with alkali atoms.

For instance, the optically stimulated alkali plasma is one of the promising tools for the development of ecologically clean devices for direct transformation of light energy to electric one in upper atmosphere (Palmer, 1977).

Chemi-ionization processes are responsible for the formation of LPT when an absorbing medium is optically excited by the light of an intensity which is neither sufficient for the multi-photon transitions neither for stimulated radiation, nor has photons capable to ionize the medium in a direct photo-ionization process. In the first experiment to report a new physical phenomenon so called "photoplasma" or "photoresonant plasma" a quasistationary plasma was observed with $N_e = 10^{12}$ cm^{-3} after cesium vapor was illuminated with light from alkali gas discharged lamp (Morgulis et al., 1967).

Calculations show that for alkali-metal vapor with $10^{15} \leqslant No \leqslant 10^{17}$ cm^{-3} and light illumination of $10^5 \leqslant I \leqslant 10^6$ W cm^{-2} (line width about 0.05 nm), AI is the dominant source of primary electrons in Na.

Scheme (see Fig. 16) illustrates possible mechanisms for the evolution of photoplasma during absorption of resonant radiation. Here are included 1 – optical excitation of the resonant atomic states, 2 – energy pooling processes, 3 – *AI* in binary resonant excited atom collisions, 4 – collisional production of negative and positive ion pair, 5,6 – *AI* and *PI* processes with *RA*, correspondingly, 7 – the collisions leading to the fast electron formation, 8 – excitation and 9 – subsequent ionization with the fast electrons participation.

It is useful to note that optical (laser) experiments concerned with ionization phenomena for $I \geqslant 10^5\ \mathrm{W\,cm^{-2}}$ have not revealed any saturation effects in the charged-particle current. However, optical-signal saturation, i.e., resonant fluorescence, is seen for much lower illumination power densities (see, for example, Weiner and Polak-Dingels, 1981). This means that the dynamics of the colliding atoms system may change significantly in the laser radiation field, and laser-induced associative and Penning ionization processes may come into play. The measured cross

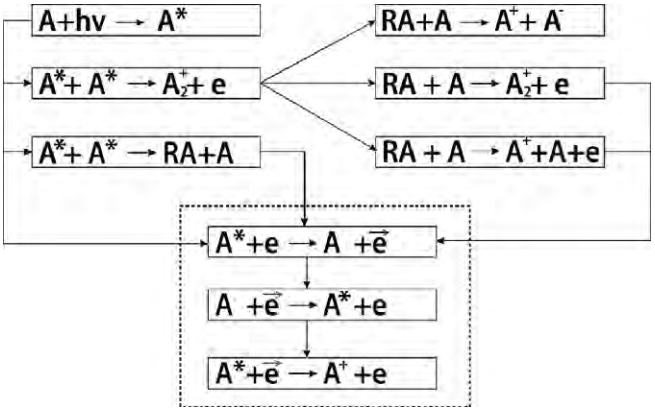

Fig. 16. Photoplasma steps creation.

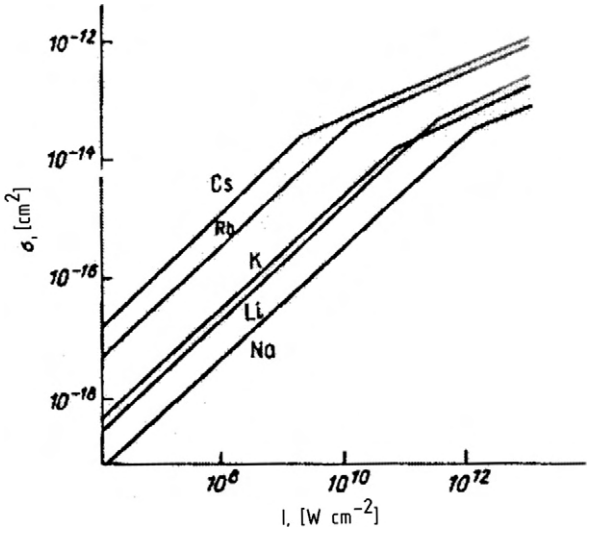

Fig. 17. Cross sections for Penning ionization stimulated by radiation (Geltman, 1988).

section for such processes with $I \approx 10^6\ \mathrm{W\,cm^{-2}}$ are $3 \times 10^{-19}\ \mathrm{cm^2}$ for Na and is in reasonable agreement with calculations (Geltman, 1988) (Fig. 17). When the exciting laser pulse length is comparable with the lifetime of the excited states, one begins to see the effects of the photo-dissociation of molecular ions produced in *AI* channels. Thus, in crossed-beam experiments using sodium beams ($N_0 = 10^9\ \mathrm{cm^{-3}}$), the Na_2^+ ions for $10^5\ \mathrm{W\,cm^{-2}}$ undergo partial photo-dissociation during the laser pulse. Since molecular ions produced in dimmer *AI* and photo-ionization channels have different vibrational excitation, the photo-dissociation cross sections are correspondingly different (Roussel et al., 1983).

6. Conclusion

The efficiency of collision-induced ionization of chemi-ionization type at thermal ($E > 10^2$ K) and subthermal ($E < 10^2$ K) collisions involving excited atoms was examined. In contrast to the rate constants for ultracold ($E < 10^{-3}$ K) collisions, which need special theoretical approaches because the motion of the nuclei cannot be treated here as classical, the rate constants for subthermal and thermal collisions are modeled essentially in the same way.

The results obtained show that the theoretical models proposed for collision-induced ionization are adequate in a wide range of principal quantum numbers of the excited hydrogen-like atoms. It was established that for slow collisions, in systems with few degrees of freedom, the stochastic dynamics processes occurring during the single collision may be observed.

Above considered models of the chemi-ionization processes with alkaline atoms are equally applicable to ionized gas and gas dynamics media as well as to atomic beams (thermal and subthermal conditions). This opens up prospects for consideration of the alkali metals, first of all sodium, present significantly in a number of cosmic objects, which is of interest from the astrophysical aspect.

Recently, in connection with development of basic researches in the field of interaction of radiation with single atoms and molecules the circle of problems in which highly excited atoms play the leading part was essentially extended. Laser cooled atoms, Bose–Einstein condensation, and management of the single atom conditions, new prospects in creation of logic devices of quantum computers, quantum teleportation etc. concern to them. All this increases interest to experimental and theoretical researches with participation of excited and, first of all, highly excited atoms, including the processes of their atomic collision ionization.

The classical model describing the ionization process in collisions of Rydberg atom with ground-state one (Ignjatović and Mihajlov, 2005) was supplemented in Miculis et al. (2005) and Beterov et al. (2005). The most substantial modification was the modeling of the quasi-molecular manifold of Rydberg states using the stochastic dynamics

of the Rydberg electrons. The results presented above may be recommended for the interpretation of the hydrogen-like excited atom species in the weakly ionized astrophysical formations of alkalis, specifically in volcanic gases on Io.

We note that this work is not envisaged as a particular one, but as a basis for planned modelling of sodium formations in Io atmosphere, representing the most impressive object where the sodium problem is actual. Namely, results of this work provide part of kinetics for the modelling of sodium formations in Io atmosphere, not investigated before. The other needed processes are well known and could be easily included in the model. One should take into account that the atmosphere of Io is not calm, and that processes there are in the presence of numerous powerful electric discharges. Consequently, one could assume that sodium vapor is there under strong influence of UV radiation and discharge products, so that the processes investigated here are present and presented results could be useful.

Acknowledgements

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References

Aslanov, I.A., Hieldebrandt, G., Khokhlova, V.L., Shoneich, W., 1973. Astrophys. Space. Sci. 21, 447.
Beterov, I.M., Fateev, N.V., 1983. Abstracts of Papers Presented to the Sixth All-Union Conference on the Physics of Low-Temperature Plasmas, Leningrad, p. 31 (in Russian).
Beterov, I.M., Kurochkin, V.L., Fateev, N.V., 1982. Khim. Fizika 1, 95.
Beterov, I., Vasilenko, G., Smirnov, B., Fateev, N., 1987. Sov. Phys. JETP 66, 17.
Beterov, I., Tretyakov, D., Ryabtsev, I., Bezuglov, N., Miculis, K., Ekers, A., Klucharev, A., 2005. J. Phys. B 38, 4349.
Bezuglov, N., Klucharev, A., Sheverev, V., 1984. J. Phys. B 17, L449.
Bezuglov, N., Klucharev, A., Sheverev, V., 1987. J. Phys. B 20, 2495.
Bezuglov, N., Vujnovic, V., Klucharev, A., Sheverev, V., 1989. Opt. Spectrosc. 66, 721.
Bezuglov, N., Klucharev, A., Stacevicz, T., Taratin, B., Molish, A., Allegrini, M., 1995a. Opt. Commun. 120, 249.
Bezuglov, N.N., Borodin, V.M., Klyucharev, A.N., Allegrini, M., 1995b. Opt. Spectrosc. 79 (1), 680.
Bezuglov, N.N., Borodin, V.M., Klyucharev, A.N., Fuso, F., Allegrini, M., 1997a. Opt. Spectrosc. 83, 338–344.
Bezuglov, N.N., Borodin, V.M., Klyucharev, A.N., Orlovskii, K.V., Allegrini, M., 1997b. Opt. Spectrosc. 82 (3), 334–337.
Bezuglov, N.N., Borodin, V.M., Klyucharev, A.N., Fuso, F., Allegrini, M., Janson, M.L., Orlovskii, C.V., 1999a. Opt. Spectrosc. 86, 824.
Bezuglov, N., Molish, A., Klucharev, A., Fuso, F., Allegrini, M., 1999b. Phys. Rev. A 59, 4340.
Bonanno, R., Boulmer, J., Weiner, J., 1983. Phys. Rev. A 28, 604.
Borodin, V.M., Dobrolezh, B.V., Klucharev, A.N., Tsyganov, A., 1995. Opt. Spectrosc. 78, 15.
Boulmer, J., Bonano, R., Weiner, J., 1983. J. Phys. B 16, 3015.
Burrows, A., Volobuyev, M., 2003. Astrophys. J. 583, 985.
Carre, B., Roussel, F., Breger, P., Spiss, G., 1981. J. Phys. B 14, 4271.
Carre, B., Spiss, G., Bizau, J.M., Dhez, P., et al., 1984. Opt. Commun. 52, 19.
Chirikov, B.V., 1979. Phys. Rep. 52, 265.
Combi, M., DiSanti, M., Func, U., 1997. Icarus 130, 336.
Coroniti, F., Eviater, A., Mekler, Y., 1976. Astrophys. J. 205, 622.
Dalgarno, A., Block, J., 1976. Rep. Prog. Phys. 39, 573.
D'Angelo, N., Goeler, S., Ohe, T., 1966. Appl. Phys. 37, 2519.
De Iong, A., van der Valk, F., 1979. J. Phys. B 12, L561.
Delone, N., Krainov, V., Shepelyansky, D., 1983. Sov. Phys. Usp. 26, 551.
Dengel, H., Ruf, M., Hotop, H., 1993. Europhys. Lett. 23, 567.
Devdariani, A.Z., Klyucharev, A.N., Lazarenko, A.B., Sheverev, V.A., 1978. Pis'ma Zh. Tekh. Fiz. 4, 1013–1016.
Devdariani, A.Z., Klyucharev, A.N., Penkin, N.P., Sebyakin, Y.N., 1988. Opt. Spektrosk. 64, 706–709.
Dobrolege, B., Klucharev, A., Sepman, V., 1975. Opt. Spektrosk. 38, 1090.
Duman, E.L., Shmatov, I.P., 1980. JETP 51, 1061.
Dunning, F.B., Stebbings, R.F., 1983. Rydberg States of Atoms and Molecules. Cambridge University Press, Cambridge.
Gallager, A., 1991. Phys. Rev. A 44, 4249.
Geltman, S., 1988. J. Phys. B 21, L735.
Gould, P.L., Jett, D., Julienn, P.S., Phillips, W.D., et al., 1988. Phys. Rev. Lett. 60, 788.
Harth, K., Hotop, H., Ruf, M.W., 1986. In: International Seminar on Highly Excited States of Atoms and Molecules, Fuji-Yoshida, Japan, p. 117.
Harth, K., Hotop, H., Ruf, M.W., 2004. In: Book of Abstracts of International Conference on Problems of Geocosmos, St. Petersburg, Russia, p. 4.
Herbst, E., Klemperer, W., 1973. Astrophys. J. 185, 505.
Huennekens, J., Gallager, A., 1983. Phys. Rev. A 28, 1276.
Ignjatović, L., Mihajlov, A.A., 2005. Phys. Rev. A 72, 022715.
Janev, R.K., Mihajlov, A.A., 1980. Phys. Rev. A 21, 819–826.
Jonnson, B.C., Wang, M.X., Weiner, J., 1988. J. Phys. B 52, 19.
Jonson, R., 2000. Icarus 143, 429.
Klucharev, A.N., Lazarenko, A.V., 1980. Opt. Spektrosk. 48, 412.
Klucharev, A.N., Ryazanov, N.S., 1971. Opt. Spektrosk. 31, 347.
Klucharev, A.N., Vujnović, V., 1990. Phys. Rep. 185 (2), 55–81.
Klucharev, A.N., Sepman, V.Yu., Vujnović, V., 1977. J. Phys. B 10, 715.
Koch, P.M., Leeuwen, K.A.H., 1995. Phys. Rep. 255, 289.
McGeoch, M.W., Shlier, R.E., Chawla, G., 1988. Phys. Rev. Lett. 61, 2088.
Mekler, Y., Eviatar, A., Coroniti, F., 1976. Astrophys. Space Sci. 40, 63.
Miculis, K., Beterov, I., Bezuglov, N., Ryabtsev, I., Tretyakov, D., Ekers, A., Klucharev, A., 2005. J. Phys. B 38, 1811.
Mihajlov, A.A., Janev, R.K., 1981. J. Phys. B 14, 1639.
Mihajlov, A.A., Ljepojević, N.N., Dimitrijević, M.S., 1992. J. Phys. B 25, 5121.
Mihajlov, A.A., Dimitrijević, M.S., Djurić, Z., 1996. Phys. Scr. 53, 159–166.
Mihajlov, A.A., Ignjatovic, L.M., Vasilijević, M.M., Dimitrijević, M.S., 1997. Astron. Astrophys. 324, 1206.
Mihajlov, A.A., Dimitrijević, M.S., Ignjatović, L.M., Vasilijević, M.M., 1999. Astron. Astrophys. Trans. 18, 145–149.
Mihajlov, A.A., Ignjatović, L.M., Dimitrijević, M.S., Djurić, Z., 2003a. Astrophys. J. Suppl. Ser. 147, 369–377.
Mihajlov, A.A., Jevremović, D., Hauschildt, P., Dimitrijević, M.S., Ignjatović, L.M., Alard, F., 2003b. Astron. Astrophys. 403, 787–791.
Morgulis, N.D., Korchevoi, Y.P., Przhonskii, A.M., 1967. Zh. Eksp. Teor. Fiz. 53, 417.
Moutinho, A.M.C., Aten, I.A., Los, A., 1971. Physica 53, 471.
Olson, R.E., 1979. Phys. Rev. Lett. 43, 126.

Palmer, A., 1977. Research Report 513. Hughes Research Laboratories, Malibu, p. 16.
Roussel, F., Carre, B., Breger, P., Spiess, G., 1983. J. Phys. B 16, 1749.
Schaefer, L., Fegley, B., 2005. Icarus 173, 454.
Smirnov, B.M., 1982. Vozbuzhdennye atomy (Excited Atoms). Energoatomizdat, Moscow.
Smirnov, V.M., Mihajlov, A.A., 1971. Opt. Spektrosk. 30, 984.
Takahashi, S., Misawa, H., Nozava, H., Morioka, A., Sood, R., Okano, S., Yumoto, K., 2000. Adv. Space Res. 26 (10), 1529.
Tam, A., Happer, W., Siano, D., 1977. Chem. Phys. Lett. 49, 320.
Thorsheim, H.R., Wang, Y., Weiner, J., 1989 (unpublished).
Walter, C.W., Zollars, B.C., Jonson, C., 1986. Phys. Rev. A 34, 4431.
Wang, M.X., Weiner, J., 1987. J. Phys. B 21, L15.
Weiner, J., Boulmer, J., 1986. J. Phys. B 19, 599.
Weiner, J., Polak-Dingels, P., 1981. J. Chem. Phys. 74, 508.
Weiner, J., Masnou-Seeuws, F., Giusti-Suzor, A., 1989. Adv. Atom. Mol. Opt. Phys. 26, 209.
Zagrebin, S.B., Samson, A.V., 1985. J. Phys. B 18, L217.

Stark broadening of triply ionized oxygen lines: The temperature dependence

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The Stark widths of the $3s\ ^2S$-$3p\ ^2P^o$ and $3p\ ^2P^o$-$3d\ ^2D$ transitions have been calculated and measured in the plasma of a pulsed arc. Electron densities in the range $(2.1-6.4)\times10^{17}$ cm^{-3} were determined from the width of the He II P_α line while electron temperatures between 50 800 and 131 800 K are measured from the Boltzmann plot of O IV line intensities. Our experimental O IV Stark width agrees well with another experiment and with our semiclassical theoretical results in the whole temperature range.

PACS number(s): 52.70.Kz, 32.70.Jz

I. INTRODUCTION

Broadening and shift of spectral lines in plasmas are the subject of numerous experimental studies (see, e.g., Ref. [1] and reference therein). Unfortunately, most of the reported data are from the measurements at a single electron temperature or in the best case the results are taken in a small temperature range. The lack of the experimental data for a wider temperature range makes a detailed test of the Stark broadening theoretical calculations unreliable. Furthermore, without the knowledge of the line width and shift dependence upon electron temperature comparison of the experimental results obtained at different plasma conditions becomes very difficult. This problem is of particular importance whenever comparison of the Stark broadening parameters along the isoelectronic sequence is performed (see, e.g., Ref. [2]). In this case the line widths and/or shifts of various ionization stages are compared and they are, depending upon the ionization stage, measured at considerably different electron temperatures.

The aim of this paper is to supply the theoretical and experimental data for the widths and shifts of the prominent triply ionized oxygen lines, for as large as, electron temperature range. The reported experimental results together with other experimental data will be used for the testing of semiclassical and other theoretical calculations.

II. THEORY

By using the semiclassical-perturbation formalism [3], we have calculated electron-, proton-, and ionized helium-impact line widths and shifts for O IV $3s\ ^2S$-$3p\ ^2P^o$ and $3p\ ^2P^0$-$3d\ ^2D$ multiplets. A summary of the formalism is given in Ref. [4]. The energy levels for O IV lines have been taken from Ref. [5]. The oscillator strengths have been calculated by using the method of Bates and Damgaard [6] and the tables of Oertel and Shomo [7]. For higher energy levels, the method described by Van Regemorter, Hoang, and Prud'homme [8] is employed. In addition to electron-impact full half widths and shifts, Stark-broadening parameters due to proton, and ionized helium impacts have been calculated.

Our results for O IV $3s\ ^2S$-$3p\ ^2P^0$ and $3p\ ^2P^0$-$3d\ ^2D$ multiplets are shown in Table I for perturber density of 10^{17} cm^{-3} and temperatures $T=40\,000-170\,000$ K. Data for other plasma parameters may be provided by authors

TABLE I. This table shows electron-, proton-, and ionized helium-impact broadening parameters for O IV lines for perturber density of 10^{17} cm^{-3} and temperatures from 40 000 to 170 000 K. Transitions and averaged wavelengths for the multiplet in Å units are also given. By using C [see Eq. (5) in [9]] one obtains an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used. The numbers in brackets denote multiplicative powers of ten.

		Perturber	Electrons		Protons		Ionized helium	
Transition	T (K)		Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
O IV $3s$-$3p$	40 000		1.100[−1]	−2.31[−3]	2.380[−2]	−1.22[−3]	3.250[−3]	−1.15[−3]
3066.4(Å)	70 000		8.560[−2]	−2.20[−3]	3.660[−3]	−1.85[−3]	4.420[−3]	−1.67[−3]
$c=0.28$[21]	100 000		7.410[−2]	−2.40[−3]	4.440[−3]	−2.24[−3]	5.200[−3]	−1.97[−3]
	170 000		6.100[−2]	−2.80[−3]	5.630[−3]	−2.89[−3]	5.880[−3]	−2.47[−3]
O IV $3p$-$3d$	40 000		1.170[−1]	−2.24[−3]	2.230[−3]	−1.54[−3]	3.080[−3]	−1.45[−3]
3410.9(Å)	70 000		9.100[−2]	−1.85[−3]	3.620[−3]	−2.35[−3]	4.310[−3]	−2.11[−3]
$c=0.34$[21]	100 000		7.840[−2]	−2.22[−3]	4.410[−3]	−2.83[−3]	5.200[−3]	−2.49[−3]
	170 000		6.420[−2]	−2.50[−3]	5.850[−3]	−3.65[−3]	6.050[−3]	−3.12[−3]

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upon request. In this table we also specify parameter C [9], which gives an estimate for the maximum perturber density for which the line may be treated as isolated when it is divided by the corresponding electron-impact full width at half maximum.

III. EXPERIMENT

The light source was a low pressure pulsed arc with a quartz discharge tube 11 mm internal diameter. The distance between aluminum electrodes was 18 cm, and 3 mm diameter holes were located at the center of both electrodes to allow end-on plasma observations to be made. The central part around the pulsed arc axis was imaged 1:1 onto the entrance slit of the 1 m monochromator by means of the concave 1 m focal length focusing mirror. A 30 mm diaphragm placed in front of the focusing mirror ensures that light comes from the narrow cone about the arc axis.

The monochromator with inverse linear dispersion 8.33 Å/mm in the first order of the diffraction grating, was equipped with the photomultiplier tube and a stepping motor (3600 steps/revolution). Signals from the photomultiplier tube were led to a digital storage oscilloscope which was triggered by the voltage pulse from the Rogowski coil induced by the current pulse through the discharge tube. The discharge was driven by a 15.2 μF low inductance capacitor charged to 6 kV (peak current 27 kA) and fired by an ignition. The stepping motor and oscilloscope are controlled by a personal computer, which was also used for data acquisition. Recordings of spectral line shapes were performed shot by shot. At each wavelength position of the monochromator time evolution and decay of the plasma radiation were recorded by the oscilloscope. Four such signals were averaged at each wavelength. Further, to construct the line profiles these averaged signals at different wavelengths and at various times of the plasma existence were used to construct line profiles, see a typical example in Fig. 1. All line profiles were recorded with 20 μm entrance and exit slits of the monochromator. With these slits measured instrumental half width was 0.185 Å. To determine the Stark half width from the measured profile, a standard deconvolution procedure for the Lorentzian (Stark) and the Gaussian (instrumental+Doppler) profiles [10] was used.

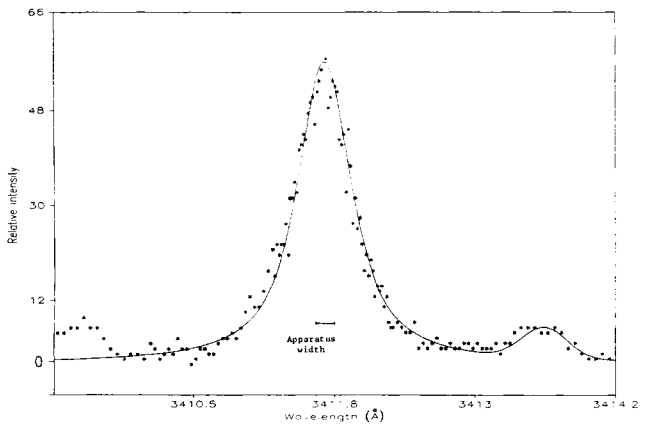

FIG. 1. Example of recording line spectra; *, measured; ——, Voigt function best fit.

Greatest care was taken to find the optimum conditions with the least line self absorption. This was achieved by careful examination of the O IV line intensities and line shapes as a function of experimental conditions (total gas pressure, oxygen-to-helium ratio and condenser bank energy), and by checking the optical depth of the strongest lines by measuring the intensity ratios within multiplets and comparing them with the theoretical predictions based on L-S coupling (see, e.g., Ref. [11]). It was found that the percentage of oxygen in the mixture was of crucial importance for the elimination of self-absorption. The ratio O_2:He=1.6:98.4 was determined after a number of experiments in which O_2 was diluted gradually until line intensities within investigated multiplets agree within 3% with the values derived from transition probabilities [12]. During the spectral line recording continuous flow of oxygen-helium mixture was maintained at a pressure of about 3 torr.

IV. PLASMA DIAGNOSTICS

For the electron-density measurements we use the width of the He II P_α 4686-Å line. The full width at half maximum $\Delta\lambda_{\mathrm{FWHM}}$ of this line is related to the electron density N_e using the following relationship [13–15]

$$N_e = 2.04\times 10^{16}(\Delta\lambda_{\mathrm{FWHM}})^{1.21}\mathrm{cm}^{-3}\ , \tag{1}$$

where $\Delta\lambda$ is in Å units. This equation is based on the fitting of the experimental data, and in fact closely agrees with calculations by Griem and Shen [16]. Our main concern in electron-density measurements is a possible presence of self-absorption of the 4686-Å line which may distort the line profile. This would result in erroneous reading of the line half width which, after the use of Eq. (1), introduces an error in electron-density measurements. There are several experimental methods which can be used for a self-absorption check (see, e.g., Ref. [11]) but unfortunately, none of them is convenient for the He II 4686-Å line or for our long, pulsed plasma source. Recently, in order to determine the optical thickness of the investigated line, Kobilarov, Konjević, and Popović [17] have introduced in the discharge an additional movable electrode. By placing the movable electrode at two different positions and by recording the line profiles from two plasma lengths, it is possible to determine $k_\lambda l$, where k_λ is the spectral line absorption coefficient and l is the plasma length along the direction of observation. If $k_\lambda l$ is not large ($k_\lambda 1 < 1$, see, e.g., Ref. [18]) it is possible to recover the line profile (see example, in Fig. 2 of Ref. [17]) for the optically thin case. The same method is used here for the He II 4686-Å line self-absorption testing. For this purpose an additional aluminum electrode (10 mm thick) is located inside the discharge tube. By means of this movable auxiliary electrode it was possible to vary the plasma length and, accordingly the absorption conditions of the plasma layer under investigation, without changing

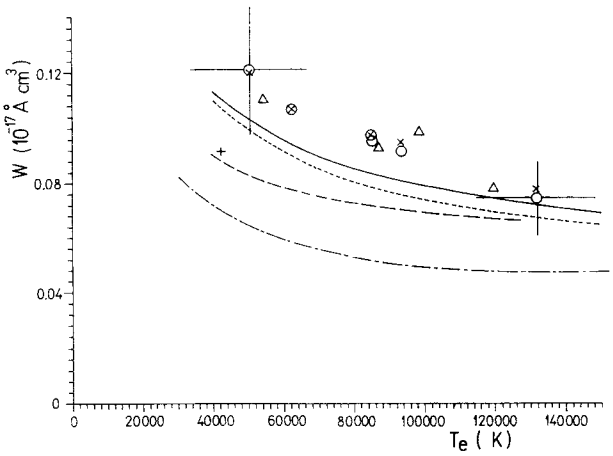

FIG. 2. Full Stark widths (normalized to an electron density of 10^{17} cm^{-3}) for the O IV $3s\ ^2S$-$3p\ ^2P^o$ multiplet vs electron temperature. Theory: ——, semiclassical, electrons $+He^+$ impact widths, see Table I); · · · ·, semiclassical electrons only (see Table I); — — —, semiclassical approximation (Griem [20], Eq. (526) taken from [20]); —·—·—·; modified semiempirical formula (Dimitrijević and Konjević [19]), and classical-path approximation (Hey and Breger [22] taken from [20]). Experiment: ×, 3063.46-Å, ○, 3071.66-Å lines this work; +, Purić *et al.* [23]; △, Glenzer, Hey, and Kunze [21].

the electrical impedance of the circuit (for details see, e.g., Ref. [17]). In this way, the profiles of 4686 Å line are recorded with two plasma lengths. Since the measured $k_\lambda l$ was smaller than 0.82 it was possible to recover the line profile for the optically thin case.

The axial electron temperatures in the range 50 800–131 800 K were determined from the Boltzmann plot of the relative intensities of O IV 3063.46-, 3071.66-, 3403.56-, and 3400.76-Å lines with transition probabilities being taken from Wiese, Peters, and Fuhr [12]. To determine the electron temperature, the thermal equilibrium in an optically thin medium is assumed. The spectral response of photomultiplier monochromator system is calibrated against standard coiled-coil quartz iodine lamp.

The results of the electron density and the electron temperature measurements at different times of the current pulse through the discharge tube are given in Fig. 2 and in Table II, together with results of O 2IV Stark linewidth measurements. The stated uncertainties for electron densities are due to the uncertainty of Eq. (1) (±10% see Ref. [13–15]) and estimated error in He II P_α half width measurements. The estimated error in electron temperature measurements includes uncertainties in the line intensity measurements and estimated accuracies of transition probabilities (±10%, [12]). Since the energy gap between upper energy levels of the O IV lines used for temperature measurements is only 3.6 eV, we were more conservative in estimation of uncertainties at higher temperatures.

V. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results for Stark widths (FWHM), w_m, of O IV lines are given in Table II together with plasma parameters and estimated errors for the various measured quantities. Table II also contains spectroscopic data for the investigated lines and comparison with the theoretical results of Dimitrijević, Sahal-Brechot, and Bommier w_{DSB} (electron+He^+ impact widths, see Table I) and Dimitrijević and Konjević w_{DK}, evaluated from modified semiempirical formula [19]. Here, in evaluation of w_{DSB} from data in Table I we assumed for our experimental conditions (low percentage of oxygen in O_2–He mixture) equal electron and singly ionized helium concentrations and temperatures. This assumption should not influence the results of the comparison more than a few percent (see Table I).

In order to facilitate the comparison of our experimental results with other available experimental data obtained at different electron densities N_e, measured Stark widths are normalized to $N_e = 1.0 \times 10^{17}$ cm^{-3} in Figs. 2 and 3. We assumed here a linear Stark width dependence upon the electron density of the spectral lines of nonhydrogenic ions, as has been verified in a number of experiments (see, e.g., Refs. [1,11,20,24]). In order to test the theoretical dependence of the Stark width upon the electron temperature $w(T_e)$, theoretical results are introduced in Figs. 2 and 3 for the comparison: semiclassical calculations (see Table I) w_{DSB}, and the modified semiempirical formula [18] w_{DK}. In addition, in Fig. 2 the results of the semiclassical formula [Eq. (526) in Ref. [20]], w_G, and the classical-path approximation of Hey and Breger [22], w_{HB}, are given too. These results are taken from Ref. [21].

The comparison of experimental and theoretical results in Fig. 2 shows (a) very good agreement between experimental data of Ref. [21] and this experiment, and (b) good agreement of both experiments with semiclassical theoretical results from Table I. Here one should point out that for the comparison of experimental data with semiclassical theoretical results from Table I one must, in addition to electron temperature, determine the ion concentration as well. This may not be an easy task, in particular, in multicomponent plasmas. Since it was practically impossible to estimate the contribution of ion broadening in Refs. [21] and [23], which were taken for the comparison, an ion broadening in Fig. 2 and 3 was estimated only for the plasma conditions of this experiment. Fortunately, the contribution of ion broadening to the Stark width is in the range of several percent, see Table I so it does not influence to a large extent the comparison in Figs. 2 and 3.

The comparison of three approximate calculations w_G, w_{DK}, and w_{BH}, with experimental results shows (a) semiclassical data of Griem [20] w_G, agree best with the experiments in particular if one takes into account the results of Purić *et al.* [23] and (b) modified semiempirical formula w_{DK}, describes better $w(T_e)$ dependence. The results obtained by comparing the theoretical and experimental results for the $3p\ 2P^0$-$3d\ ^2D$ multiplet in Fig. 3 are

TABLE II. Experimental Stark widths w_m (FWHM) of investigated $3s$-$3p$ and $3p$-$3d$ transitions in O IV. Experimental results are compared with semiclassical theoretical widths (electron + He^+ impact, see Table I), w_{DSB}, and with results of modified semiempirical formula, w_{DK} [18].

Transition array	Multiplet	λ (Å)	N_e (10^{17} cm^{-3})	T_e [K]	W_m	W_m/W_{DSB}	W_m/W_{DK}
$3s$-(^1S)$3p$	^2S-$^2P^o$	3063.43	2.06±15 %	62 600±27 %	0.220±10 %	1.13	1.83
			4.14±14 %	85 100±20 %	0.403±7 %	1.15	1.91
			5.07±14 %	93.600±18 %	0.479±7 %	1.17	1.93
			6.45±13 %	131 800±13 %	0.501±5 %	1.07	1.65
			5.38±14 %	85 000±20 %	0.525±5 %	1.16	1.91
			4.92±14 %	50 800±33 %	0.596±6 %	1.16	1.87
		3071.60	2.06±15 %	62.600±27 %	0.220±10 %	1.13	1.83
			4.14±14 %	85 100±20 %	0.397± 7 %	1.14	1.88
			5.07±14 %	93 600±18 %	0.465± 7 %	1.13	1.87
			6.45±13 %	131 800±13 %	0.478± 5 %	1.02	1.58
			5.38±14 %	85 000±20 %	0.524± 5 %	1.16	1.91
			4.92±14 %	50 800±33 %	0.599± 6 %	1.17	1.88
$3p$-(^1S)$3d$	$^2P^0$-^2D	3403.60	2.06±15 %	62 600±27 %	0.235±10 %	1.15	1.85
			4.14±14 %	85 100±20 %	0.416± 7 %	1.14	1.85
			5.07±14 %	93 600±18 %	0.486± 7 %	1.12	1.81
			6.45±13 %	131 800±13 %	0.521± 5 %	1.05	1.63
			5.38±14 %	85 000±20 %	0.563± 5 %	1.18	1.92
			4.92±14 %	50 800±33 %	0.622± 6 %	1.15	1.83
		3411.76	2.06±15 %	62 600±27 %	0.235±10 %	1.15	1.85
			4.14±14 %	85 100±20 %	0.445± 7 %	1.19	1.92
			5.07±14 %	93 600±18 %	0.495± 7 %	1.14	1.84
			6.45±13 %	131 800±13 %	0.534± 5 %	1.07	1.67
			5.38±14 %	85 000±20 %	0.558± 5 %	1.17	1.90
			4.92±14 %	50 800±33 %	0.596± 6 %	1.09	1.73

fully consistent with those for the $3s\,^2S$-$3p\,^2P^0$ multiplet in Fig. 3 (see Table II also).

VI. CONCLUSIONS

The results of semiclassical theoretical calculations for the Stark widths and shifts of O IV $3s\,^2S$-$3p\,^2P^0$ and $3p\,^2P^0$-$3d\,^2D$ multiplets have been reported. Experimental Stark widths for the lines of the same O IV multiplets were measured in a plasma of a low pressure pulsed arc. Our experimental results are compared with other available ones and our semiclassical theoretical results. The results of simplified semiclassical [20], modified semiempirical [19], and classical-path approximation calculations [21] are also taken for a comparison. Our experimental data are in very good agreement with those of another experiment [21] performed with a plasma created in a different plasma source (gas-liner pinch) and diagnosed with another diagnostic technique (Thomson scattering). Both experiments and the data by Purić *et al.* [23] measured at a single temperature agree within ±10–15 % with the semiclassical theoretical results (see Table I) in a large electron temperature range 50 800–131 800 K. The comparison of three approximate theoretical methods for calculation of the Stark width shows that the simplified semiclassical approach [20] agrees best with the experiments while the modified semiempirical approach [19] describes better $w(T_e)$ dependence.

The results of the comparison of the experimental results and the semiclassical theory in the case of O IV lines are very encouraging. The theory describes the Stark width dependence upon electron temperature correctly. However, recently Uzelac *et al.* [25] showed a gradual change of discrepancy between the experiment and some theoretical results with an increase of the ionization stage

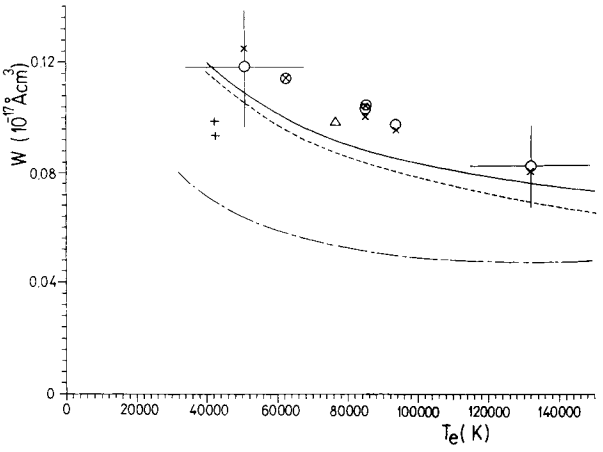

FIG. 3. Same as in Fig. 2 but for O IV $3p\,^2P^o$-$3d\,^2D$ multiplet. Experimental results of this work: ×, 3403.56 Å and ○, 3411.76 Å.

of the element. Although this finding is detected in relation to the simplified theoretical approaches [19, 20, and 22], the new experiments with the lines of different ionization stages are still required for a reliable testing of the theory.

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[1] N. Knojević and W. L. Wiese, J. Phys. Chem. Ref. Data **19**, 1307 (1990).
[2] R. Kobilarov and N. Konjević, Phys. Rev. A **41**, 6023 (1990).
[3] S. Sahal-Brechot, Astron. Astrophys. **1**, 91 (1969); **2**, 322 (1969).
[4] M. S. Dimitrijević, S. Sahal-Brechot, and V. Bommier, Astron. Astrophys. **89**, 581 (1991).
[5] S. Bashkin and J. O. Stonner, Jr., *Atomic Energy Levels and Grotrian Diagram* (North-Holland, Amsterdam, 1975), Vol. 1.
[6] D. R. Bates and A. Damgaard, Trans. R. Soc. London., Ser. A **242**, 101 (1949).
[7] G. K. Oertel and L. P. Shomo, Appl. J. Spectrosc. **16**, 175 (1968).
[8] H. Van Regemorter, Dy. Binh Hoang, and M. Prud'homme, J. Phys. B **12**, 1073 (1979).
[9] M. S. Dimitrijević and S. Sahal-Brechot, J. Quant. Spectrosc. Radiat. Transfer **21**, 301 (1984).
[10] J. T. Davies and J. M. Vaughan, Astrophys. J. **137**, 1302 (1963).
[11] N. Konjević and W. L. Wiese, J. Phys. Chem. Ref. Data **5**, 259 (1976).
[12] W. L. Wiese, T. M. Peters, and J. R. Fuhr (unpublished).
[13] T. L. Pittman and C. Fleurier, in *Proceedings of the Sixth International Conference on Spectral Line Shapes,* Boulder, 1982 (de Gruyter, Berlin, 1983).
[14] C. Fleurier and P. Le Gall, J. Phys. B **17**, 4311 (1984).
[15] T. L. Pittman and C. Fleurier, Phys. Rev. A **33**, 1291 (1986).
[16] H. R. Griem and K. Y. Shen, Phys. Rev. **122**, 1490 (1961).
[17] R. Kobilarov, N. Konjević, and M. V. Popović, Phys. Rev. A **40**, 3871 (1981).
[18] W. L. Wiese, in *Plasma Diagonostic Techniques,* edited by R. M. Huddleston and S. L. Leonard (Academic, New York, 1965).
[19] M. S. Dimitrijević and N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **24**, 451 (1980).
[20] H. R. Griem, *Spectral Line Broadening by Plasmas* (Academic, New York, 1974).
[21] S. Glenzer, J. D. Hey, and H.-J. Kunze, J. Phys. B **27**, 413 (1994).
[22] J. D. Hey and P. Breger, J. Quant. Spectrosc. Radiat. Transfer **24**, 349 (1980); **4**, 427 (1980); S. Afr. J. Phys. **5**, 111 (1982).
[23] J. Puric´, S. Deniže, A. Srećković, M. Platiša, and J. Labat, Phys. Rev. A **37**, 498 (1988).
[24] N. Konjević, M. S. Dimitrijević, and W. L. Wiese, J. Phys. Chem. Ref. Data **13**, 619 (1984).
[25] N. I. Uzelac, S. Glenzer, N. Konjević, J. D. Hey, and H. J. Kunze, Phys. Rev. E **47**, 3623 (1993).

Comparison of measured and calculated Stark broadening parameters for neutral-helium lines

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Stark broadening parameters for neutral-helium lines obtained using a semiclassical perturbation formalism are compared with critically selected experimental data. Our data are also compared with the results of Benett and Griem as well as with the semiclassical convergent calculations of Bassalo, Cattani, and Walder.

I. INTRODUCTION

Recently, we have calculated[1] electron and proton impact linewidths and line shifts of 56 neutral-He lines in the ultraviolet, visible, and infrared regions of the spectrum using a semiclassical perturbation formalism.[2,3] The version of semiclassical approach used in our calculations differs in several respects from the other large-scale calculations[4–7] of neutral-He lines. Since He is a simple atomic system and since many experimental Stark broadening data are available for He lines,[8,9] the data we obtained provide an opportunity for testing various approximations included in the semiclassical perturbation formalism. Our data as well as the results of Benett and Griem[4] and semiclassical convergent calculations of Bassalo *et al.*[7] are compared here with the critically selected[8,9] experimental data[10–22] in order to test various sets of assumptions involved in different approaches.

II. THEORY

We calculated electron-impact broadening parameters of isolated neutral He lines using the semiclassical perturbation formalism.[2,3] The relations for (full) half width (w) and shift (d) in the framework of the above-mentioned approach are

$$w=N\int_0^\infty vf(v)\,dv\left[\sum_{j\neq i}\sigma_{ij}(v)+\sum_{j'\neq f}\sigma_{fj'}(v)+\sigma_{\rm el}\right], \quad (1)$$

$$d=N\int_0^\infty vf(v)\,dv\int_{R_3}^{R_d}2\pi\rho\sin(2\phi_p)d\rho\,. \quad (2)$$

The inelastic cross section $\sigma_{ij}(v)$ can be expressed by an integration over the impact parameter of the transition probabilities P_{ij} as

$$\sum_{j\neq i}\sigma_{ij}(v)=\tfrac{1}{2}\pi R_1^2+\int_{R_1}^{R_d}2\pi\rho\,d\rho\sum_{j\neq i}P_{ij}(\rho,v)\,. \quad (3)$$

Using the adiabatic approximation, the elastic cross section is

$$\sigma_{\rm el}=2\pi R_2^2+\int_{R_2}^{R_d}8\pi\rho\,d\rho\sin^2\delta\,, \quad (4)$$

$$\delta=(\phi_p^2+\phi_q^2)^{1/2}\,, \quad (5)$$

$$\phi_p=\sum_{j\neq i}\phi_{ij}-\sum_{j'\neq f}\phi_{fj'}\,.$$

Here, i and f denote, respectively, the initial and final levels and j and j' the corresponding perturbing levels. The phase shifts ϕ_p and ϕ_q, due respectively to the polarization ($\sim r^{-4}$) and to the quadrupole potential ($\sim r^{-3}$), are given in Ref. 2 (Sec. 3, Chap. 2).

All of the cutoffs (R_1, R_2, R_3, R_d) are described in Ref. 3 (Sec. 1, Chap. 3). We recall here that we have "symmetrized" the inelastic cross section by replacing v^2 by its modified value due to collisions, i.e., $v^2-(\hbar\omega_{jj'}/m)$, where $\hbar\omega_{jj'}$ is the threshold energy.

In terms of the S matrix for a collision of a single electron with the atom, one has

$$\sum_{j,j'\neq j}(P_{jj'}+P_{jj})=2\{1-S_iS_f^{-1}\}_{\rm av}\,, \quad (6)$$

where the curly brackets $\{\ \}_{\rm av}$ indicate an angular average. Griem *et al.*[4] as well as Sahal-Bréchot[2,3] adopted a perturbative method based on the series expansion of the S-matrix elements. Griem *et al.*[4] neglected the elastic term P_{jj} and took into account elastic collisions via the strong collision term. The low cutoff is determined by the condition[4]

$$\{1-S_iS_f^{-1}\}_{\rm av}\approx(\tfrac{3}{4})^{3/2}$$

or

$$\sum_{j,j'\neq j}(P_{jj'}+P_{jj})\approx 1.3\,,$$

while in Refs. 2 and 3 the lower cutoff for inelastic collisions (R_1) is determined from the condition $\sum_{j'\neq j}P_{jj'}=\frac{1}{2}$ and the corresponding one for elastic collisions (R_2) from the condition $P_{jj}=2$.

The "convergent approach" is based on the analogy between the Dyson-series and Taylor-series expansion of e^x. In this case the divergence for small impact parameters

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does not exist and lower cutoffs are not needed. This approach, developed by Vainshtein and Sobel'man[23] in a two-level approximation, was applied with some modifications by Dyne and O'Mara[24] and, recently, in the many-level approximation by Cattani, Yamamoto, Bassalo, and Walder[7,25,26] to calculate Stark broadening parameters of neutral-helium lines. In Refs. 1–3 ions had been treated in the impact approximation. To take the ion contribution into account, here we use the approach developed by Griem *et al.*[4] and Griem,[27] due to its simple applicability to different kinds of perturbing ions. In terms of the parameters A and R,[4,27] total width and shift are given by

$$W_{\text{tot}}=[1+1.75A(1-0.75R)]w ,$$

$$d_{\text{tot}}=d\pm 2.0A(1-0.75R)w .$$

The sign in the shift equation is equal to that of the low-velocity limit of d.

III. COMPARISON OF MEASURED AND CALCULATED VALUES

Our results[1] as well as the calculations of Benett and Griem[6] and Bassalo *et al.*,[7] are compared with the critically selected[8,9] experimental data.[10–22] The criteria for selection of experimental papers were as follows:[8,9] (a) an independent and accurate determination of the plasma electron density N_e, (b) a reasonably accurate determination of the electron temperature, (c) a discussion of other interfering broadening mechanisms and appropriate ex-

TABLE I. Key data on experiments.

Author	Year	Plasma source	Method of measurement: Electron density	Method of measurement: Temperature
Wulff (Ref. 10)	1958	Low-pressure pulsed arc	Inglis-Teller limit and composition data	He II to He I line intensity ratio
Berg *et al.* (Ref. 11)	1962	Electric T tube	Absolute hydrogen plus helium continuum intensity	He II to He I line intensity ratio
Bötticher *et al.* (Ref. 12)	1963	Wall-stabilized arc	Absolute intensities of He I lines	Absolute intensities of He I lines
Lincke (Ref. 13)	1964	Electric T tube	H_α, H_β, H_γ, 3889-Å He I line profiles and absolute hydrogen plus helium continuum intensity	Hydrogen line to continuum intensity ratio
Greig *et al.* (Ref. 14)	1968	Electric T tube	H_β	H_β to continuum intensity ratio
Greig and Jones (Ref. 15)	1970			
Kusch (Ref. 16)	1971	Pulsed arc	H_β	H_β to continuum intensity ratio
Morris and Cooper (Ref. 17)	1973	Plasma jet	Stark widths of H_β and He I 5016- and 4921-Å lines	Absolute intensities of He II lines
Einfeld and Sauerbrey (Ref. 18)	1975	Low-pressure pulsed arc	Absolute intensity of the He continuum radiation at 5300 Å	Absolute intensity of He I 5016-Å and He II 4686-Å line
Chiang *et al.* (Ref. 19)	1977	T tube	Michelson-type interferometer at 6328 Å	H_β line to continuum intensity ratio
Solwitsch and Kusch (Ref. 20)	1979	Low-pressure pulsed discharge	Michelson-type interferometer at 5145 and 6471 Å	Absolute intensity of He II 3203- and 4686-Å lines
Kelleher (Ref. 21)	1981	Wall-stabilized arc	H_β Stark width	Absolute intensity of He I lines
Gauthier *et al.* (Ref. 22)	1981	CO_2 laser produced plasma	He I 3889-Å Stark linewidth	Absolute intensity of He I 3889- and 6678-Å lines

TABLE II. Comparison of measured (W_m) and calculated half widths for some neutral-helium lines. W_{DSB}, our results; W_{BCW}, Bassalo *et al.*;[7] W_{BG}, Benett and Griem.[6]

Transition	Wavelength (Å)	Temperature (K)	Electron density (10^{16} cm^{-3})	W_m/W_{DSB}	W_m/W_{BCW}	W_m/W_{BG}	Accuracy	Ref.
$2s\ ^1S-3p\ ^1P^o$	5015.68	30 000	3.2	0.84	0.78	0.72	*B*	10
		24 000	16.5	1.01	0.97	0.86	*B*	11
		15 600–16 900	1.0–2.0	1.33–1.11	1.20–0.99	1.13–0.94	*C*	12
		22 700	9.3	1.01	0.91	0.86	*B*	13
		25 000 and 23 000	2.7 and 1.7	1.42 and 1.38	1.28 and 1.23	1.20 and 1.17	*C*	15
		18 000–26 000	0.8–4.6	1.96–2.19	1.76–1.99	1.66–1.86	*D*	16
		38 000	2.6–3.6	1.11–1.09	1.05–1.03	0.99–0.97	*B*	18
		17 400	10.5 and 12.6	1.20 and 1.04	1.05 and 1.02	1.01 and 0.88	*A*	19
		20 000	6.7 and 7.7	1.07 and 1.13	0.95 and 1.00	0.91 and 0.96	*B*	20
		20 900	1.03	1.09	1.10	0.92	B^+	21
$2s\ ^1S-4p\ ^1P^o$	3964.73	20 900	1.03	1.14	1.01	0.91	B^+	21
$2p\ ^1P^o-3s\ ^1S$	7281.35	20 900	1.03	1.25	1.10	0.96	B^+	21
$2p\ ^1P^o-4s\ ^1S$	5047.74	30 000	3.2	1.05	0.88	0.78	*B*	10
		14 500–16 900	0.5–2.0	1.84–1.26	1.64–1.09	0.98–0.60	*C*	12
		20 900	1.03	1.20	1.06	0.92	B^+	21
$2p\ ^1P^o-3d\ ^1D$	6678.15	20 900	1.03	1.25	1.26	1.11	B^+	21
		20 000	10–160	1.13–0.47	1.07–0.50	1.01–0.48	*C*	22
$2p\ ^1P^o-5d\ ^1D$	4387.9	14 500–15 100	0.5–0.75	0.74–0.92	0.57–0.90	0.49–0.52	*C*	12
$2s\ ^3S-2p\ ^3P^o$	3888.65	30 000	3.2	1.08	1.04	0.87	*B*	10
		26 000	15	1.36	1.30	1.11	*B*	11
		18 000–26 000	0.8–4.6	2.06–2.33	1.91–2.22	1.64–1.88	*D*	16
		20 000	6.7–11.4	1.20–1.35	1.12–1.26	0.96–1.08	*B*	20
		20 900	1.03	1.16	1.09	0.92	B^+	21
$2s\ ^3S-4p\ ^3P^o$	3187.74	29 000	15	1.23	1.18	1.00	*B*	11
		20 000	6.7–11.4	1.15–1.18	1.05–1.07	0.92–0.95	*B*	20
		20 900	1.03	1.18	1.08	0.94	B^+	21
$2s\ ^3S-5p\ ^3P^o$	2945.10	40 000	1.2	1.16	1.07	0.98	*C*	23
		20 900	1.03	1.12	1.01	0.89	B^+	21
$2p\ ^3P^o-3s\ ^3S$	7065.19	20 900	1.03	1.14	1.02	0.90	B^+	21
$2p\ ^3P^o-4s\ ^3S$	4713.15	30 000	32	1.05	0.97	0.85	*B*	10
		20 000	13	1.33	1.16	1.02	*B*	11
		22 700	9.3	1.22	1.04	0.91	*B*	13
		20 900	1.03	1.24	1.06	0.93	B^+	21
$2p\ ^3P^o-5s\ ^3S$	4120.82	30 000	3.2	1.02	0.76	0.77	*B*	10
		14 500–16 900	0.5–2.0	1.92–1.19	1.45–0.89	1.39–0.89	*C*	12
		20 900	1.03	1.23	0.92	0.91	B^+	21
$2p\ ^3P^o-3d\ ^3D$	5875.62	20 900	1.03	1.18	1.39	1.00	B^+	21

TABLE III. Comparison of measured and calculated shifts (d_m) for some neutral-helium lines. d_{DSB}, our results; d_{BCW}, Bassalo *et al.*;[7] d_{BG}, Benett and Griem.[6]

Transition	Wavelength (Å)	Temperature (K)	Electron density (10^{16} cm^{-3})	d_m/d_{DSB}	d_m/d_{BCW}	d_m/d_{BG}	Accuracy	Ref.
$2s\ ^1S-3p\ ^1P^o$	5015.68	24000	16.5	1.05	1.23	0.98	*B*	11
		15600–16900	1.0–2.0	0.79–0.92	0.66–0.76	0.69–0.80	*C*	12
		22700	9.3	0.70	0.60	0.66	*B*	13
		10000–16000	0.6–2.3	1.61–1.00	1.39–0.83	1.26–0.87	*B*	17
		20900	1.03	1.29	1.23	1.17	*B*	21
$2s\ ^1S-4p\ ^1P^o$	3964.73	20900	1.03	1.16	1.10	0.96	*B*	21
$2p\ ^1P^o-3s\ ^1S$	7281.35	20900	1.03	1.05	1.31	1.19	*B*	21
$2p\ ^1P^o-4s\ ^1S$	5047.74	14500–16900	0.5–2.0	0.85–0.83	0.99–0.96	0.58–0.50	*C*	12
		20900	1.0–1.03	1.10	1.31	1.20	*B*	21
$2p\ ^1P^o-3d\ ^1D$	6678.15	20900	1.03	1.27	1.87	1.22	*B*	21
		20000	10–49	0.28–0.30	0.32–0.37	0.56–0.58	*C*	22
$2p\ ^1P^o-5d\ ^1D$	4387.9	14500–15100	0.5–0.75	0.088–0.11[a]	0.072–0.11[a]	0.059–0.061[a]	*C*	12
$2s\ ^3S-2p\ ^3P^o$	3888.65	26000	15	1.27	1.82	1.27	*B*	11
		14500–18000	0.5–3.5	1.89–0.97	2.48–1.28	1.91–0.99	*C*	12
		10000–16000	0.6–2.3	1.43–1.27	1.81–1.66	1.44–1.25	*B*	17
		20900	1.03	1.31	1.82	1.37	*B*	21
		20000	10–160	0.91–0.44	0.80–0.43	0.66–0.33	*C*	22
$2s\ ^3S-4p\ ^3P^o$	3187.74	29000	15	1.18	1.74	1.19	*B*	11
		20900	1.03	1.24	1.52	1.28	*B*	21
$2s\ ^3S-5p\ ^3P^o$	2945.10	20900	1.03	1.25	1.59	1.17	*B*	21
$2p\ ^3P^o-3s\ ^3S$	7065.19	20900	1.03	1.09	1.31	1.22	*B*	21
$2p\ ^3P^o-4s\ ^3S$	4713.15	20000	13	0.85	1.12	0.93	*B*	11
		22700	9.3	0.88	1.02	0.96	*B*	13
		10000–16000	0.6–2.3	1.72–1.08	1.98–1.26	1.44–1.19	*B*	17
		20900	1.03	1.04	1.25	1.18	*B*	21
$2p\ ^3P^o-5s\ ^3S$	4120.82	14500–16900	0.5–2.0	1.21–0.84	1.15–0.79	1.25–0.86	*C*	12
		20900	1.03	1.02	1.03	1.10	*B*	21
$2p\ ^3P^o-3d\ ^3D$	5875.62	20900	1.03	2.57	0.76	1.81	*B*	21

[a]Not taken in averaging.

TABLE IV. Average accuracy of different theoretical methods compared to Stark width and shift experimental data for helium lines. The results in parentheses are obtained by excluding the $2p\,^3D$–$3d\,^3D$ line which exhibits a strong unexplained difference between d_m and the calculated shift (especially for d_{DSB} and d_{BG}).

	All experiments included	Experiments with C and D accuracy excluded
$(W_m/W_{\mathrm{DSB}})_{\mathrm{av}}$	1.17±0.04	1.17±0.02
$(W_m/W_{\mathrm{BCW}})_{\mathrm{av}}$	1.07±0.04	1.07±0.04
$(W_m/W_{\mathrm{BG}})_{\mathrm{av}}$	0.92±0.04	0.93±0.02
$(d_m/d_{\mathrm{DSB}})_{\mathrm{av}}$	1.20±0.13 (1.07±0.04)	1.13±0.03
$(d_m/d_{\mathrm{BCW}})_{\mathrm{av}}$	1.23±0.08 (1.27±0.07)	1.34±0.09
$(d_m/d_{\mathrm{BG}})_{\mathrm{av}}$	1.14±0.07 (1.07±0.04)	1.14±0.03

perimental problems. Total uncertainties (in electron density and Stark width or shift measurements) are subdivided into four ranges and coded by letters.[8,9] The letters represent the following uncertainties: A, within 15%; B, within 30%; C, within 50%; D, larger than 50%. Further differentiations are made by singling out slightly better pieces of data among similar ones by assigning a plus sign (+) to indicate the first choice.[8,9] Key data from selected experiments are given in Table I. Comparisons between various calculations and experimental data are given in Tables II and III for widths and shifts, respectively.

The averaging is first performed within a multiplet and then the obtained values are averaged over the number of multiplets. The average values of the ratios of measured to calculated linewidths and line shifts are presented in Table IV.

The calculations of Bassalo *et al.*[7] and of Benett and Griem[6] give, on the average, the better agreement with linewidth measurements than the present calculations, while the results of Benett and Griem[6] and the present calculations are in better agreement with experimental shifts. Since the assumed uncertainty of the semiclassical approach is within 20%[27] and the typical uncertainties of experimental data are within 30%, one can conclude that all three variants of the semiclassical approach are successful in the calculation of the Stark broadening parameters.

[1]M. S. Dimitrijević and S. Sahal-Bréchot, J. Quant. Spectrosc. Radiat. Transfer **31**, 301 (1984).
[2]S. Sahal-Bréchot, Astron. Astrophys. **1**, 91 (1969).
[3]S. Sahal-Bréchot, Astron. Astrophys. **2**, 322 (1969).
[4]H. R. Griem, M. Baranger, A. C. Kolb, and G. Oertel, Phys. Rev. **125**, 177 (1962).
[5]J. Cooper and G. K. Oertel, Phys. Rev. **180**, 286 (1969).
[6]S. Benett and H. R. Griem, University of Maryland Technical Report No. 71-097, College Park, Maryland, 1971 (unpublished). (See also Ref. 27.)
[7]J. M. Bassalo, M. Cattani, and V. S. Walder, J. Quant. Spectrosc. Radiat. Transfer **28**, 75 (1982).
[8]N. Konjević and J. R. Roberts, J. Phys. Chem. Ref. Data **5**, 209 (1976).
[9]N. Konjević, M. S. Dimitrijević, and W. L. Wiese, J. Phys. Chem. Ref. Data (in press).
[10]H. Wulff, Z. Phys. **150**, 614 (1958).
[11]H. F. Berg, A. W. Ali, R. Lincke, and H. R. Griem, Phys. Rev. **125**, 199 (1962).
[12]W. Bötticher, O. Roder, and K. H. Wobig, Z. Phys. **175**, 480 (1963).
[13]R. Lincke, Ph.D. thesis, University of Maryland, 1964.
[14]J. R. Greig, C. P. Lim, G. A. Moo-Yong, G. Palumbo, and H. R. Griem, Phys. Rev. **172**, 148 (1968).
[15]J. R. Greig and L. A. Jones, Phys. Rev. A **1**, 1261 (1970).
[16]H. J. Kusch, Z. Naturforsch. Teil A **26**, 1970 (1971).
[17]R. N. Morris and J. Cooper, Can. J. Phys. **51**, 1746 (1973).
[18]D. Einfeld and G. Sauerbrey, Z. Naturforsch. Teil A **31**, 310 (1975) and private communication.
[19]W. T. Chiang, D. P. Murphy, Y. G. Chen, and H. R. Griem, Z. Naturforsch. Teil A **32**, 818 (1977).
[20]H. Solwitsch and H. J. Kusch, Z. Naturforsch. Teil A **34**, 300 (1979).
[21]D. E. Kelleher, J. Quant. Spectrosc. Radiat. Transfer **25**, 191 (1981).
[22]J. C. Gauthier, J. P. Geindre, C. Goldbach, N. Grandjouan, A. Mazure, and G. Nollez, J. Phys. B **14**, 2099 (1981).
[23]L. A. Vainshtein and I. I. Sobel'man, Opt. Spectrosc. **6**, 279 (1959).
[24]R. J. Dyne and B. J. O'Mara, Astron. Astrophys. **18**, 363 (1972).
[25]M. Cattani, Phys. Lett. **38A**, 147 (1972).
[26]Y. Yamamoto and M. Cattani, J. Quant. Spectrosc. Radiat. Transfer **20**, 271 (1978).
[27]H. R. Griem, *Spectral Line Broadening by Plasmas* (Academic, New York, 1974).

Stark broadening parameters of the Kr II and Kr III spectral lines

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Stark widths and shifts of 14 singly (Kr II) and 11 doubly charged (Kr III) krypton ion spectral lines have been measured in the linear, low pressure, pulsed arc at 17 000 K electron temperature and 1.65×10^{23} m^{-3} electron density. The measured width and shift values have been compared to the theoretical data calculated by us by using the modified semiempirical method.

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I. INTRODUCTION

For the first time with the help of the Goddard high resolution spectrograph on the Hubble space telescope, krypton has been detected in the spectra of the interstellar medium [1,2], which represents the material from which the young early type stars (as, e.g., Ap and Bp type stars where Stark broadening data are of interest) are formed [3]. Moreover, krypton is present in many light sources and lasers as the working gas. If the Stark broadening is the principal pressure broadening mechanism in plasmas (with 10^{22}–10^{27} m^{-3} electron density), it is possible to obtain from Stark width and shift values other basic plasma parameters as, e.g., electron temperature (T) and density (N), essential for the stellar atmospheres modeling. Consequently, the knowledge of the Stark broadening parameters (the width and the shift) of ionized krypton (Kr II and Kr III) spectral lines is of interest for plasma diagnostic purpose.

Stark widths of Kr II spectral lines have been investigated in a number of references, starting with the first measurements, presented in Refs. [4–6]. For example, seven experiments from Refs. [7–13] have been performed within the 10 000 K and 17 400 K electron temperature range. These values show mutual scatter up to the factor 3. The theoretical Stark widths for several lines are given in Ref. [14]. Authors have calculated Stark widths (only for $T=10\,000$ K and $N=1\times10^{23}$ m^{-3}) by using Griem's semiempirical formula [15] and by using the approach based on the Born approximation with and without the empirical modification for the collision strength suggested by Robb (see Ref. [14]). Moreover, in Ref. [16] Stark widths of 37 Kr II lines, which belong to the $5s$-$5p$ and $5s'$-$5p'$ transitions, have been calculated within the modified semiempirical approach [17]. In the case of the Kr III spectrum only two experiments [18,19] deal with the Stark widths investigations of seven spectral lines. Calculations of the Kr III Stark widths have been performed in Refs. [18,20–24].

In the case of the Stark shift the situation is much different. Namely, from the first Kr II lines Stark shift investigation [4], only one experiment [10] provided reliable Stark line shifts of three Kr II spectral lines. We note here as well that today there are neither reliable Stark shift measurements nor theoretical Stark shifts for the Kr III specral lines. In Ref. [25], Kr II and Kr III line shifts have been investigated but without the reliable plasma parameter determination so that the comparison with our results is not possible.

In this paper we will present measured and calculated Stark FWHM (full width at half intensity maximum, W) and Stark shift (d) values of 14 Kr II and 11 Kr III spectral lines. Stark FWHM values of 2 Kr II and 7 Kr III lines and Stark shift values of 11 Kr II lines were not known before. To our knowledge, present d values of Kr III lines are the first published with reliably determined plasma parameters on this topic. In addition, to our knowledge, our calculated Stark widths of the $5p$-$5d$ Kr II lines are, also, the first theoretical data.

Measurements were been performed at 17 000 K electron temperature and 1.65×10^{23} m^{-3} electron density in krypton plasma created in the linear, low pressure, pulsed arc discharge. The W and d values were been calculated within the frame of the modified semiempirical method [17,20,26–31] for the electron temperature range between 10 000 and 70 000 K.

II. EXPERIMENT

The modified version of the linear low pressure pulsed arc [32–34] has been used as a plasma source. A pulsed discharge was driven in a quartz discharge tube of 5 mm inner diameter and effective plasma length of 7.2 cm (Fig. 1 in Refs. [32,33]). The tube has an end-on quartz window. On the opposite side of the electrodes the glass tube was expanded in order to reduce erosion of the glass wall and also sputtering of the electrode material onto the quartz windows. The working gas was pure krypton at 130 Pa filling pressure in flowing regime. Spectroscopic observation of isolated spectral lines was made end-on along the axis of the discharge tube. A capacitor of 14 μF was charged up to 1.5 kV. The line profiles were recorded using a shot-by-shot technique with a photomultiplier (EMI 9789 QB and EMI 9659B) and a grating spectrograph (Zeiss PGS-2, reciprocal linear dispersion 0.73 nm/mm in first order) system. The instrumental FWHM of 0.008 nm was determined by using the narrow spectral lines emitted by the hollow cathode discharge. The recorded profiles of these lines are Gaussian in shape within 8% accuracy within the range of the investi-

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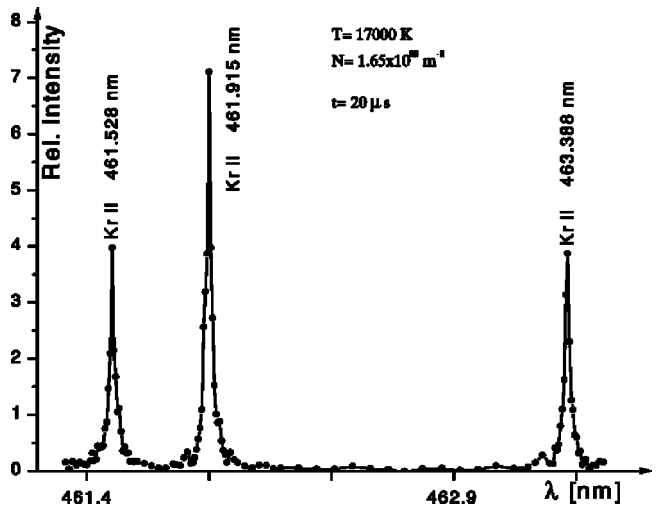

FIG. 1. Recorded Kr II spectrum at 20 μs after the beginning of the discharge.

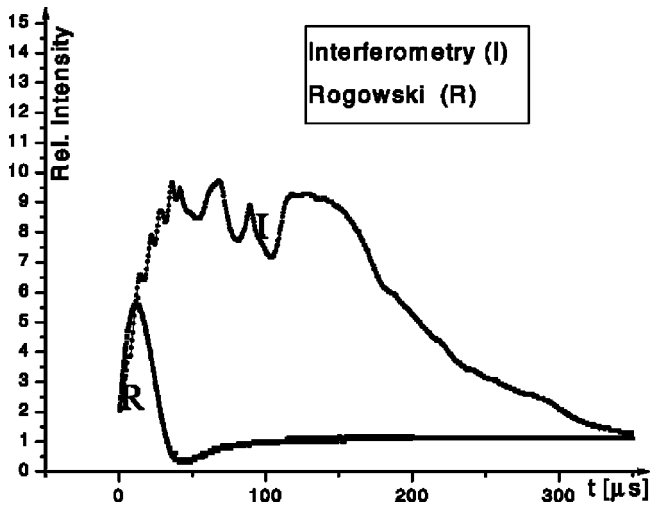

FIG. 3. Temporal evolution of the coil Rogowski (R) and interferometry (I) signals.

gated spectral line wavelengths. The spectrograph exit slit (10 μm) with the calibrated photomultiplier was micrometrically traversed along the spectral plane in small wavelength steps (0.0073 nm). The averaged photomultiplier signal (five shots at the same spectral range) was digitalized using an oscilloscope, interfaced to a computer. A sample output, as example, is shown in Figs. 1 and 2.

Plasma reproducibility was monitored by the Kr II line radiation and by the discharge current (it was found to be within 4%). Discharge characteristics were determined by analyzing the Rogowski coil signal. The found values were discharge current, 1.60 kA; discharge period, 82 μs; thermal resistance, 0.80 Ω; and decrement, 5.6. A typical Rogowski coil signal is presented in Fig. 3.

The measured profiles were of the Voigt type due to the convolution of the Lorentzian, Stark, and the Gaussian profiles from Doppler and instrumental broadening. For the electron density and temperature of our experiments the Lorentzian fraction in the Voigt profile was dominant (over 80%). van der Waals and resonance broadening were estimated to be smaller by more than an order of magnitude in comparison to Stark, Doppler, and instrumental broadening. The standard deconvolution procedure [35] was computerized using the least square algorithm. The Stark widths were measured with $\pm 15\%$ error. Great care was taken to minimize the influence of self-absorption on Stark width determinations. The opacity was checked by measuring relative line intensity ratios within the multiplet ^4P-$^4P^0$ in Kr II spectrum during the decaying plasma (465.89 nm and 483.21 nm). The values obtained were compared with calculated ratios of the products of the spontaneous emission probabilities and the corresponding statistical weights of the upper levels of the lines. The necessary atomic data were taken from Ref. [36]. It turns out that these ratios differed by less than $\pm 12\%$ (in a wide part of the decaying plasma, see Fig. 4) testing the absence of self-absorption. In the 20th μs after the beginnig of the discharge (when the profiles were analyzed) the theoretical ratio I_1/I_2 is only 10% above the experimental data. It should be pointed out that the experimental I_1/I_2 ratio is within $\pm 5\%$ accuracy constant during the plasma decay. This fact also shows the absence of self-absorption. The constant difference among measured and calculated line intensity ratios can be explained taking into account the high uncertainties ($\pm 50\%$) of the used transition probabilities [36].

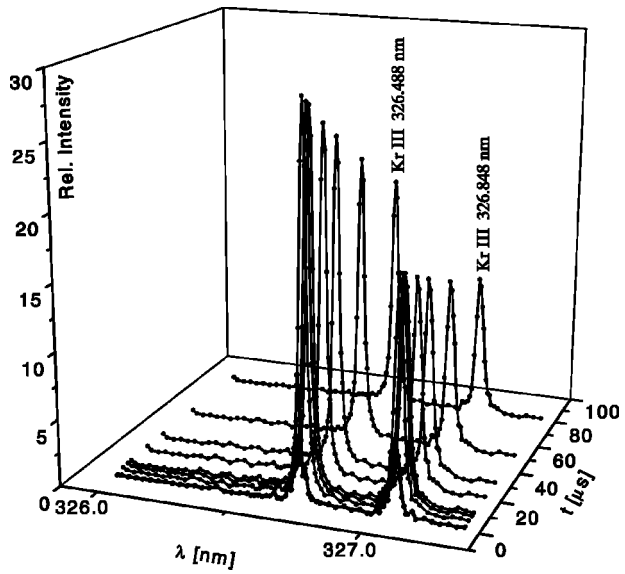

FIG. 2. Temporal evolution of several investigated Kr III spectral line profiles during the plasma decay.

The Stark shifts were measured relative to the unshifted spectral lines emitted by the same plasma [37]. The Stark shift of the spectral line can be measured experimentally by evaluating the position of the spectral line center recorded at two various electron density values during the plasma decay. In principle the method requires recording of the spectral line profile at the high electron density (N_1) that causes an appreciable shift, and then later when the electron concentration has dropped to the value (N_2) lower for at least an order of magnitude. The difference of the line center positions in the two cases is Δd, so that the shift d_1 at the higher electron density N_1 is

$$d_1 = N_1 \Delta d/(N_1 - N_2).$$

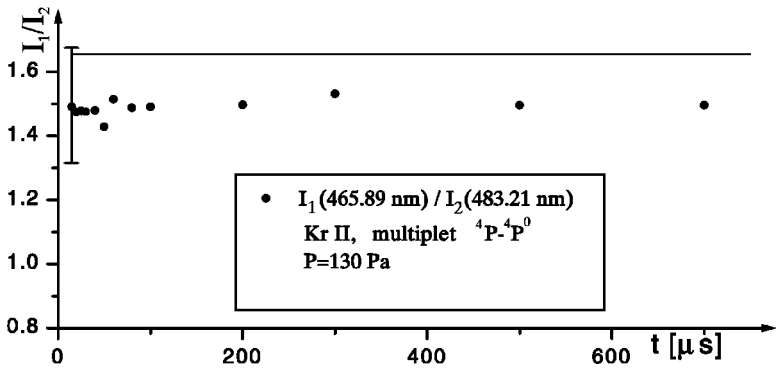

FIG. 4. Intensity ratio of two Kr II spectral lines belonging to the same multiplet during the plasma decay. —, theoretical prediction; ●, our measured values with ±12% accuracy.

The Stark shift data have been corrected for the electron temperature decay [38]. Stark shift data are determined with ±0.0008 nm error at a given N and T. The plasma parameters were determined using standard diagnostic methods [39]. Thus, the electron temperature was determined from the ratios of the relative intensities of nine Kr II spectral lines (435.547 nm, 457.720 nm, 461.529 nm, 461.915 nm, 463.388 nm, 465.887 nm, 473.900 nm, 476.577 nm, 483.207 nm) to the five Kr I spectral lines (435.136 nm, 436.264 nm, 446.369 nm, 557.028 nm, 587.091 nm) with an estimated error of ±9%, assuming the existence of local thermodynamic equilibrium, according to the criterion from Ref. [40]. All the necessary atomic data were taken from Refs. [36,41]. The electron temperature decay is presented in Fig. 5. The electron density decay was measured using a well known single laser interferometry technique [42] for the 632.8 nm He-Ne laser wavelength with an estimated error of ±7%. Temporal evolution of the typical interferometry signal is presented in Fig. 3. The electron density decay is presented, also, in Fig. 5.

At 20 μs after the beginning of the discharge, when the Kr II and Kr III spectral line profiles were analyzed, electron temperature was 17 000 K±9% and the electron density was 1.65×10^{23} m^{-3}±7%.

III. METHOD OF CALCULATION

According to the modified semiempirical (MSE) approach [17,20,26–31] the electron impact full width (FWHM) of an ion line is given as

$$W_{MSE}=N\frac{8\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}\times\left\{\sum_{\ell_i\pm1}\mathbf{R}^2[n_i\ell_i,n_i(\ell_i\pm1)]\tilde{g}\left(\frac{E}{\Delta E_{\ell_i,\ell_i\pm1}}\right)+\sum_{\ell_f\pm1}\mathbf{R}^2[n_f\ell_f,n_f(\ell_f\pm1)]\tilde{g}\left(\frac{E}{\Delta E_{\ell_f,\ell_f\pm1}}\right)+\left(\sum_{i'}\mathbf{R}^2_{ii'}\right)_{\Delta n\neq0}g(x_{n_i,n_i+1})+\left(\sum_{f'}\mathbf{R}^2_{ff'}\right)_{\Delta n\neq0}g(x_{n_f,n_f+1})\right\},\tag{1}$$

and the corresponding Stark shift as

$$d=N\frac{4\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}\left\{\varepsilon_{\ell_i,\ell_i+1}\mathbf{R}^2[n_i\ell_i,n_i(\ell_i+1)]\tilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_i,\ell_i+1}}\right)-\varepsilon_{\ell_i,\ell_i-1}\mathbf{R}^2[n_i\ell_i,n_i(\ell_i-1)]\tilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_i,\ell_i-1}}\right)-\varepsilon_{\ell_f,\ell_f+1}\mathbf{R}^2[n_f\ell_f,n_f(\ell_f+1)]\tilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_f,\ell_f+1}}\right)+\varepsilon_{\ell_f,\ell_f-1}\mathbf{R}^2[n_f\ell_f,n_f(\ell_f-1)]\tilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_f,\ell_f-1}}\right)+\left(\sum_{i'}\mathbf{R}^2_{ii'}\right)_{\Delta n\neq0}g_{sh}(x_{n_i},x_{n_i+1})-2\sum_{i'(\Delta E_{ii'}<0)}\mathbf{R}^2_{ii',\Delta n\neq0}g_{sh}\left(\frac{E}{\Delta E_{n_i,\ell_i,n_{i'}\ell_{i'}}}\right)-\left(\sum_{f'}\mathbf{R}^2_{ff'}\right)_{\Delta n\neq0}g_{sh}(x_{n_f},x_{n_f+1})+2\sum_{f'(\Delta E_{ff'}<0)}\mathbf{R}^2_{ii',\Delta n\neq0}g_{sh}\left(\frac{E}{\Delta E_{n_f,\ell_f,n_{f'}\ell_{f'}}}\right)+\sum_k\delta_k\right\},\tag{2}$$

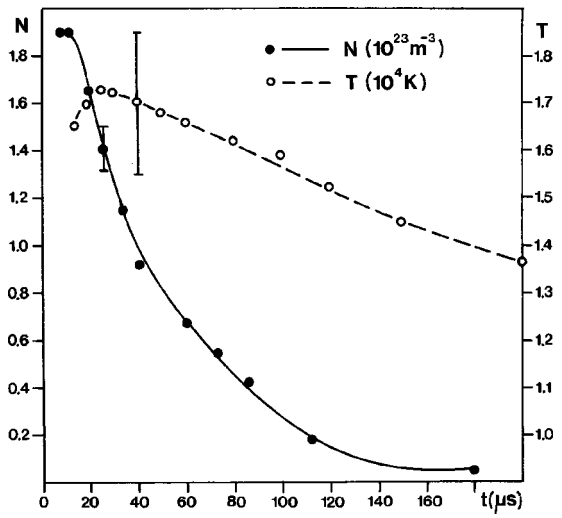

FIG. 5. Temporal evolution of the electron temperature (T) and electron density (N) during the plasma decay.

where the initial level is denoted with i and the final one with f and the square of the matrix element $\{\mathbf{R}^2[n_k\ell_k, n_k(\ell_k \pm 1)],\ k=i,f\}$ is

$$\mathbf{R}^2[n_k\ell_k, n_k(\ell_k\pm 1)] = \left(\frac{3n_k^*}{2Z}\right)^2 \frac{\ell_>}{2\ell_k+1} \times (n_k^{*2}-\ell_k^2)\Phi^2(n^{*2}_{\ell_k-1}, n^{*2}_{\ell_k}, \ell_k) \tag{3}$$

and

$$\left(\sum_{k'} \mathbf{R}^2_{kk'}\right)_{\Delta n\neq 0} = \left(\frac{3n_k^*}{2Z}\right)^2 \frac{1}{9}(n_k^{*2}+3\ell_k^2+3\ell_k+11), \tag{4}$$

where $\ell_> = \max(\ell_k, \ell_{k'})$, with ℓ denoting the angular momentum quantum number.

In Eqs. (1)–(4), N and T are electron density and temperature, respectively, and Φ is the Bates-Damgaard factor tabulated e.g., in Ref. [43]. Here, $g(x), g_{sh}(x)_{sh}$ and $\tilde{g}(x), \tilde{g}_{sh}(x)$ are the semiempirical [15] and the modified semiempirical [17,27] Gaunt factors for Stark width and shift, respectively. The factor $\varepsilon_{kk'} = (E_{k'}-E_k)/|E_{k'}-E_k|$, where E_k and $E_{k'}$ are the energy of the considered and its perturbing level. The sum $\Sigma_k \delta_k$ is different from zero only if perturbing levels strongly violating the assumed approximations exist and may be evaluated as

$$\delta_i = \pm \mathbf{R}^2_{ii'}\left[g_{sh}\left(\frac{E}{\Delta E_{i,i'}}\right) \mp g_{sh}(x_{n_i, n_i+1})\right], \tag{5}$$

for the upper level, and

$$\delta_f = \mp \mathbf{R}^2_{ff'}\left[g_{sh}\left(\frac{E}{\Delta E_{f,f'}}\right) \mp g_{sh}(x_{n_f, n_f+1})\right], \tag{6}$$

for the lower level. In Eqs. (5) and (6) lower signs correspond to $\Delta E_{jj'} < 0$; $x_{n_k, n_k+1} \approx 3kTn_k^{*3}/(2Z^2E_H)$, where $\Delta E_{kk'} = |E_k - E_{k'}|$, n_k is the principal, n_k^* the effective principal quantum number, $E = 3kT/2$, and $(Z-1)$ is the ionic charge.

In comparison with the semiclassical perturbation approach [40], the modified semiempirical method needs a considerably smaller number of atomic data. In fact, if there are no perturbing levels strongly violating the assumed approximation, for, e.g., the linewidth calculations, we need only the energy levels with $\Delta n = 0$ and $\ell_{if} = \ell_{if} \pm 1$, since all perturbing levels with $\Delta n \neq 0$ needed for a full semiclassical investigation are lumped together and approximately estimated. When there are not enough atomic data to perform calculations within the modified semiempirical approach, of particular interest might be the simplified semiempirical formula [20] for Stark widths of isolated, singly, and multiply charged ion lines applicable in the cases when the nearest atomic energy level ($j' = i'$ or f') where a dipole allowed transition can occur from or to initial (i) or final (f) energy level of the considered line, is so far, that the condition

$$x_{jj'} = E/|E_{j'} - E_j| \leqslant 2$$

is satisfied. In such a cases full width at half maximum is given by the expression [20]:

$$W(\text{nm}) = 2.2151 \times 10^{-9} \frac{\lambda^2(\text{cm}) N(\text{cm}^{-3})}{T^{1/2}(\text{K})}\left(0.9 - \frac{1.1}{Z}\right) \times \sum_{\text{j = i,f}} \left(\frac{3n_j^*}{2Z}\right)^2 (n_j^{*2} - \ell_j^2 - \ell - 1). \tag{7}$$

Similarly, in the case of the shift

$$d(\text{nm}) = 1.1076 \times 10^{-9} \frac{\lambda^2(\text{cm}) N(\text{cm}^{-3})}{T^{1/2}(\text{K})}\left(0.9 - \frac{1.1}{Z}\right) \times \frac{9}{4Z^2} \sum_{j=i,f} \frac{n_j^* \varepsilon_j^2}{2\ell_j+1}\{(\ell_j+1)[n_j^{*2} - (\ell_j+1)^2] - \ell_j(n_j^{*2} - \ell_j^2)\}, \tag{8}$$

where $\varepsilon = +1$ if $j = i$ and -1 if $j = f$.

If all levels $\ell_{i,f} \pm 1$ exist, an additional summation may be performed in Eq. (8) to obtain

$$d(\text{nm}) = 1.1076 \times 10^{-9} \frac{\lambda^2(\text{cm}) N(\text{cm}^{-3})}{T^{1/2}(\text{K})} \times \left(0.9 - \frac{1.1}{Z}\right) \frac{9}{4Z^2} \sum_{j=i,f} \frac{n_j^* \varepsilon_j^2}{2\ell_j+1} \times (n_j^{*2} - 3\ell_j^2 - 3\ell_j - 1). \tag{9}$$

In order to test the modified semiempirical approach, selected experimental data for 36 multiplets (7 different ion species) of doubly charged ions and 7 multiplets (4 different ion species) of triply charged ions were compared with theoretical results. The averaged values of the ratios of mea-

TABLE I. Measured Stark FWHM (W_m) and shift (d_m) values for the Kr II and Kr III lines at an observed electron temperature (T) of 17 000 K and electron density (N) of 1.65×10^{23} m^{-3}. W_m/W_{th} presents the ratio between our mesured (W_m) and calculated (W_{th}) values (from Ref. [16] and from Tables II–IV). An asterisk denotes the W_{th} values taken from Ref. [16]. + denotes the W_{th} values calculated by using the simplified semiempirical method. Positive shift is toward the red.

Emitter	Transition	Multiplet	λ (nm)	W_m (nm)	d_m (nm)	W_m/W_{th}
Kr II	$5s$-$5p$	$^4P_{5/2}$-$^4P^0_{3/2}$	465.89	0.0399	−0.0010	0.90*
		$^4P_{3/2}$-$^4P^0_{1/2}$	483.21	0.0429	−0.0014	0.84*
		$^4P_{5/2}$-$^4D^0_{7/2}$	435.55	0.0378	−0.00	0.95*
		$^4P_{5/2}$-$^4D^0_{5/2}$	473.90	0.0338	−0.0014	0.73*
		$^4P_{3/2}$-$^4D^0_{5/2}$	476.57	0.0454	−0.00	0.92*
		$^2P_{3/2}$-$^2P^0_{1/2}$	484.66	0.0426	−0.00	0.89*
		$^2P_{3/2}$-$^2P^0_{3/2}$	461.53	0.0454	−0.00	1.05*
		$^2P_{3/2}$-$^2D^0_{5/2}$	461.91	0.0305	−0.00	0.74*
	$5s'$-$5p'$	$^2D_{3/2}$-$^2F^0_{5/2}$	463.39	0.0391	−0.0018	0.64*
		$^2D_{5/2}$-$^2F^0_{7/2}$	457.72	0.0449	−0.00	1.00*
		$^2D_{5/2}$-$^2P^0_{3/2}$	447.50	0.0512	−0.0017	1.03*
		$^2D_{5/2}$-$^2D^0_{5/2}$	408.83	0.0274	−0.0017	0.79*
	$5p$-$5d$	$^4D^0_{7/2}$-$^4F_{9/2}$	378.31	0.0879		0.83
		$^4D^0_{5/2}$-$^4F_{7/2}$	377.81	0.0848	0.0090	0.79
Kr III	$5s$-$5p$	$^5S^0_2$-$^5P_1$	335.19	0.0308	0.0032	1.09
		$^5S^0_2$-$^5P_2$	332.58	0.0290	0.0031	1.04
		$^5S^0_2$-$^5P_3$	324.57	0.0300	0.0026	1.13
		$^3S^0_1$-$^3P_2$	350.74	0.0328	0.0020	0.99
	$5s'$-$5p'$	$^3D^0_2$-$^3D_2$	343.95	0.0306	0.0021	1.01
		$^3D^0_1$-$^3F_2$	326.85	0.0261		1.12
		$^3D^0_3$-$^3F_4$	326.49	0.0214	0.0015	0.92
		$^3D^0_3$-$^3P_2$	302.44	0.0280	0.0011	0.91
	$5s''$-$5p''$	$^3P^0_2$-$^3D_3$	337.49	0.0480	0.0013	1.44+
		$^3P^0_2$-$^3P_2$	304.69	0.0395	0.00	1.46+
	$4d''$-$5p''$	$^3D^0_2$-$^3D_3$	302.23	0.0455	0.00	

sured to calculated widths are as follows [17]: for doubly charged ions 1.06 ± 0.32 and for triply charged ions 0.91 ± 0.42. The modified semiempirical approach has been tested several times on numerous examples (see, e.g., Ref. [44]).

In Ref. [16] Stark widths of 37 Kr II lines that belong to the $5s$-$5p$ and $5s'$-$5p'$ transitions have been calculated within the frame of the modified semiempirical approach. We present here the results of the Stark shift calculations for 12 Kr II lines that belong to the $5s$-$5p$ and $5s'$-$5p'$ transitions. The needed atomic energy levels have been taken from Ref. [45]. Moreover, we present here the results for Stark widths and shifts obtained within the modified semiempirical approach for two lines that belong to the Kr II $5p^4D$-$5d^4F^o$ multiplet. For these lines $5f$ levels are not in the LS coupling but we took them together within the one electron approximation (see, e.g., Ref. [40]).

The needed atomic energy levels for Kr III have been taken from Ref. [45] as for Kr II. We present here the results of the Stark widths (FWHM) and shifts calculations within the frame of the modified semiempirical approach for 5 Kr III multiplets. In the case of Kr II $5s'^3D^o$-$5p'^3F$ and the $5s'^3D^o$-$5p'^3P$ multiplets $5d'$ energy levels needed for calculations are incomplete and they do not have the LS coupling designations. We have taken $5d'$ levels within the one electron approximation with the energy of 237 970.03 cm^{-1}. The Kr III $5s''^3P^o$-$5p''^3D$ and $5s''^3P^o$-$5p''^3P$ multiplets may be treated only within the simplified modified semiempirical method [20] [Eqs. (7)–(9)], since there is not enough atomic energy level data for the full modified semiempirical calculation. Consequently, the corresponding calculation has been performed.

IV. RESULTS

The results of the measured Stark FWHM (W_m) and shift (d_m) values at $T=17\,000$ K electron temperature and 1.65×10^{23} m^{-3} electron density are shown in Table I. Ratios W_m/W_{th} are also given, where W_{th} is the Stark FWHM calculated within the modified semiempirical approach by us and from Ref. [16].

Stark shift values (d) calculated by using the modified semiempirical method [Eqs. (1)–(6)] [17,27], for the Kr II lines at an electron density of 10^{23} m^{-3}, are presented in Table II, together with the Stark FWHM values (W) calculated for the lines that belong to the $5p$-$5d$ transition.

Stark FWHM (W) and shift (d) values calculated by using the modified semiempirical method [Eqs. (1)–(6)] [17,27], for the Kr III multiplets at 10^{23} m^{-3} electron density, are presented in Table III.

TABLE II. Stark shift values (d in nm) calculated by using the modified semiempirical method [Eqs. (1)–(6)] [17,27] for the Kr II spectral lines, at 10^{23} m^{-3} electron density. The Stark FWHM values (W in nm) are also given for the lines that belong to the $5p$-$5d$ transition.

		$T(10^4$ K)				
λ (nm)		1	2	3	4	5
473.90	d	−0.0101	−0.0074	−0.0063	−0.0058	−0.0056
465.89	d	−0.0111	−0.0082	−0.0070	−0.0064	−0.0062
483.21	d	−0.0111	−0.0082	−0.0070	−0.0064	−0.0062
435.55	d	−0.0083	−0.0061	−0.0051	−0.0047	−0.0044
476.53	d	−0.0089	−0.0066	−0.0056	−0.0051	−0.0049
484.66	d	−0.0125	−0.0092	−0.0078	−0.0071	−0.0069
461.53	d	−0.0104	−0.0076	−0.0064	−0.0058	−0.0055
461.91	d	−0.0099	−0.0073	−0.0061	−0.0055	−0.0052
463.39	d	−0.0056	−0.0036	−0.0029	−0.0029	−0.0028
457.72	d	−0.0091	−0.0066	−0.0056	−0.0051	−0.0049
447.50	d	−0.0103	−0.0071	−0.0057	−0.0051	−0.0049
408.83	d	−0.0065	−0.0047	−0.0039	−0.0035	−0.0033
378.31	W	0.0743	0.0624	0.0586	0.0567	0.0559
	d	0.0057	0.0108	0.0134	0.0149	0.0154
377.81	W	0.0749	0.0638	0.0599	0.0581	0.0572
	d	0.0076	0.0128	0.0155	0.0168	0.0172

Stark FWHM values calculated by using the simplified modified semiempirical method [20] [Eqs. (7)–(9)] for the Kr III multiplets at 10^{23} m^{-3} electron density are presented in Table IV.

V. DISCUSSION

In order to make the comparison easier between measured and calculated Stark width values, the theoretical Stark FWHM dependence on the electron temperature together with the values of the other authors and our experimental results at an electron density of 1×10^{23} m^{-3} are presented graphically in Figs. 6 and 7.

On the basis of the Table I, Table II, and Fig. 6 one can conclude that the comparison between our measured Stark FWHM values of the Kr II lines with the theoretical predictions from Ref. [16] show a satisfactory agreement taking into account that the assumed error bars of the modified semiempirical method are ±50% [17]. Generally, our W_m values lie below the theoretical up to −13% in average (see W_m/W_{th}, values in Table I). It should be pointed out that our new W_m values at 17 000 K electron temperature agree

TABLE III. Stark FWHM (W) and shift (d) values (in nm) calculated by using the modified semiempirical method [Eqs. (1)–(6)] [17,27] for the Kr III spectral lines, at 10^{23} m^{-3} electron density. $\overline{\lambda}$ is the mean wavelength of the multiplet.

Transition		$T(10^4$ K)						
$\overline{\lambda}$ (nm)		1	2	3	4	5	6	7
$5s^5S^o$-$5p^5P$								
329.394	W	0.0212	0.0148	0.0120	0.0104	0.0094	0.0087	0.0083
	d	−0.0033	−0.0024	−0.0020	−0.0016	−0.0015	−0.0014	−0.0013
$5s^3S^o$-$5p^3P$								
352.504	W	0.0261	0.0182	0.0148	0.0129	0.0117	0.0109	0.0103
	d	−0.0044	−0.0032	−0.0025	−0.0022	−0.0020	−0.0018	−0.0017
$5s'^3D^o$-$5p'^5D$								
335.996	W	0.0201	0.0140	0.0114	0.0099	0.0089	0.0083	0.0078
	d	−0.0074	−0.0058	−0.0051	−0.0047	−0.0045	−0.0044	−0.0042
$5s'^3D^o$-$5p'^3F$								
331.936	W	0.0191	0.0133	0.0108	0.0094	0.0085	0.0079	0.0074
	d	−0.0068	−0.0050	−0.0041	−0.0035	−0.0032	−0.0030	−0.0028
$5s'^3D^o$-$5p'^3P$								
292.412	W	0.0194	0.0135	0.0110	0.0095	0.0086	0.0080	0.0075
	d	−0.0057	−0.0044	−0.0039	−0.0038	−0.0037	−0.0036	−0.0037

TABLE IV. Stark FWHM values (in nm) calculated by using the simplified modified semiempirical method [Eqs. (7)–(9)] [20]. For the Kr III spectral lines, at 10^{23} m^{-3} electron density. $\overline{\lambda}$ is the mean wavelength for the multiplet.

Transition	$T(10^4$ K)				
$\overline{\lambda}$ (nm)	1	2	3	4	5
$5s''^3P^o$-$5p''^3D$					
338.647	0.0262	0.0185	0.0151	0.0131	0.0117
$5s''^3P^o$-$5p''^3P$					
311.773	0.0229	0.0162	0.0132	0.0115	0.0102
$4d''^3D^o$-$5p''^3D$					
279.607	0.00849	0.00600	0.00490	0.00425	0.00380

well with those from Ref. [10]. In the case of the Kr III spectral lines (see Table I, Table III, and Fig. 7) one can conclude that our measured (W_m) and calculated (W_{th}) values show very good mutual agreement (W_m/W_{th} ratios in Table I). Absence of the knowledge of the complete set of perturbing energy levels in the case of the $5s''$-$5p''$ and $4d''$-$5p''$ transitions make the calculations of W values possible only within the frame of the simplified semiempirical method [20]. Experimental Stark FWHM values from Ref. [18] agree with our calculated values (and with those from Ref. [23]) within a few percent. Contrarily, the measured W values from Ref. [19] lie above our (and Ref. [23]) results (see the $^5S^o$-^5P multiplet Fig. 7), especially around the electron temperature of 40 000 K, up to factor 2. It should be pointed out that the theoretical W values [24], calculated by using the quasiclassical Gaunt factor method [46,47], show agreement with our calculations. Calculations in Ref. [24] have been performed only for the plasma conditions for experiments in Ref. [19] and the results are given only for electron temperatures higher than 37 000 K. The possible reasons for disagreement between measurements from Ref. [19] and calculations from Ref. [24] are discussed in detail in Ref. [19].

In the case of the Stark shift the situation is much different. Generally, we have measured very small d_m values in the case of the Kr II and Kr III lines (see Table I). Within the accuracy of measurements (0.0008 nm) many of them were equal to zero. Our calculations give higher absolute d values than measured ones. Our calculated and measured Stark shift values, in the case of the Kr II lines (Table I and Table II), have the same sign. For the lines that belong to the $5s$-$5p$ and $5s'$-$5p'$ transitions d is negative and for lines from the $5p$-$5d$ transition d is positive. Our measured d_m values confirm the observed negative sign from Ref. [10] for three Kr II lines (473.90 nm, 465.89 nm, and 435.55 nm). Evident Stark shift, in our measurements, was observed only for the 377.81 nm Kr II line that belongs to the higher lying $5p$-$5d$ transition. In all cases shift values are considerably smaller than width ones. This indicates that particular important contributions have different sign and that their mutual cancellation occurs resulting in shifts much smaller than widths. Since the assumed accuracy of the method is $\pm 50\%$ of the width value, the reliability of these small shifts is much lower. Consequently, d_m/d_{th} ratios are not presented in this paper.

In the case of the Kr III lines our measured and calculated Stark shift values show different signs. Calculations give negative d values while the measured shifts are positive. One can see in Table III that shifts of the considered Kr III spectral lines are almost an order of magnitude smaller than the corresponding widths. Consequently, the mutual cancellations of important contributions are so significant that error bars of such results which might be an upper limit around 50% of the width value are extended to the positive shift values, too. Theoretical reasons for the discrepancies between the signs of measured and calculated Kr III shifts could be the consequence of the complexity of the Kr III many electron atom and its spectrum where the neglected optically forbidden transitions might have an important influence.

VI. CONCLUSION

We have presented in this paper experimental Stark widths and shifts for 14 Kr II and 11 Kr III spectral lines at an electron temperature of 17 000 K and an electron density of 1.65×10^{23} m^{-3}. Our results present the Kr III Stark line shift determination, and our work shows the second experimental result of reliable Kr II Stark line shifts. Moreover, we have calculated 14 Kr II Stark line shifts and 2 Kr II Stark linewidths within the frame of the modified semiempirical method. We have also presented the results of calculations by using the modified semiempirical approach of Stark widths and shifts for 5 Kr III multiplets and such results for 3 Kr III multiplets by using the simplified modified semiempirical method. Our results have been compared with other experimental and theoretical results.

We hope the obtained results will be of help not only for laboratory plasma diagnostics and krypton plasma research and modeling, but also (especially by using space borne telescopes and instruments such as the Goddard high resolution spectrograph on the Hubble space telescope), for the analysis of the trace element spectral lines and abundances. Such data may be of interest as well for the investigation of regularities within homologous noble gas ion sequences, and for examination of possibilities to use such regularities for the interpolation of new data.

One should emphasize here that all reliable experimental data for Kr II spectral lines are within a narrow temperature range between 10 000 and 17 400 K, where Stark widths decrease quicker than for higher temperatures. In order to check the theoretical temperature dependence it is of interest

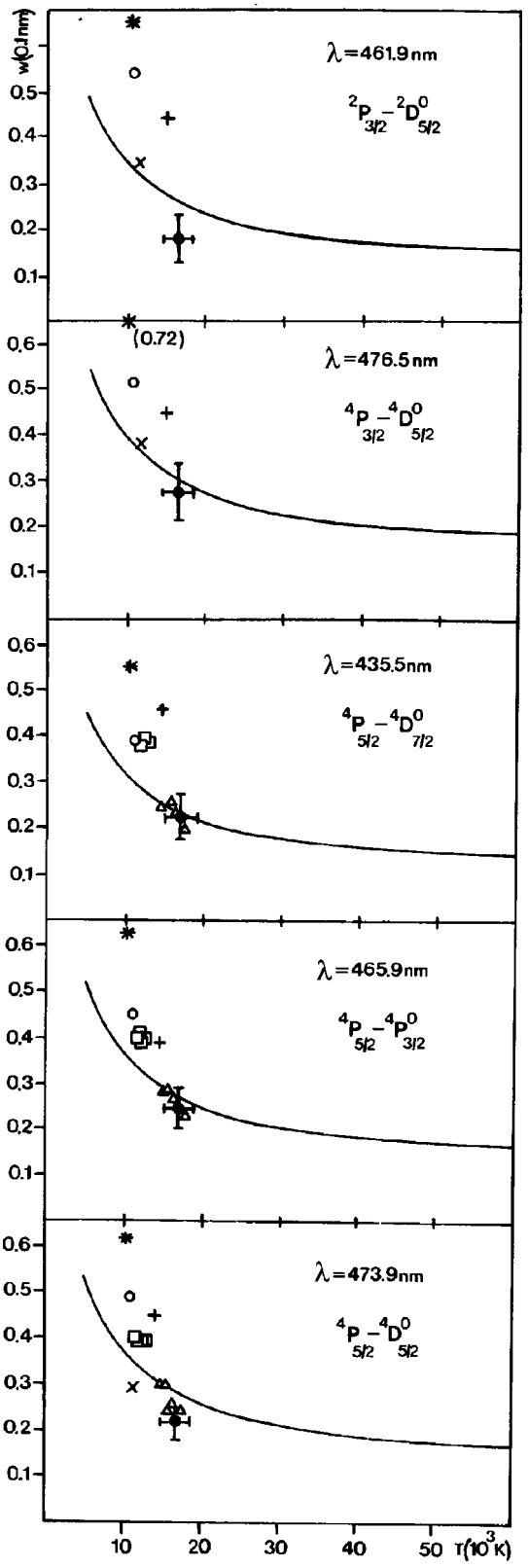

FIG. 6. Stark FWHM (W) dependence on the electron temperature for the most investigated Kr II spectral lines belonging to the $5s$-$5p$ transition at 1×10^{23} m^{-3} electron density. —, calculations by using the modifed semiempirical approach [16]. ● our experimental results and those of other authors: ×, Ref. [7]; *, Ref. [8]; △, Ref. [10]; □, Ref. [11]; ○, Ref. [12] and +, Ref. [13]. The error bars include the uncertainties of the width, electron density, and temperature measurements.

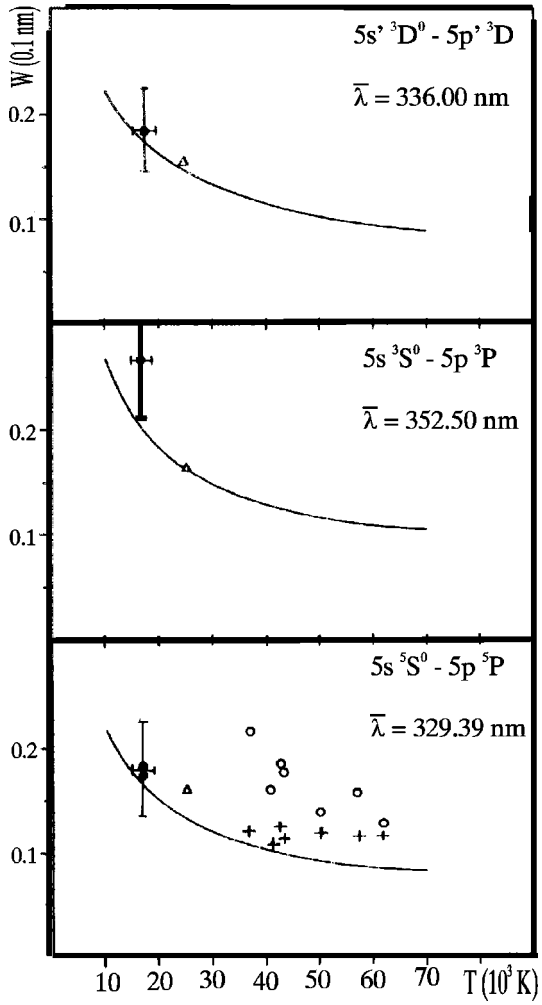

FIG. 7. Stark FWHM (W) dependence on the electron temperature for the most investigated Kr III spectral lines belonging to the $5s$-$5p$ and $5s'$-$5p'$ transition at 1×10^{23} m^{-3} electron density. —, our calculations by using the modifed semiempirical approach. ●, our experimental results and those of other authors: △, Ref. [18] and ○, Ref. [19]. +, calculations by using the quasiclassical Gaunt factor method [24] performed only for the plasma parameters observed in the experiment in Ref. [19]. The error bars include the uncertainties of the width, electron density, and temperature measurements.

to perform reliable experimental determinations on higher temperatures. It is of interest also to perform high precision measurements of Stark widths within the Kr III $5s^5S^o$-$5p^5P$ multiplet, where three experimental results within a wide temperature range exist. For this multiplet it is of interest to perform calculations of higher precision than here, when new atomic energy level data become available.

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[1] J. A. Cardelli, B. D. Sarage, and D. C. Ebbets, Astrophys. J. Lett. **383**, L23 (1991).
[2] J. A. Cardelli and S. Mayer, Astrophys. J. Lett. **477**, L57 (1997).
[3] D. S. Leckrone *et al.*, in *Peculiar Versus Normal Phenomena in A-type and Related Stars*, edited by M. M. Dworetski, F. Castelli, and R. Faraggiana, ASP Conf. Ser. No. 44 (Astronomical Society of the Pacific, San Francisco, 1993), p. 42.
[4] S. L. Mandel'shtam, *Optik und Spektroskopie Aller Wellenlängen* (Akademie Verlag, Berlin, 1962), p. 372.
[5] M. A. Mazing and N. A. Vrublevskaya, Opt. Spectrosc. **13**, 308 (1962).
[6] S. L. Mandel'shtam *et al.*, in *Proceedings of the VI International Conference on the Phenomena in Ionized Gases*, edited by J. Taillet (SERMA, Paris, 1963), Vol. III, p. 331.
[7] T. Brandt, V. Helbig, and K. P. Nick, in *Spectral Line Shapes*, edited by B. Wende (W. de Gruyter, Berlin, 1981), p. 265.
[8] J. Richou *et al.*, in *Proceedings of the 16th International Conference on Phenomena in Ionized Gases, Düsseldorf, Germany*, edited by W. Bötticher, H. Wenk, and E. Schultz-Gulde (Universität Düsseldorf, Düsseldorf, 1983), Vol. 4, p. 632.
[9] T. L. Pittman and N. Konjević, J. Quant. Spectrosc. Radiat. Transf. **35**, 247 (1986).
[10] Y. Vitel and M. Skowronek, J. Phys. B **20**, 6493 (1987).
[11] N. I. Uzelac and N. Konjević, J. Phys. B **22**, 2517 (1989).
[12] A. Lesage, D. Abadie, and M. H. Miller, Phys. Rev. A **40**, 1367 (1989).
[13] G. Bertuccelli and H. D. Di Rocco, Phys. Scr. **44**, 138 (1991).
[14] G. Bertuccelli and H. D. Di Rocco, Phys. Scr. **47**, 747 (1993).
[15] H. R. Griem, Phys. Rev. **165**, 258 (1968).
[16] L. Č. Popćvić and M. S. Dimitrijević, Astron. Astrophys., Suppl. Ser. **127**, 295 (1998).
[17] M. S. Dimitrijević and N. Konjević, J. Quant. Spectrosc. Radiat. Transf. **24**, 451 (1980).
[18] N. Konjević and T. L. Pittman, J. Quant. Spectrosc. Radiat. Transf. **37**, 311 (1987).
[19] I. Ahmad *et al.*, Phys. Rev. E **58**, 6524 (1998).
[20] M. S. Dimitrijević and N. Konjević, Astron. Astrophys. **172**, 345 (1987).
[21] M. S. Dimitrijević, N. Konjević, and V. Kršljanin, in *Spectral Line Shapes*, edited by R. J. Exton (A. Deepak, Hampton, 1987), Vol. 4, p. 65.
[22] M. S. Dimitrijević and M. M. Popović, Astron. Astrophys. **217**, 201 (1989).
[23] R. Konjević and N. Konjević, in *Proceedings of the 17th Symposium on the Physics of Ionized Gases, Belgrade, Serbia, Yugoslavia*, edited by B. Marinković and Z. Petrović (Institute of Physics, Belgrade, 1994), p. 194.
[24] J. D. Hey (private communication in Ref. [19]).
[25] H. D. Di Rocco *et al.*, J. Quant. Spectrosc. Radiat. Transf. **41**, 161 (1989).
[26] M. S. Dimitrijević and N. Konjević, in *Spectral Line Shapes*, edited by B. Wende (W. de Gruyter, Berlin, 1981), p. 211.
[27] M. S. Dimitrijević and V. Kršljanin, Astron. Astrophys. **165**, 269 (1986).
[28] M. S. Dimitrijević, Bull. Obs. Astron. Belgrade **139**, 31 (1988).
[29] M. S. Dimitrijević, Astron. Astrophys., Suppl. Ser. **76**, 53 (1988).
[30] L. Č. Popović and M. S. Dimitrijević, Phys. Scr. **53**, 325 (1996).
[31] L. Č. Popović and M. S. Dimitrijević, Astron. Astrophys., Suppl. Ser. **120**, 373 (1996).
[32] S. Djeniže *et al.*, Phys. Rev. A **44**, 410 (1991).
[33] S. Djeniže, V. Milosavljević, and A. Srećković, J. Quant. Spectrosc. Radiat. Transf. **59**, 71 (1998).
[34] V. Milosavljević and S. Djeniže, Astron. Astrophys., Suppl. Ser. **128**, 197 (1998).
[35] J. T. Davies and J. M. Vaughan, Astrophys. J. **137**, 1302 (1963).
[36] *Handbook of Chemistry and Physics*, 74th ed., edited by D. R. Lide (CRC Press, Boca Raton, FL, 1994).
[37] J. Purić and N. Konjević, Z. Phys. **249**, 440 (1972).
[38] L. Č. Popović, A. Srećković, and S. Djeniže, in *Proceedings of the 11th International Conference on Spectral Line Shapes, A25, Carry le Rouet, France, 1992*, edited by N. Feautrier *et al.* (Université de Provence en Marseille, Marseille, 1992).
[39] R. Rompe and M. Steenbeck, *Ergebnisse der Plasmaphysik und der Gaselektronik* (Akademie Verlag, Berlin, 1967), Band 1.
[40] H. R. Griem, *Spectral Line Broadening by Plasmas* (Academic Press, New York, 1974).
[41] R. A. Striganov and N. S. Sventickij, *Tablicy Spektral'nykh linij* (Atomizdat, Moskva, 1966).
[42] D. E. T. F. Ashby *et al.*, Appl. Phys. B: Photophys. Laser Chem. **36**, 29 (1965).
[43] G. K. Oertel and L. P. Shomo, Astrophys. J., Suppl. Ser. **16**, 175 (1968).
[44] M. S. Dimitrijević, in *Accuracy of Element Abundances from Stellar Atmospheres*, edited by R. Wehrse, Lecture Notes in Physics Vol. 356 (Springer, Berlin, 1990), p. 31.
[45] J. Sugar and A. Musgrove, J. Phys. Chem. Ref. Data **20**, 859 (1991).
[46] J. D. Hey and P. Breger, J. Quant. Spectrosc. Radiat. Transf. **24**, 349 (1980).
[47] J. D. Hey and P. Breger, J. Quant. Spectrosc. Radiat. Transf. **24**, 427 (1980).

Plasma broadening and shifting of spectral lines along the isoelectronic sequence of boron

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Temperature dependence of the Stark widths (N III and F V) and shifts (N III and O IV) of the $3s^2S$-$3p(^1S)^2P^0$ and $3p^2P^0$-$3d(^1S)^2D$ transitions have been studied theoretically using the impact semiclassical method and experimentally observed in the plasma of a low pressure pulsed arc. Plasma electron densities were determined from the width of the He II P_α line while electron temperatures were measured from the relative line intensities. To estimate the influence of different ions on the width and shift of lines, evaluations of the plasma composition data were performed and, in conjunction with our theoretical results, the contribution of ion broadening was estimated. Within the estimated uncertainties experimental Stark widths agree well with the results of our semiclassical electron impact widths in the studied electron temperature range. For the conditions of the present experiment, estimated contribution of the ion broadening has never exceeded five percent of the total width. So within the precision of this experiment it was not possible to detect its presence with certainty. Along the boron isoelectronic sequence the experimental widths and shifts agree with semiclassical electron impact data predictions. In the case of O IV lines the inclusion of *the energy levels with different parent terms* in our semiclassical calculations of the Stark widths and shifts improved the agreement between theory and experiment considerably. Comparisons of the experimental widths with simple theoretical formulas for estimation of plasma broadened linewidths show an agreement within estimated uncertainties. [S1063-651X(96)00307-8]

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I. INTRODUCTION

Knowledge of the Stark width and shift dependence upon the temperature of the charged perturbers in the plasma is of importance for testing of the theory and for the reliable diagnostics of laboratory and astrophysical plasmas. Namely, the dependence of the Stark broadening parameters upon the electron concentration N_e has been tested in a number of experiments (see, e.g., Refs. [1] and [2] and references therein) while the dependence of these parameters upon the electron temperature T_e in a wider temperature range is tested only in a few cases. Usually, experimental results are reported for a single electron temperature and in most of the cases when comparison with another experiment is performed, temperature dependence of the Stark broadening parameter is neglected. This is justified by assuming weak dependence of the width w and shift d upon electron temperature T_e. This assumption may be used only in a small temperature range whose magnitude depends upon the shape of $w(T_e)$ and $d(T_e)$ curves (see, e.g., comparison between experimental and theoretical results in Figs. 1–4). Furthermore, the usual assumption that, in comparison with the electron impact contribution to the width or shift of ionized atom lines, one can neglect the contribution of ions, may not be correct (see, e.g., theoretical results for widths and shifts of O IV lines in Ref. [3] and Table I). This ion contribution may change the Stark broadening parameters and maybe temperature dependence at elevated temperatures. To answer quantitatively the above questions both theoretical and experimental study of the plasma broadened spectral line parameters of multiply ionized atoms are required.

Here, we present the results of experimental and theoretical study of the broadening and shift of the analogous transitions along the isoelectronic sequence of boron. These type of studies, which are very convenient for the testing of theory (similar energy level structure of the emitter with gradual increase of the ionic charge), also enables determination of the Stark width and/or shift dependence upon spectroscopic charge number Z of the emitter. This also is of importance for the estimation of the broadening parameters for the ions with no available data. An early study of the experimental line widths along isoelectronic sequence was performed in [4]. Although the analysis was based only on the few experimental data it was clearly demonstrated that the widths decrease strongly with increasing ionic charge [4]. Since then several publications have reported experimental measurements of the Stark widths and shifts of the analogous transitions along isoelectronic sequences [5–8]. In all the experiments gradual decrease of the Stark widths with an increase of Z is detected. A Z^{-1} scaling of the Stark widths was found for $3s-3p$ transitions in Li-like ions (up to $Z=6$) [5]. In another experiment this study is extended to higher ionized species (up to $Z=8$) and systematic deviations of the line widths from the theoretically expected Z^{-2} scaling is detected [7]. In a recent experiment [8] along boron isoelectronic sequence, $3s$-$3p$ and $3p$-$3d$ transitions, considerable widths deviations are detected for $Z=5$ and $Z=6$ from those predicted by some theoretical calculations. Recent experimental studies of the Stark shifts of the $4s$-$4p$ transition along the P isoelectronic sequence (S II, Cl III, and Ar IV) also showed a gradual decrease of shifts with increase of Z [6] (see also [9]). Furthermore, the change of the sign of the

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TABLE I. This table shows Stark broadening parameters for the $3s^2S$-$3p(^1S)^2P^0$ and the $3p^2P^0$-$3d(^1S)^2D$ multiplets of *N* III, *O* IV, and *F* V for the perturber density of 10^{17} cm^{-3} and temperatures from 10 000 up to 300 000 K. Transition and averaged wavelengths for the multiplet in Å are also given. If one divides the *C* value by the Stark width value, we obtain an estimate for the maximum perturber density (in cm^{-3}) for which the line may be treated as isolated and the tabulated data may be used. Brackets in the table enclose powers of ten.

Perturber density$=1\times10^{17}$ cm^{-3}					
Perturbers are:		Electrons		Protons	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
N III $3s$-$3p$	10 000	0.474	0.116[−02]	0.388[−02]	−0.131[−02]
4100.5 Å	20 000	0.339	−0.682[−02]	0.786[−02]	−0.268[−02]
$C=0.36E+21$	30 000	0.283	−0.743[−02]	0.105[−01]	−0.370[−02]
	50 000	0.231	−0.625[−02]	0.137[−01]	−0.506[−02]
	100 000	0.183	−0.832[−02]	0.168[−01]	−0.697[−02]
	150 000	0.162	−0.742[−02]	0.183[−01]	−0.773[−02]
N III $3p$-$3d$	10 000	0.584	−0.827[−02]	0.101[−01]	−0.409[−02]
4639.9 Å	20 000	0.424	−0.857[−02]	0.229[−01]	−0.916[−02]
$C=0.46E+21$	30 000	0.355	−0.752[−02]	0.325[−01]	−0.132[−01]
	50 000	0.290	−0.688[−02]	0.436[−01]	−0.191[−01]
	100 000	0.229	−0.940[−02]	0.586[−01]	−0.268[−01]
	150 000	0.205	−0.764[−02]	0.641[−01]	−0.304[−01]
Perturbers are:		He II		He III	
N III $3s$-$3p$	10 000	0.597[−02]	−0.129[−02]	0.710[−02]	−0.232[−02]
4100.5 Å	20 000	0.103[−01]	−0.253[−02]	0.149[−01]	−0.512[−02]
$C=0.36E+21$	30 000	0.127[−01]	−0.344[−02]	0.203[−01]	−0.725[−02]
	50 000	0.156[−01]	−0.466[−02]	0.267[−01]	−0.102[−01]
	100 000	0.178[−01]	−0.583[−02]	0.334[−01]	−0.142[−01]
	150 000	0.191[−01]	−0.649[−02]	0.364[−01]	−0.158[−01]
N III $3p$-$3d$	10 000	0.129[−01]	−0.225[−02]	0.163[−01]	−0.406[−02]
4639.9 Å	20 000	0.205[−01]	−0.427[−02]	0.317[−01]	−0.878[−02]
$C=0.46E+21$	30 000	0.252[−01]	−0.570[−02]	0.403[−01]	−0.123[−01]
	50 000	0.288[−01]	−0.737[−02]	0.520[−01]	−0.166[−01]
	100 000	0.327[−01]	−0.929[−02]	0.617[−01]	−0.230[−01]
	150 000	0.350[−01]	−0.104[−01]	0.665[−01]	−0.256[−01]
Perturbers are:		N II		N III	
N III $3s$-$3p$	10 000	0.753[−02]	−0.127[−02]	0.963[−02]	−0.231[−02]
4100.5 Å	20 000	0.118[−01]	−0.240[−02]	0.183[−01]	−0.495[−02]
$C=0.36E+21$	30 000	0.143[−01]	−0.319[−02]	0.231[−01]	−0.692[−02]
	50 000	0.162[−01]	−0.410[−02]	0.296[−01]	−0.927[−02]
	100 000	0.184[−01]	−0.516[−02]	0.348[−01]	−0.127[−01]
	150 000	0.197[−01]	−0.576[−02]	0.374[−01]	−0.142[−01]
N III $3p$-$3d$	100 000	0.160[−01]	−0.220[−02]	0.214[−01]	−0.402[−02]
4639.9 Å	20 000	0.236[−01]	−0.407[−02]	0.372[−01]	−0.838[−02]
$C=0.46E+21$	30 000	0.274[−01]	−0.520[−02]	0.461[−01]	−0.116[−01]
	50 000	0.303[−01]	−0.675[−02]	0.559[−01]	−0.154[−01]
	100 000	0.340[−01]	−0.832[−02]	0.638[−01]	−0.203[−01]
	150 000	0.358[−01]	−0.921[−02]	0.684[−01]	−0.226[−01]
Perturbers are:		N IV		N V	
N III $3s$-$3p$	10 000	0.103[−01]	−0.305[−02]	0.102[−01]	−0.354[−02]
4100.5 Å	20 000	0.222[−01]	−0.732[−02]	0.251[−01]	−0.952[−02]
$C=0.36E+21$	30 000	0.304[−01]	−0.105[−01]	0.359[−01]	−0.141[−01]
	50 000	0.400[−01]	−0.149[−01]	0.485[−01]	−0.210[−01]
	100 000	0.501[−01]	−0.211[−01]	0.656[−01]	−0.301[−01]
	150 000	0.546[−01]	−0.237[−01]	0.718[−01]	−0.345[−01]
N III $3p$-$3d$	10 000	0.236[−01]	−0.534[−02]	0.239[−01]	−0.620[−02]
4639.9 Å	20 000	0.471[−01]	−0.126[−01]	0.538[−01]	−0.164[−01]

TABLE I. (*Continued*.)

Perturber density=1×10^{17} cm^{-3}					
Perturbers are:		Electrons		Protons	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
$C=0.46E+21$	30 000	0.603[−01]	−0.178[−01]	0.731[−01]	−0.238[−01]
	50 000	0.779[−01]	−0.243[−01]	0.965[−01]	−0.343[−01]
	100 000	0.925[−01]	−0.341[−01]	0.120	−0.490[−01]
	150 000	0.997[−01]	−0.383[−01]	0.130	−0.550[−01]
Perturbers are:		N VI		N VII	
N III $3s$-$3p$	10 000	0.976[−02]	−0.385[−02]	0.962[−02]	−0.416[−02]
4100.5 Å	20 000	0.271[−01]	−0.115[−01]	0.284[−01]	−0.133[−01]
$C=0.36E+21$	30 000	0.399[−01]	−0.177[−01]	0.434[−01]	−0.211[−01]
	50 000	0.568[−01]	−0.268[−01]	0.647[−01]	−0.328[−01]
	100 000	0.802[−01]	−0.393[−01]	0.938[−01]	−0.490[−01]
	150 000	0.882[−01]	−0.463[−01]	0.105	−0.580[−01]
N III $3p$-$3d$	10 000	0.231[−01]	−0.675[−02]	0.230[−01]	−0.730[−02]
4639.9 Å	20 000	0.591[−01]	−0.199[−01]	0.631[−01]	−0.230[−01]
$C=0.46E+21$	30 000	0.838[−01]	−0.298[−01]	0.920[−01]	−0.357[−01]
	50 000	0.112	−0.442[−01]	0.126	−0.543[−01]
	100 000	0.147	−0.644[−01]	0.174	−0.803[−01]
	150 000	0.161	−0.737[−01]	0.191	−0.924[−01]
Perturbers are:		Electrons		Protons	
O IV $3s$-$3p$	10 000	0.299	0.188[−01]	0.407[−03]	0.288[−04]
3066.4 Å	20 000	0.198	0.171[−01]	0.107[−02]	0.648[−04]
$C=0.28E+21$	30 000	0.155	0.129[−01]	0.173[−02]	0.100[−03]
	50 000	0.121	0.104[−01]	0.276[−02]	0.170[−03]
	100 000	0.903[−01]	0.803[−02]	0.416[−02]	0.322[−03]
	150 000	0.776[−01]	0.650[−02]	0.501[−02]	0.433[−03]
O IV $3p$-$3d$	10 000	0.278	0.174[−01]	0.910[−03]	0.222[−03]
3410.9 Å	20 000	0.177	0.147[−01]	0.230[−02]	0.499[−03]
$C=0.34E+21$	30 000	0.144	0.110[−01]	0.356[−02]	0.762[−03]
	50 000	0.112	0.871[−02]	0.542[−02]	0.122[−02]
	100 000	0.824[−01]	0.737[−02]	0.782[−02]	0.199[−02]
	150 000	0.701[−01]	0.643[−02]	0.896[−02]	0.240[−02]
Perturbers are:		He III		O III	
O IV $3s$-$3p$	10 000	0.722[−03]	0.475[−04]	0.112[−02]	0.475[−04]
3066.4 Å	20 000	0.199[−02]	0.121[−03]	0.289[−02]	0.121[−03]
$C=0.28E+21$	30 000	0.325[−02]	0.193[−03]	0.442[−02]	0.193[−03]
	50 000	0.528[−02]	0.334[−03]	0.663[−02]	0.331[−03]
	100 000	0.810[−02]	0.643[−03]	0.944[−02]	0.620[−03]
	150 000	0.982[−02]	0.875[−03]	0.107[−01]	0.831[−03]
O IV $3p$-$3d$	10 000	0.162[−02]	0.367[−03]	0.247[−02]	0.367[−03]
3410.9 Å	20 000	0.429[−02]	0.933[−03]	0.602[−02]	0.930[−03]
$C=0.34E+21$	30 000	0.674[−02]	0.147[−02]	0.880[−02]	0.145[−02]
	50 000	0.104[−01]	0.241[−02]	0.124[−01]	0.231[−02]
	100 000	0.152[−01]	0.401[−02]	0.171[−01]	0.364[−02]
	150 000	0.177[−01]	0.487[−02]	0.186[−01]	0.445[−02]
Perturbers are:		O IV		O V	
O IV $3s$-$3p$	10 000	0.104[−02]	0.573[−04]	0.977[−03]	0.645[−04]
3066.4 Å	20 000	0.309[−02]	0.171[−03]	0.317[−02]	0.231[−03]
$C=0.28E+21$	30 000	0.504[−02]	0.279[−03]	0.540[−02]	0.359[−03]
	50 000	0.814[−02]	0.493[−03]	0.924[−02]	0.645[−03]
	100 000	0.124[−01]	0.959[−03]	0.150[−01]	0.130[−02]
	150 000	0.149[−01]	0.130[−02]	0.184[−01]	0.179[−02]
O IV $3p$-$3d$	10 000	0.232[−02]	0.442[−03]	0.219[−02]	0.498[−03]
3410.9 Å	20 000	0.664[−02]	0.131[−02]	0.693[−02]	0.164[−02]

TABLE I. *(Continued.)*

Perturber density $=1\times10^{17}$ cm^{-3}					
Perturbers are:		Electrons		Protons	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
$C=0.34E+21$	30 000	0.104[−01]	0.212[−02]	0.114[−01]	0.274[−02]
	50 000	0.160[−01]	0.355[−02]	0.185[−01]	0.471[−02]
	100 000	0.232[−01]	0.593[−02]	0.281[−01]	0.830[−02]
	150 000	0.268[−01]	0.724[−02]	0.340[−01]	0.101[−01]
Perturbers are:		O VI		C III	
O IV $3s$-$3p$	10 000	0.915[−03]	0.675[−04]	0.104[−02]	0.475[−04]
3066.4 Å	20 000	0.318[−02]	0.249[−03]	0.272[−02]	0.121[−03]
$C=0.28E+21$	30 000	0.561[−02]	0.434[−03]	0.421[−02]	0.193[−03]
	50 000	0.100[−01]	0.793[−03]	0.641[−02]	0.332[−03]
	100 000	0.174[−01]	0.162[−02]	0.923[−02]	0.625[−03]
	150 000	0.214[−01]	0.229[−02]	0.106[−01]	0.839[−03]
O IV $3p$-$3d$	10 000	0.206[−02]	0.521[−03]	0.231[−02]	0.367[−03]
3410.9 Å	20 000	0.703[−02]	0.192[−02]	0.571[−02]	0.931[−03]
$C=0.34E+21$	30 000	0.120[−01]	0.333[−02]	0.844[−02]	0.145[−02]
	50 000	0.204[−01]	0.586[−02]	0.121[−01]	0.233[−02]
	100 000	0.327[−01]	0.105[−01]	0.169[−01]	0.371[−02]
	150 000	0.403[−01]	0.133[−01]	0.185[−01]	0.454[−02]
Perturbers are:		C IV		C V	
O IV $3s$-$3p$	10 000	0.963[−03]	0.573[−04]	0.906[−03]	0.645[−04]
3066.4 Å	20 000	0.290[−02]	0.171[−03]	0.296[−02]	0.213[−03]
$C=0.28E+21$	30 000	0.477[−02]	0.279[−03]	0.508[−02]	0.359[−03]
	50 000	0.781[−02]	0.494[−03]	0.883[−02]	0.645[−03]
	100 000	0.120[−01]	0.963[−03]	0.146[−01]	0.130[−02]
	150 000	0.146[−01]	0.132[−02]	0.180[−01]	0.181[−02]
O IV 3p-3d	10 000	0.215[−02]	0.442[−03]	0.204[−02]	0.498[−03]
3410.9 Å	20 000	0.625[−02]	0.131[−02]	0.649[−02]	0.164[−02]
$C=0.34E+21$	30 000	0.990[−02]	0.212[−02]	0.108[−01]	0.275[−02]
	50 000	0.154[−01]	0.357[−02]	0.177[−01]	0.473[−02]
	100 000	0.227[−01]	0.602[−02]	0.274[−01]	0.839[−02]
	150 000	0.265[−01]	0.733[−02]	0.334[−01]	0.103[−01]
Perturbers are:		Electrons		Protons	
F V $3s$-$3p$	10 000	0.124	0.151[−01]	0.685[−04]	−0.756[−04]
2455.0 Å	30 000	0.658[−01]	−0.536[−05]	0.353[−03]	−0.277[−03]
$C=0.22E+21$	50 000	0.514[−01]	−0.840[−03]	0.684[−03]	−0.464[−03]
	100 000	0.375[−01]	−0.863[−03]	0.135[−02]	−0.817[−03]
	200 000	0.283[−01]	−0.102[−02]	0.207[−02]	−0.120[−02]
	300 000	0.243[−01]	−0.106[−02]	0.250[−02]	−0.147[−02]
F V $3p$-$3d$	10 000	0.129	−0.773[−02]	0.145[−03]	−0.830[−04]
2701.6 Å	30 000	0.758[−01]	−0.140[−02]	0.716[−03]	−0.304[−03]
$C=0.27E+21$	50 000	0.594[−01]	−0.914[−03]	0.131[−02]	−0.511[−03]
	100 000	0.433[−01]	−0.686[−03]	0.237[−02]	−0.908[−03]
	200 000	0.324[−01]	−0.101[−02]	0.342[−02]	−0.135[−02]
	300 000	0.279[−01]	−0.859[−03]	0.390[−02]	−0.165[−02]
Perturbers are:		He II		He III	
F V $3s$-$3p$	10 000	0.127[−03]	−0.756[−04]	0.118[−03]	−0.115[−03]
2455.0 Å	30 000	0.596[−03]	−0.275[−03]	0.661[−03]	−0.524[−03]
$C=0.22E+21$	50 000	0.102[−02]	−0.450[−03]	0.130[−02]	−0.905[−03]
	100 000	0.169[−02]	−0.759[−03]	0.262[−02]	−0.163[−02]
	200 000	0.236[−02]	−0.107[−02]	0.406[−02]	−0.244[−02]
	300 000	0.258[−02]	−0.125[−02]	0.495[−02]	−0.299[−02]
F V $3p$-$3d$	10 000	0.268[−03]	−0.830[−04]	0.250[−03]	−0.126[−03]

TABLE I. (*Continued*.)

Perturber density=1×10^{17} cm^{-3}					
Perturbers are:		Electrons		Protons	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
2701.6 Å	30 000	0.117[-02]	−0.302[−03]	0.134[−02]	−0.576[−03]
$C=0.27E+21$	50 000	0.189[−02]	−0.497[−03]	0.250[−02]	−0.997[−03]
	100 000	0.290[−02]	−0.845[−03]	0.462[−02]	−0.182[−02]
	200 000	0.381[−02]	−0.120[−02]	0.672[−02]	−0.274[−02]
	300 000	0.413[−02]	−0.141[−02]	0.776[−02]	−0.334[−02]
Perturbers are:		F III		F IV	
F V $3s$-$3p$	10 000	0.199[−03]	−0.115[−03]	0.179[−03]	−0.135[−03]
2455.0 Å	30 000	0.104[−02]	−0.521[−03]	0.110[−02]	−0.749[−03]
$C=0.22E+21$	50 000	0.186[−02]	−0.883[−03]	0.213[−02]	−0.131[−02]
	100 000	0.321[−02]	−0.154[−02]	0.416[−02]	−0.240[−02]
	200 000	0.459[−02]	−0.221[−02]	0.630[−02]	−0.357[−02]
	300 000	0.510[−02]	−0.262[−02]	0.753[−02]	−0.435[−02]
F V $3p$-$3d$	10 000	0.420[−03]	−0.126[−03]	0.380[−03]	−0.148[−03]
2701.6 å	30 000	0.206[−02]	−0.573[−03]	0.223[−02]	−0.823[−03]
$C=0.27E+21$	50 000	0.346[−02]	−0.976[−03]	0.406[−02]	−0.145[−02]
	100 000	0.550[−02]	−0.171[−02]	0.725[−02]	−0.267[−02]
	200 000	0.748[−02]	−0.248[−02]	0.104[−01]	−0.400[−02]
	300 000	0.811[−02]	−0.296[−02]	0.117[−01]	−0.489[−02]
Perturbers are:		F V		F VI	
F V $3s$-$3p$	10 000	0.163[−03]	−0.141[−03]	0.137[−03]	−0.131[−03]
2455.0 Å	30 000	0.113[−02]	−0.956[−03]	0.113[−02]	−0.114[−02]
$C=0.22E+21$	50 000	0.229[−02]	−0.173[−02]	0.238[−02]	−0.212[−02]
	100 000	0.481[−02]	−0.327[−02]	0.536[−02]	−0.417[−02]
	200 000	0.771[−02]	−0.507[−02]	0.911[−02]	−0.662[−02]
	300 000	0.972[−02]	−0.617[−02]	0.116[−01]	−0.811[−02]
F V $3p$-$3d$	10 000	0.345[−03]	−0.155[−03]	0.290[−03]	−0.144[−03]
2701.6 Å	30 000	0.230[−02]	−0.105[−02]	0.233[−02]	−0.125[−02]
$C=0.27E+21$	50 000	0.442[−02]	−0.191[−02]	0.466[−02]	−0.233[−02]
	100 000	0.856[−02]	−0.364[−02]	0.954[−02]	−0.463[−02]
	200 000	0.128[−01]	−0.569[−02]	0.149[−01]	−0.745[−02]
	300 000	0.152[−01]	−0.692[−02]	0.184[−01]	−0.911[−02]
Perturbers are:		F VII		F VIII	
F V $3s$-$3p$	100 000	0.100[−03]	−0.109[−03]	0.922[−04]	−0.106[−03]
2455.0 Å	30 000	0.113[−02]	−0.131[−02]	0.113[−02]	−0.145[−02]
$C=0.22E+21$	50 000	0.245[−02]	−0.250[−02]	0.250[−02]	−0.287[−02]
	100 000	0.585[−02]	−0.507[−02]	0.626[−02]	−0.590[−02]
	200 000	0.105[−01]	−0.827[−02]	0.119[−01]	−0.993[−02]
	300 000	0.135[−01]	−0.101[−01]	0.153[−01]	−0.121[−01]
F V $3p$-$3d$	10 000	0.212[−03]	−0.120[−03]	0.195[−03]	−0.117[−03]
2701.6 Å	30 000	0.234[−02]	−0.143[−02]	0.233[−02]	−0.159[−02]
$C=0.27E+21$	50 000	0.482[−02]	−0.276[−02]	0.494[−02]	−0.315[−02]
	100 000	0.104[−01]	−0.561[−02]	0.111[−01]	−0.653[−02]
	200 000	0.169[−01]	−0.926[−02]	0.190[−01]	−0.111[−01]
	300 000	0.212[−01]	−0.113[−01]	0.239[−01]	−0.135[−01]
Perturbers are:		S III		S IV	
F V $3s$-$3p$	10 000	0.222[−03]	−0.115[−03]	0.201[−03]	−0.135[−03]
2455.0 Å	30 000	0.114[−02]	−0.520[−03]	0.122[−02]	−0.748[−03]
$C=0.22E+21$	50 000	0.199[−02]	−0.878[−03]	0.230[−02]	−0.131[−02]
	100 000	0.332[−02]	−0.152[−02]	0.437[−02]	−0.237[−02]
	200 000	0.468[−02]	−0.216[−02]	0.646[−02]	−0.350[−02]
	300 000	0.514[−02]	−0.254[−02]	0.757[−02]	−0.423[−02]

TABLE I. (*Continued*.)

Perturber density=1×10^{17} cm^{-3}					
Perturbers are:		Electrons		Protons	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
F V $3p$-$3d$	10 000	0.469[−03]	−0.126[−03]	0.425[−03]	−0.148[−03]
2701.6 Å	30 000	0.225[−02]	−0.572[−03]	0.245[−02]	−0.823[−03]
$C=0.27E+21$	50 000	0.368[−02]	−0.970[−03]	0.437[−02]	−0.144[−02]
	100 000	0.570[−02]	−0.169[−02]	0.754[−02]	−0.263[−02]
	200 000	0.758[−02]	−0.242[−02]	0.107[−01]	−0.391[−02]
	300 000	0.822[−02]	−0.286[−02]	0.118[−01]	−0.476[−02]
Perturbers are:		S V		S VI	
F V $3s$-$3p$	10 000	0.182[−03]	−0.141[−03]	0.153[−03]	−0.131[−03]
2455.0 Å	30 000	0.125[−02]	−0.956[−03]	0.126[−02]	−0.114[−02]
$C=022E+21$	50 000	0.249[−02]	−0.172[−02]	0.261[−02]	−0.212[−02]
	100 000	0.510[−02]	−0.322[−02]	0.568[−02]	−0.411[−02]
	200 000	0.799[−02]	−0.493[−02]	0.936[−02]	−0.645[−02]
	300 000	0.985[−02]	−0.603[−02]	0.119[−01]	−0.789[−02]
F V $3p$-$3d$	10 000	0.386[−03]	−0.155[−03]	0.325[−03]	−0.144[−03]
2701.6 Å	30 000	0.254[−02]	−0.105[−02]	0.259[−02]	−0.125[−02]
$C=0.27E+21$	50 000	0.480[−02]	−0.190[−02]	0.508[−02]	−0.233[−02]
	100 000	0.903[−02]	−0.359[−02]	0.101[−01]	−0.457[−02]
	200 000	0.133[−01]	−0.554[−02]	0.155[−01]	−0.725[−02]
	300 000	0.154[−01]	−0.675[−02]	0.188[−01]	−0.888[−02]
Perturbers are:		S VII		S VIII	
F V $3s$-$3p$	10 000	0.112[−03]	−0.109[−03]	0.103[−03]	−0.106[−03]
2455.0 Å	30 000	0.126[−02]	−0.131[−02]	0.126[−02]	−0.145[−02]
$C=0.22E+21$	50 000	0.270[−02]	−0.250[−02]	0.276[−02]	−0.286[−02]
	100 000	0.621[−02]	−0.501[−02]	0.667[−02]	−0.585[−02]
	200 000	0.108[−01]	−0.807[−02]	0.122[−01]	−0.972[−02]
	300 000	0.138[−01]	−0.989[−02]	0.156[−01]	−0.119[−01]
F V $3p$-$3d$	10 000	0.238[−03]	−0.120[−03]	0.219[−03]	−0.117[−03]
2701.6 Å	30 000	0.260[−02]	−0.143[−02]	0.260[−02]	−0.159[−02]
$C=0.27E+21$	50 000	0.529[−02]	−0.275[−02]	0.543[−02]	−0.315[−02]
	100 000	0.110[−01]	−0.556[−02]	0.118[−01]	−0.648[−02]
	200 000	0.175[−01]	−0.906[−02]	0.196[−01]	−0.109[−01]
	300 000	0.217[−01]	−0.111[−01]	0.245[−01]	−0.133[−01]

shift along the S sequence ($4s'$-$4p'$ transition Cl II and Ar III) is detected [6]. This shift behavior was explained by the irregular change of the perturbing energy levels distribution around the upper level of the transition along the sequence. In this case simple theory [10] predicted the sign of the shift [6].

A general problem in the experimental studies along isoelectronic sequences is scaling of the data to the same temperature. Namely, experimental results for low ionization stages obtained at lower temperatures have to be compared with results for higher ionization stages measured at much higher temperatures. To perform a sensible comparison of the data along the sequence it is necessary to scale all experimental results to the same temperature. In cases when width or shift dependence upon temperature is not known this procedure may introduce an uncertainty in the comparison. Therefore the emphasis of this work is concentrated for several reasons on the temperature dependence of the Stark broadening parameters. Both experimental and theoretical investigations will be an extension of our study of $3s$-$3p$ and $3p$-$3d$ transitions of O IV [3] to N III and F V and it will be related to the recent study of the same transitions in another experiment performed with a different plasma source, diagnosed with another diagnostic technique [8].

II. THEORY

By using the semiclassical-perturbation formalism [11,12] we have calculated Stark broadening parameters for N III, O IV, and F V $3s^2S$-$3p(^1S)^2P^0$ and $3p^2P^0$-$3d(^1S)^2D$ multiplets. Besides electron impact line widths and shifts, Stark broadening parameters due to all relevant ion perturbers have been calculated as well. The corresponding data when perturbers are N II–N VI are calculated for N III multiplets and O III–O VI for O IV multiplets. Since in the case of the considered O IV transitions, several transitions between atomic energy levels with different parent terms may influence significantly, particularly on the shift values, the calculations with the inclusions of $2s2p(^3P^0)3p^2S$, $2s2p(^1P^0)3p^2S$, $2s2p(^3P^0)3p^2P$, $2s2p(^1P^0)3p^2P$, $2s2p(^3P^0)3p^2D$, $2s2p(^1P^0)3p^2D$, and $2p^2(^1D)3s^2D$ perturbing $2s^2(^1S)3p^2P^0$; transitions $2s2p(^3P^0)3s^2P^0$ and

$2s2p(^1P^0)3d^2P^0$ perturbing $2s^2(^1S)3d^2D$ and $2s2p(^1P^0)3s^2P^0$ perturbing $2s^2(^1S)3s^2S$ transitions have been performed here.

In order to assure the consistency of the data set, all oscillator strengths (and not only those for added transitions with different parent terms) have been taken from the TOP base (the complete package of the opacity project (OP) data with the database management system is usually referred to as TOP base) [13,14]. In order to compare experimental results for O IV lines from another experiment [8] performed in CO_2, the contribution of the C III–C V perturbers to the width of O IV multiplets are calculated as well. If one compares Stark widths and shifts for O IV calculated with the Coulomb oscillator strengths and oscillator strengths from the TOP base, one obtains for the $3s$-$3p$ multiplet at an electron density of 10^{17} cm^{-3} and $T=100\,000$ K, $w=0.0741$ Å and $d=-0.002\,40$ Å with Coulomb oscillator strengths and $w=0.0741$ Å and $d=-0.002\,33$ Å with TOP base oscillator strengths. For the $3p$-$3d$ multiplet one obtains $w=0.0784$ Å and $d=-0.002\,22$ Å and $w=0.0716$ Å and $d=-0.000\,955$ Å, respectively. If one adds the above mentioned transitions with different parent terms $w=0.0903$ Å and $d=+0.008\,03$ Å for the $3s$-$3p$ multiplet and $w=0.0824$ Å and $d=+0.007\,37$ Å for the $3p$-$3d$ multiplet. One can see that the influence of the perturbing levels with different parent terms is more significant than the differences between Coulomb and TOP base oscillator strengths. Since the measurements of F V Stark widths were performed in the mixture of SF_6 with He and in [8] SF_6 with hydrogen, Stark widths and shifts when S III–S VII and F III–F VII are perturbers have been calculated also. A summary of the formalism used for these calculations is given in [15].

Energy levels needed for calculations have been taken from [16]. For all radiators except O IV oscillator strengths were calculated by using the method by Bates and Damgaard [17,18]. We have been using the method described in Ref. [19] for higher energy levels. Our results are shown in Table I for a perturbers density of 10^{17} cm^{-3} and temperatures $T=10\,000$–$150\,000$ K for N III, O IV, and F V. We also specify a parameter C [15] which, when divided by the corresponding electron-impact full width at half maximum (FWHM), gives an estimate for the maximum perturbers density for which the line may be treated as isolated. For each value given in Table I the collision volume V multiplied by the perturbers density N is much less than one and therefore the binary approximation is valid. Since V is proportional to the cube of the typical emitter-perturber distance $\rho_{\rm typ}^3$, and $\rho_{\rm typ}^3$ may be estimated from the width, representing the width as proportional to the perturber density N, the average velocity v, and the average total cross section $\sigma_{\rm typ}$ ($\sigma_{\rm typ}=\pi\rho_{\rm typ}^2$), this is a good estimate of the validity of the impact approximation [15]. When the impact approximation is not valid, the ion-broadening contribution may be estimated by using quasistatic estimations [1,20]. In the significant parameter region in between where neither of these two approximations is valid, a unified type theory should be used. For example, in Ref. [21] simple analytical forms for such cases are given. The accuracy of the results obtained decreases when broadening by ion interaction becomes important. At high densities, the results are no longer linear with density due to the Debye screening. This effect is more important for the shifts than for the widths.

III. EXPERIMENT

The experimental apparatus and procedure are described in [3] so only minimum details will be given here. The light source was a low pressure pulsed arc with a quartz discharge tube 10 mm internal diameter. The distance between aluminum electrodes was 161 mm, and 3 mm diameter holes were located at the center of both electrodes to allow end-on plasma observations. A 30 mm diaphragm placed in front of the focusing mirror ensures that light comes from the narrow cone about the arc axis. All plasma observations are performed with 1 m monochromator with inverse linear dispersion 8.33 Å/mm in the first order of the diffraction grating, equipped with the photomultiplier tube and a stepping motor. The discharge was driven by a 15.2 μF low inductance capacitor charged to 3 kV (nitrogen experiment: peak current $I_p=14.8$ kA, critically damped current pulse duration $\tau=7.7$ μs, pressure of the gas mixture $p=3$ torr, continuous flow of the gas mixture, composition: 2.0% of N_2 in He) and to 4.8 kV (fluorine experiment: $I_p=20.5$ kA, $\tau=8.3$ μs, $p=0.8$ torr, continuous flow of the mixture 1.4% of SF_6 in He) and fired by an ignitron. The stepping motor and oscilloscope are controlled by a personal computer, which was also used for data acquisition. Recordings of spectral line shapes were performed shot by shot. At each wavelength position of the monochromator time evolution and decay of the plasma radiation were recorded by the digital oscilloscope. Four such signals were averaged at each wavelength. To construct the line profiles these averaged signals at different wavelengths and at various times of the plasma existence were used to construct line profiles. Spectral line profiles were recorded with instrumental half widths of 0.168 Å and 0.192 Å in nitrogen and fluorine experiments, respectively. To determine the Stark half width from the measured profile, a standard deconvolution procedure for the Lorentzian (Stark) and Gaussian (instrumental+Doppler) profiles [22] was used.

For the line-shift measurements we used line profiles at the different times of the plasma existence [23]. For this technique of shift measurements it is necessary to know plasma parameters (electron density and temperature) at the times when both profiles are recorded.

For the electron-density measurements we used, as in our oxygen experiment [3], the width of the He II P_α 4686 Å line [24]. Our main concern in the electron-density measurements was a possible presence of self-absorption of the P_α line which may distort the line profile. This would result in erroneous reading of the line width which would introduce an error in the electron-density measurements. In order to determine the optical thickness of the investigated lines we have introduced in the discharge an additional movable electrode [3,25]. By placing the movable electrode (10 mm thick) at two different positions and by recording the line profiles from two plasma lengths, it is possible to determine $\kappa_\lambda l$, where κ_λ is the spectral line absorption coefficient and l is the plasma length along the direction of observation. Since the measured $\kappa_\lambda l$ for the He II P_α line was always smaller than one it was possible to recover the line profile [26]. Great care was also taken to find the optimum conditions with the least self-absorption of the investigated lines. This was

TABLE II. Transition probabilities for the spectral lines used for the electron temperature measurements.

Ion	Wavelength (Å)	Transition	A (10^8 s^{-1})	Ref.
N III	4097.33	$3s^2S_{1/2}$-$3p^2P^0_{3/2}$	0.853	[28]
	4103.43	$3s^2S_{1/2}$-$3p^2P^0_{1/2}$	0.844	[28]
	4634.16	$3p^2P^0_{1/2}$-$3d^2D_{3/2}$	0.721	[28]
	4640.64	$3p^2P^0_{3/2}$-$3d^2D_{5/2}$	0.864	[28]
N IV	4057.80	$3p^1P^0_1$-$3d^1D_2$	0.662	[44]
F IV	2451.58	$3p^3D_2$-$3d^3F^0_3$	2.39	[45]
	2820.74	$3s^3P^0_1$-$3p^3D_2$	1.11	[45]
	2823.80	$3s^3P^0_0$-$3p^3D_1$	0.823	[45]
	2826.13	$3s^3P^0_2$-$3p^3D_3$	1.48	[45]
F V	2450.66	$3s^2S_{1/2}$-$3p^2P^0_{3/2}$	1.74	[28]
	2703.96	$3p^2P^0_{3/2}$-$3d^2D_{5/2}$	1.30	[28]

achieved by careful examination of the N III and F V line shapes as a function of the experimental conditions (total gas pressure, gas mixture composition, and condenser bank energy), and by checking the optical depth of the strongest lines by measuring the intensity ratios within multiplets and comparing them with theoretical predictions based on the L-S coupling (see, e.g., Ref. [27]). The ratios of N_2 and SF_6 in the mixture with helium were determined after a number of experiments in which these gases were diluted gradually until line intensities within investigated multiplets agree within 3% with the values derived from transition probabilities [28].

The axial electron temperatures were determined in the nitrogen-helium mixture from (a) the Boltzmann plot of the relative intensities of N III 4097.33, 4103.43, 4634.16, and 4640.64 Å lines and (b) from relative intensities of two lines 4097.33 and 4057.80 Å belonging to two successive ionization stages of nitrogen, N III and N IV, respectively. In the SF_6-helium mixture electron temperatures are determined (a) from a Boltzmann plot of F IV 2451.58, 2820.74, 2823.80, and 2826.13 Å lines and (b) from the relative intensities of the 2451.58, and 2450.66 Å lines belonging to F IV and F V, respectively. Transition probabilities and data sources for these measurements are given in Table II. The spectral response of the photomultiplier-monochromator system was calibrated against a standard coiled-coil quartz iodine lamp.

TABLE III. Experimental electron densities N_e and temperatures T_I and T_B derived from the relative intensities of the lines of successive ionization stages and from the Boltzmann plots of relative line intensities, respectively. Estimated uncertainties are given also.

Ion	t (μs)	N_e (10^{17} cm^{-3})	T_I (K)	R_B (K)
N III	1.5	1.38±15%	55 300	33 000±10%
	2.0	1.71±14%	59 300	36 100±10%
	2.5	2.52±14%	64 800	44 300±10%
	3.0	2.64±14%	70 500	39 600±10%
	6.0	1.11±15%	54 700	37 900±10%
F V	1.0	2.54±15%	89 900	71 200±12%

IV. RESULTS AND DISCUSSION

The experimental results for the electron densities and temperatures at the axis of the discharge at various times of the current pulse through the discharge tube are given in Table III together with estimated uncertainties. Since we have been studying Stark broadening parameters dependence upon temperature T_e we made an attempt to determine T_e as accurately as possible using two independent methods. Unfortunately, to apply a very sensitive method of the relative line intensities from two successive ionization stages one requires much higher plasma electron densities [see the local thermodynamic equilibrium (LTE) condition in Eq. (6.55) of Ref. [29]] than were available in our experiment, see Table III. Nevertheless both sets of electron temperatures are given in Table III. For obvious reasons only electron temperatures derived from the Boltzmann plots of the N III and F IV relative line intensities are given with estimated errors, see Table III, and they are used in further discussions. Here it should be pointed out that the possible presence of plasma inhomogeneity may influence electron temperature measurements considerably, namely, if the plasma is inhomogeneous the different ions will radiate primarily from different temperature regions and this can yield large errors in the temperature determination. In order to test the homogeneity of the observed plasma cone electron temperatures were determined with the different apertures of the optical system; observations were performed with a 3 cm and a 10 cm diaphragm in front the focusing mirror. This corresponds to the change of the diameter of the base of the observed plasma cone from 3.6 mm to 7.9 mm (internal diameter of the discharge tube is 10 mm). Within an experimental scatter of the temperature measurements in the time of interest no difference in T_e is detected.

The experimental results for the Stark widths (FWHM), of N III and F V lines are given in Table IV together with the estimated errors. Table IV also contains spectroscopic data for the investigated lines and comparisons with the semiclassical theoretical results obtained by using the semiclassical perturbation approach [11,12] with the code used in a number of papers by M. S. Dimitrijević and S. Sahal-Bréchot (see, e.g., Refs. [30–34]) denoted here as W_{DSB} (electron +ion impact widths, see Table I). Comparison is also made in the same table with theoretical results calculated after

TABLE IV. Experimental Stark widths w_m (FWHM) of investigated N III and F V lines from the $3s^2S$-$3p(^1S)^2P^0$ and the $3p^2P^0$-$3d(^1S)^2D$ multiplets are compared in this table with theoretical widths: semiclassical electron impact, w^e_{DSB}, electron+ion impact, w^{ei}_{DSB}, simplified semiclassical approach after Griem [Eq. (526) of Ref. [1]], w_G, and modified semiempirical formula after Dimitrijević and Konjević [35]. Theoretical widths w^e_{DSB} and w^{ei}_{DSB} are calculated from the data in Table I.

Ion	Transition	λ (Å)	N_e (10^{17} cm^{-3})	T_e (K)	w_m (Å)	w_m/W^e_{DSB}	w_m/w^{ei}_{DSB}	$w_m/_G$	w_m/w_{DK}
N III	$3s^2S_{1/2}$-$3p^2P^0{}_{3/2}$	4097.33	1.38±15%	33 000	0.34_5±7%	0.92	0.89	1.02	1.36
			1.71±14%	36 100	0.42_3±7%	0.93	0.91	1.05	1.40
			2.52±14%	44 300	0.55_7±6%	0.91	0.88	1.01	1.39
			2.64±14%	39 600	0.58_7±6%	0.88	0.85	0.98	1.33
			1.11±15%	37 900	0.26_2±6%	0.92	0.88	1.02	1.38
	$3s^2S_{1/2}$-$3p^2P^0{}_{1/2}$	4103.43	1.38±15%	33 000	0.34_3±7%	0.92	0.89	1.02	1.36
			1.71±14%	36 100	0.40_0±7%	0.90	0.87	1.00	1.32
			2.52±14%	44 300	0.55_7±5%	0.91	0.88	1.01	1.39
			2.64±14%	39 600	0.58_7±5%	0.88	0.85	0.98	1.33
			1.11±15%	37 900	0.27_9±8%	0.98	0.94	1.09	1.46
	$3p^2P^0{}_{1/2}$-$3d^2D_{3/2}$	4634.16	1.38±15%	33 000	0.47_0±7%	1.00	0.97	1.02	1.49
			1.71±14%	36 100	0.55_3±7%	0.97	0.94	0.99	1.46
			2.52±14%	44 300	0.76_6±6%	1.00	0.96	1.00	1.51
			2.64±14%	39 600	0.79_5±6%	0.95	0.91	0.96	1.44
			1.11±15%	37 900	0.35_2±8%	0.98	0.94	0.99	1.49
	$3p^2P^0{}_{3/2}$-$3d^2D_{5/2}$	4640.64	1.38±15%	33 000	0.443±7%	0.95	0.91	0.96	1.40
			1.71±14%	36 100	0.52_6±7%	0.94	0.90	0.95	1.41
			2.52±14%	44 300	0.74_6±5%	0.97	0.93	0.96	1.47
			2.64±14%	39 600	0.79_5±5%	0.95	0.91	0.96	1.44
			1.11±15%	37 900	0.35_2±8%	0.98	0.94	0.99	1.49
F V	$3s^2S_{1/2}$-$3p^2P^0{}_{3/2}$	2450.66	2.54±14%	71 200	0.11_6±5%	1.04	0.99	1.49	1.76
	$3p^2P^0{}_{3/2}$-$3d^2D_{5/2}$	2703.96	2.54±14%	71 200	0.13_4±5%	1.04	0.99	1.54	2.02

Griem [Eq. (526) in Ref. [1]] W_G, and results obtained after Dimitrijević and Konjević [35] W_{DK}. In order to evaluate the contribution of ion impact widths it was necessary to compute plasma composition data for the conditions of the width measurements (electron density and temperature). Here, to simplify calculations we assumed the LTE for our plasma conditions ($N_e > 10^{17}$ cm^{-3}) and the plasma composition data was evaluated as described for the LTE conditions in [29]. The assumption of the LTE conditions is obviously very crude (see two sets of results for electron temperatures in Table III). Its use may be justified by the fact that (a) the expected contribution of all ions in the plasma to the line width or shift may not exceed 10% of the electron width, see Table I, and (b) the difference in the contribution of various ions to the linewidths and shifts is so small (see Table I) that small differences in the computed concentrations of various ions in our experimental conditions is of marginal importance for the final result. For the computation of plasma composition data the energy levels necessary for evaluation of the partition functions are taken from [16,43]. Knowing the concentration of each type of the ion in the plasma, it is trivial (by the help of Table I) to estimate the ion contribution to the plasma broadened linewidth. This estimation is simplified by the fact that electron and ion impact widths have a Lorentzian shape, so the width of the profile represents the sum of the electron and all ion profiles.

The experimental shifts are given in Table V in the form $\Delta d_m/\Delta N_e$, so the estimated error also includes the uncertainty in the electron-density measurements. Since shifts are measured as a difference of two line profiles determined at two different times of the plasma existence corresponding plasma conditions N_e, T are also given in Table V. The experimental Stark shifts are compared with *our semiclassical results* (electrons and electrons+ions, see Table I) Δd_{DSB}, evaluated as for the widths. Since it is difficult to estimate plasma composition data in another experiment in order to estimate the contribution of ions, N III Stark shifts measured by Purić *et al.* [40] are compared in Table V only with our electron impact shifts.

To facilitate comparison between various experiments and theories all available results for studied N III and F V line widths are given in graphical form in Figs. 1–4. In these figures experimental widths are compared with (a) our semiclassical electron impact widths, (b) semiclassical electron impact widths calculated after Griem in [36], given only in Fig. 1, (c) simplified semiclassical results calculated here after Griem [Eq. (526) in Ref. [1]], and (d) modified semiempirical formula evaluated here after Dimitrijević and Konjević [35]. In addition, for our experimental conditions and for those in Ref. [8] plasma composition is evaluated and comparison with the semiclassical widths (electrons+ions) is performed.

Figure 1 shows N III for the $3s^2S$-$3p^2P^0$ multiplet. The large spread of the experimental data produces a very poor mutual consistency. Experimental results from Ref. [38] show large variations of linewidths within the multiplet which is usually an indication of the presence of self-absorption during line shape measurements (see also [36]). The large spread of the experimental widths in [39] may also be partially caused by the optical depth problem. If one takes

TABLE V. Experimental Stark shifts Δd_m determined as a wavelength shift between two lines profiles, compared with the corresponding theoretical shifts: electron impact, Δd^e_{DSB}, and electron+ion impact Δd^{ei}_{DSB}. Results for N III lines were calculated using Coulomb oscillator strengths while the results for O IV lines were obtained with TOP base oscillator strengths [13], [14] with transitions with different parent terms included (see Sec. II).

Ion	Transition	λ_{tab} (Å)	N_{e1} (10^{17} cm^{-3})	T_1 (K)	N_{e2} (10^{17} cm^{-3})	T_2 (K)	Δd_m (Å)	$\Delta d_m/\Delta d^e_{DSB}$	$\Delta d_m/\Delta d^{ei}_{DSB}$	Ref.
N III	$3s^2S_{1/2}$-$3p^2P^0_{3/2}$	4097.33	1.38	33 000	2.52	44 300	−0.04	5.6	7.4	[a]
	$3s^2S_{1/2}$-$3p^2P^0_{3/2}$	4097.33	∼0	∼0	1.78	50 000	−0.041	3.7	4.1	[40]
	$3s^2S_{1/2}$-$3p^2P^0_{1/2}$	4103.43	1.38	33 000	2.52	44 300	−0.04	5.6	7.4	[a]
	$3s^2S_{1/2}$-$3p^2P^0_{1/2}$	4103.43	∼0	∼0	1.78	50 000	−0.041	3.7	4.1	[40]
	$3p^2P^0_{1/2}$-$3d^2D_{3/2}$	4634.16	1.38	33 000	2.52	44 300	−0.04	5.4	8.3	[a]
	$3p^2P^0_{3/2}$-$3d^2D_{5/2}$	4640.64	1.38	33 000	2.52	44 300	−0.03	4.1	8.2	[a]
O IV	$3s^2S_{1/2}$-$3p^2P^0_{3/2}$	3063.43	2.06	62 600	5.07	93 600	0.03	1.4		[a]
	$3s^2S_{1/2}$-$3p^2P^0_{1/2}$	3071.60	2.06	62 600	5.07	93 600	0.03	1.4		[a]
	$3p^2P^0_{1/2}$-$3d^2D_{3/2}$	3403.60	2.06	62 600	5.07	93 600	0.03	1.5		[a]
	$3p^2P^0_{3/2}$-$3d^2D_{5/2}$	3411.76	2.06	62 600	5.07	93 600	0.03	1.5		[a]

[a]This work.

into account estimated experimental errors in Refs. [8], [37], and [39], all these results are in agreement with the present experiment. Spread of the experimental data, however, is rather large to make quantitative conclusions about the agreement with various theoretical approaches. Nevertheless, the best agreement is found with the semiclassical electron impact widths and the simple semiclassical formula [Eq. (526) of Ref. [1]].

Figure 2 shows N III, for the $3p^{2p0}-3d^2D$ multiplet. Comparison between the experimental results and theories is even more unclear. Three sets of experimental data [8], [37], and [39] are in good agreement with the modified semiempirical formula [35]. The present experiment, as in the preceding case, agrees best with our electron impact widths from Table I, and the simple formula [Eq. (526) in Ref. [1]].

Figure 3 shows F V, for the $3s^2S$-$3p^2P^0$ multiplet. Our experimental width is in very good agreement with the semiclassical data and lies between electron impact widths and

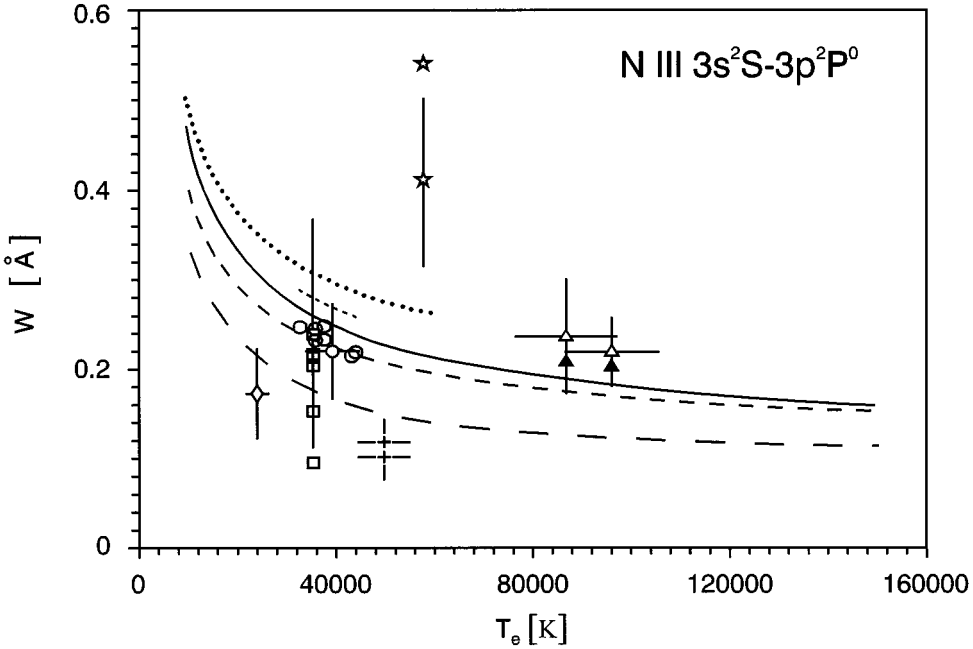

FIG. 1. Full Stark widths (normalized to an electron density of 10^{17} cm^{-3}) for the N III $3s^2S-3p^2P^0$ multiplet vs electron temperature. Theory: —, semiclassical, electron impact widths (see Table I); - - - - -, semiclassical, electron+ion impact widths (see Table I) evaluated only for the experimental conditions of this experiment; for the conditions of Ref. [8] theoretical electron+ion impact widths evaluated from Table I are denoted with Δ; ⋯, semiclassical, electron impact widths (after Griem [36]); – – –, simplified semiclassical approximation [after Griem, Eq. (526) of Ref. [1]]; and — — —, modified semiempirical formula (after Dimitrijević and Konjević [35]). Experiment: ○, this work, ◇, Popović, Platiša, and Konjević [31]; ☆, Källne, Jones, and Barnard [38]; □, Purcell and Barnard [39]; +, Purić, Srećković, Djeniže, and Platiša [40]; and △, Glenzer, Hey, and Kunze [8]. Estimated uncertainties of the experimental data are given whenever available in the original papers. Closed symbols denote theoretical widths (electrons+ions), open symbols denote experimental widths.

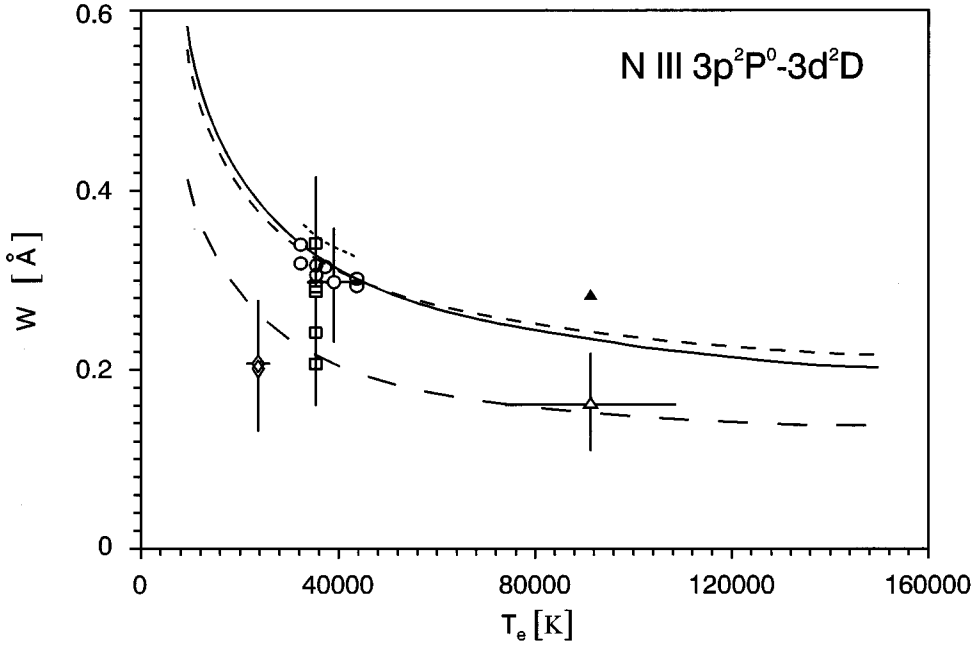

FIG. 2. Same as in Fig. 1 but for the N III $3p^2P^0$-$3d^2D$ multiplet.

electron+ion impact widths derived from data in Table I. The high temperature result of Glenzer, Heg, and Kunze [8], however, is much larger than all other theoretical results.

Figure 4 shows F V, for the $3p^2P^0$-$3d^2D$ multiplet. Both experimental results, this work and Ref. [8], are in very good agreement with our semiclassical data in Table I. On the basis of this result one may conclude that the semiclassical theory describes well the temperature dependence of the Stark widths. Unfortunately this conclusion may not be extended with such confidence to the other investigated multiplets.

Comparison of the N III experimental shifts shows reasonable agreement with our semiclassical results in spite of the fact that ratios of measured over theoretical values range from 1.8 up to 3.3 (see Table V). Measured shifts are very small in our experimental conditions and in this case accurate shift measurements are very difficult to perform. On the other side, theoretical results have a very large uncertainty

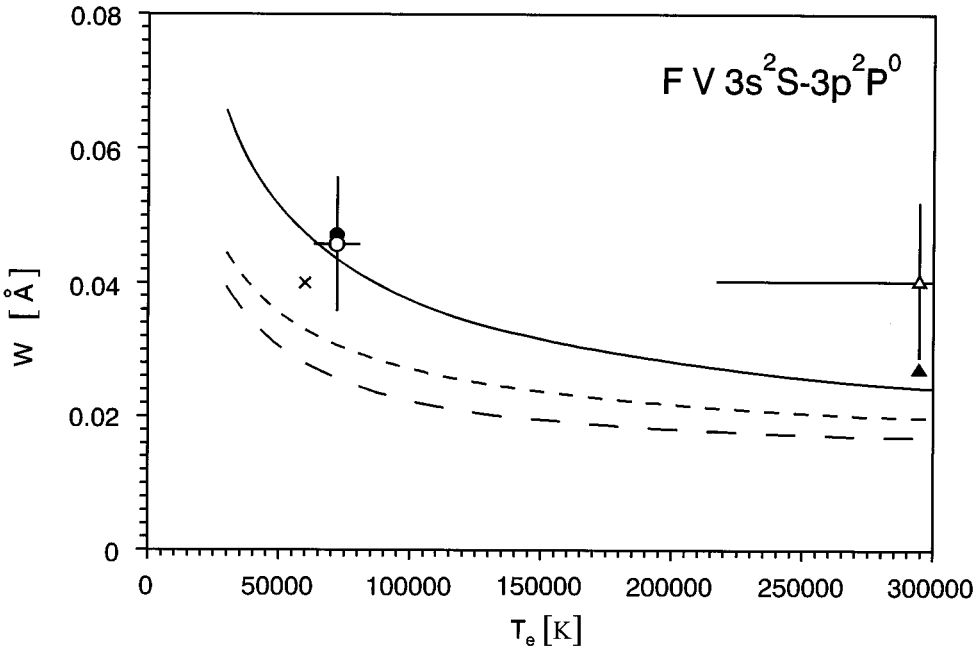

FIG. 3. Same as in Fig. 1 but for the *FV* $3s^2S$-$3p^2P^0$ multiplet; in addition, the predicted value *X*, derived from the regularity trend [47], is included.

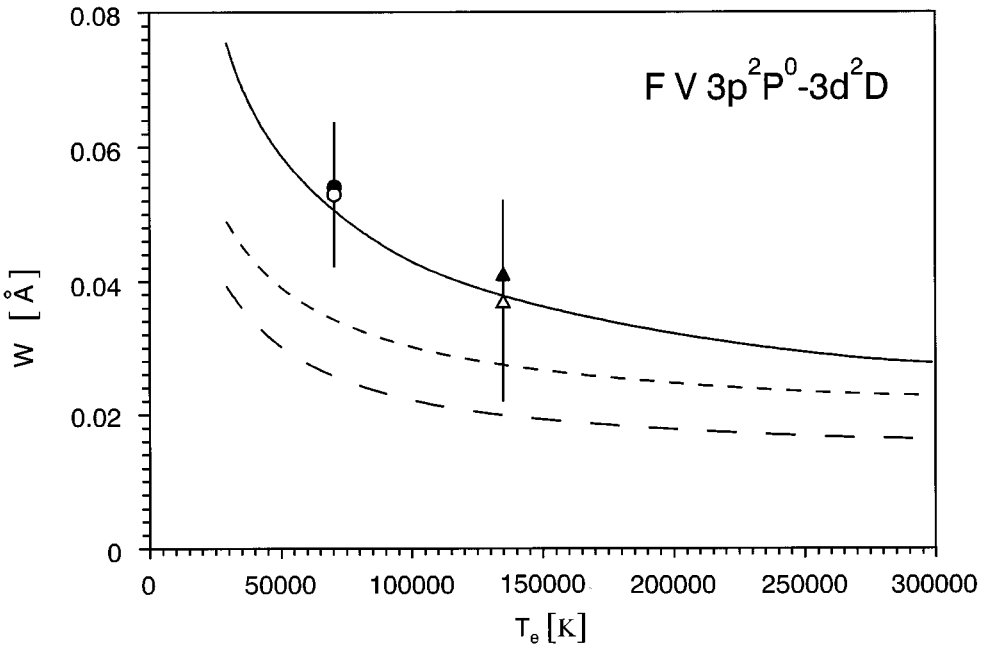

FIG. 4. Same as in Fig. 3 but for the $FV\ 3p^2P^0$-$3d^2D$ multiplet.

whenever shifts are small in comparison with widths as is the case with investigated N III and O IV lines, see Table I. Nevertheless, the results for N III lines of Purić *et al.* [40] agree better with our semiclassical results, see Table V. The agreement between theory and experiment for O IV lines is very good. Here we draw attention to the fact that, contrary to the blueshift of N III lines, O IV lines have a redshift, so good agreement with theoretical predictions is very encouraging. Once more we would like to stress that the use of perturbing energy levels with different parent terms in addition to those from allowed dipole transitions in our semiclassical calculations changed the direction of the shift of the O IV lines from blue to red (see Sec. II). Furthermore, from the comparison of the data in Table V one may conclude that the use of the theoretical ion impact shifts in addition to electron impact shift considerably improves the agreement between theory and experiment for both N III and O IV lines.

Finally, we made a comparison of the Stark widths along the isoelectronic sequence for both investigated multiplets, see Fig. 5. To perform this comparison it was necessary to normalize all experimental and theoretical results to the same temperature. Here we selected an electron temperature of 87 000 K (7.5 eV) which represent a medium value between the low and high temperature data and it was used for the same purpose in Ref. [8]. Temperature dependencies of our electron impact widths, see Table I and Table II in Ref. [3], are taken to normalize higher or lower temperature results. For clarity in comparison along the isoelectronic sequence only two sets of the most comprehensive results are used, this experiment together with Refs. [3] and [8], see Fig. 5. The relative position of the other experimental results can be determined from Figs. 1 and 2 and Figs. 2 and 3 of Ref. [3]. In Fig. 5 the theoretical dependencies of the Stark widths upon Z along the boron sequence are also introduced. Comparison of the experimental and theoretical data in Fig. 5 shows the following.

(a) The $3s^2S$-$3p^2P^0$ multiplet: with the exception of the F V experimental Stark width measured at a high temperature, 300 000 K [8] all other, lower temperature results agree, within the estimated uncertainties, with our semiclassical theoretical predictions. All simplified theoretical approaches show larger decrease of the Stark widths upon Z.

(b) The $3p^2P^0$-$3d^2D$ multiplet: with the exception of the N III Stark width from [8] all other experimental results agree with the semiclassical prediction. Although the simplified theoretical approach [Eq. (526), [1]] agrees best with experiments, the dependence upon Z is not correctly described as it is for the other simplified approaches [35] and [46].

It is common for the comparisons along the sequence for the widths of both multiplets that the agreement between our semiclassical results and experiment for the O IV lines improves if one takes into account the influence of the perturbing levels with the different parent terms.

V. CONCLUSIONS

The results of the semiclassical theoretical calculations for the Stark widths and shifts of N III and F V $3s^2S$-$3p^2P^0$ and $3p^2P^0$-$3d^2D$ multiplets have been reported. In addition to the electron impact widths and shifts, ion widths and shifts due to collisions with all ions of interest for our experimental conditions and those of Ref. [8] are calculated as well. Furthermore, for O IV lines, in addition to the data presented in [3], obtained with the LS coupling oscillator strengths, calculations by using the TOP base oscillator strengths (with and without inclusion of transitions with different parent terms) [13,14] and measured atomic energy levels [16] have been performed for the electronic and ionic perturbers. As-

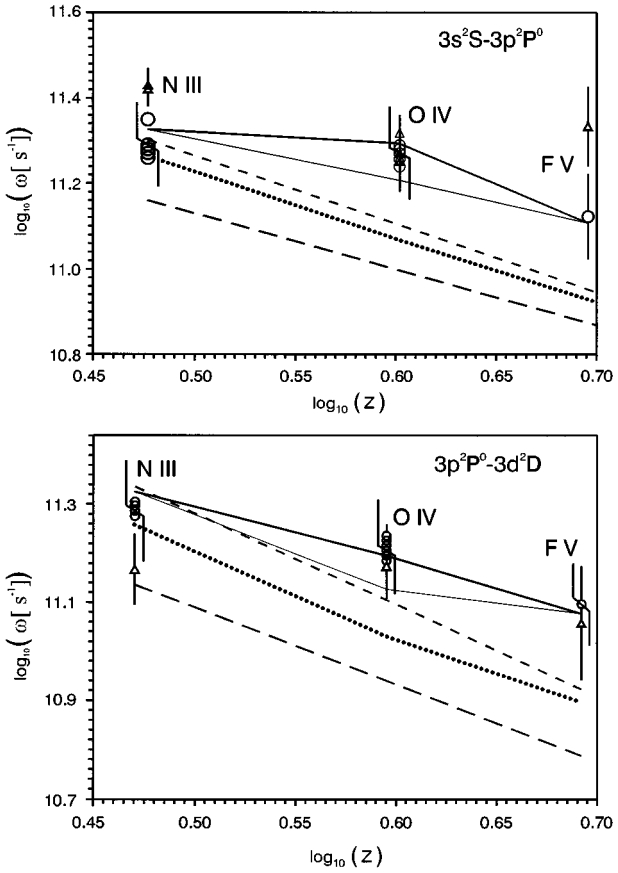

FIG. 5. Stark widths of the *B*-like spectral lines (in angular frequency units) as a function of $\log_{10}Z$. Experimental data are scaled linearly to a value of the electron density of 10^{17} cm^{-3} and to a value of the electron temperature 87 000 K (7.5 eV), Theoretical data are calculated for these values. Experimental results: △, Glenzer, Hey, and Kunze [8] and ○, this work. Error flags are calculated uncertainties including the error in the determination of the full width at half maximum and of the electron density measurements. Theoretical results: —, electron+ion impact widths, data for O IV lines with transitions with a different parent term (from Table I); —, electron+ion impact widths, data for O IV lines with transitions with a different parent term; ---, simple semiclassical, after Griem [Eq. (526) Ref. [1]]; – – –, modified semiempirical formula, after Dimitrijević and Konjević [35]; ⋯, classical-path approximation, after Hey and Breger [46] as calculated in Ref. [8].

suming plasma LTE conditions, plasma composition data are evaluated and, in conjunction with the results for the theoretical Stark broadening data, electron and ion impact widths and shifts are calculated. Experimental Stark widths of N III and F V lines and Stark shifts of N III and O IV lines of the same multiplets are measured in the plasma of a low pressure pulsed arc. Plasma electron density is determined from the width of He II P_α line while the electron temperatures are measured from the Boltzmann plot of the relative intensities of N III and F IV lines. Our experimental Stark widths are in agreement with most of the other experiments. The temperature dependence in the impact limit is characterized by two asymptotic regions and a rather narrow intermediate region. Basically they correspond to the elastic and inelastic collision regime. For neutral lines, the asymptotic analysis is presented, for example, in Refs. [41, 42]. For ions, however, such analysis is more complicated since the Stark broadening functions (A,a,B,b, see Ref. [1]) depend on two arguments and not on one as for neutrals. Consequently, an experimental investigation of the temperature dependence for ions is of higher interest. The temperature dependence of the experimental widths are best described with our semiclassical electron impact results, see Figs. 1–4. The high temperature result for the F V line of Ref. [8], see Fig. 3, represents an exception which cannot be explained within the uncertainty of the experiment and theory. Although we can conclude that all the simple formulas are in agreement with the experiments within their estimated uncertainties, which is typically about ±50%, Griem's simplified theoretical approach [Eq. (526) of Ref. [1]] agrees best with the experimental results, see Figs. 1–4, and Figs. 2 and 3 in Ref. [3].

Comparisons of the experimental widths along the isoelectronic sequence of boron in Fig. 5 show the best agreement with our semiclassical electron impact widths. Two exceptions are the $3p^2P^0$-$3d(^1S)^2D$ line of N III and, in particular, the high temperature result for the $3s^2S$-$3p(^1S)^2P^0$ line of F V, both results are from Ref. [8]. The inclusion of the oscillator strengths of the transitions with the different parent terms in the calculation of the widths of O IV lines improves the agreement between the theory and experiment. Although the simple formulas are in reasonable agreement with the experiments, none of them correctly describes $3p$-$3d$ Stark width dependence upon Z along the sequence, see Fig. 5.

Both measured experimental and calculated theoretical shifts for N III and O IV lines are very small and therefore their intercomparison under the present plasma conditions has a large uncertainty. Thus the agreement between semiclassical theory and this experiment can be considered satisfactory for N III lines, see Table V. The results for N III lines from another experiment [40] are in better agreement with our theory. For O IV lines, however, the experimental shifts have an opposite sign from the theoretically predicted ones [3]. An attempt has been made here to locate the cause of this discrepancy. It has been found that inclusion of ten transitions with different parent term improves the agreement between theory and experiment and correctly predicts a sign of the shift of the observed O IV lines.

Comparison of the data in Table V suggests that the ion impact shifts contribute considerably to the total theoretical shift of N III and O IV lines and its inclusion in the estimation of the total shift (electrons+ions) on the basis of the present experiment improves the agreement with the experiment. We cannot draw the same conclusion for the ion contribution to the Stark widths.

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[1] H. R. Griem, *Spectral Line Broadening by Plasmas* (Academic, New York, 1974).
[2] N. Konjević and W. L. Wiese, J. Phys. Chem. Ref. Data **19**, 1307 (1990).
[3] B. Blagojević, M. V. Popović, N. Konjević, and M. Dimitrijević, Phys. Rev. E **50**, 2986 (1994).
[4] W. L. Wiese and N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **28**, 185 (1982).
[5] F. Böttcher, P. Breger, J. D. Hey, and H.-J. Kunze, Phys. Rev. A **38**, 2690 (1988).
[6] R. Kobilarov and N. Konjević, Phys. Rev. A **41**, 6023 (1990).
[7] S. Glenzer, N. I. Uzelac, and H.-J. Kunze, Phys. Rev. A **45**, 8795 (1992).
[8] S. Glenzer, J. D. Hey, and H.-J. Kunze, J. Phys. B **27**, 413 (1994).
[9] W. L. Wiese and N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **47**, 185 (1992).
[10] M. S. Dimitrijević and V. Kršljanin, Astron. Astrophys. **165**, 269 (1986).
[11] S. Sahal-Bréchot, Astron. Astrophys. **1**, 91 (1969).
[12] S. Sahal-Bréchot, Astron. Astrophys. **2**, 322 (1969).
[13] K. Butler, C. Mendoza, and C. J. Zeippen, J. Phys. B **26**, 4409 (1993).
[14] W. Cunto, C. Mendoza, F. Ochsenbein, and C. J. Zeippen, Astron. Astrophys. **275**, L5 (1993).
[15] M. S. Dimitrijević, S. Sahal-Bréchot, and V. Bommier, Astron. Astrophys. Suppl. Ser. **89**, 581 (1991).
[16] S. Bashkin and J. J. Stoner, Jr., *Atomic Energy Levels and Grotrian Diagrams* (North-Holland, Amsterdam, 1975), Vol. 1.
[17] D. R. Bates and A. Damgaard, Trans. R. Soc. London, Ser. A **242**, 101 (1949).
[18] G. K. Oertel and L. P. Shomo, Astrophys. J. Suppl. Ser. **16**, 175 (1968).
[19] H. Van Regemorter, Hoang Binh Dy, and M. Prud'homme, J. Phys. B **12**, 1073 (1979).
[20] S. Sahal-Bréchot, Astron. Astrophys. **245**, 322 (1991).
[21] A. J. Barnard, J. Cooper, and E. W. Smith, J. Quant. Spectrosc. Radiat. Transfer **14**, 1025 (1974).
[22] J. T. Davies and J. M. Vaughan, Astrophys. J. **137**, 1302 (1963).
[23] J. Purić and N. Konjević, Z. Phys. **249**, 440 (1972).
[24] T. L. Pittman and C. Fleurier, in *Proceedings of the Sixth International Conference on Spectral Line Shapes*, Boulder, 1982 (de Gruyter, Berlin, 1983).
[25] R. Kobilarov, N. Konjević, and M. V. Popović, Phys. Rev. A **40**, 3871 (1989).
[26] W. L. Wiese, in *Plasma Diagnostic Techniques*, edited by R. M. Huddleston and S. L. Leonard (Academic, New York, 1965).
[27] N. Konjević and W. L. Wiese, J. Phys. Chem. Ref. Data **5**, 259 (1976).
[28] S. Glenzer, H.-J. Kunze, J. Musielok, Y.-K. Kim, and W. L. Wiese, Phys. Rev. A **49**, 221 (1994).
[29] H. R. Griem, *Plasma Spectroscopy* (McGraw-Hill, New York, 1964).
[30] M. S. Dimitrijević and S. Sahal-Bréchot, Phys. Scr. (to be published).
[31] M. S. Dimitrijević, S. Sahal-Bréchot and V. Bommier, Astron. Astrophys. Suppl. Ser. **89**, 581 (1991).
[32] M. S. Dimitrijević, S. Sahal-Bréchot and V. Bommier, Astron. Astrophys. Suppl. Ser. **89**, 591 (1991).
[33] M. S. Dimitrijević and S. Sahal-Bréchot, Astron. Astophys. Suppl. Ser. **93**, 359 (1992).
[34] M. S. Dimitrijević and S. Sahal-Bréchot, Astron. Astrophys. Suppl. Ser. **95**, 109 (1992).
[35] M. S. Dimitrijević and N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **24**, 451 (1980).
[36] M. S. Dimitrijević and N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **25**, 387 (1981).
[37] M. V. Popović, M. Platiša, and N. Konjević, Astron. Astrophys. **41**, 463 (1975).
[38] E. Källne, L. A. Jones, and A. J. Barnard, J. Quant. Spectrosc. Radiat. Transfer **22**, 589 (1979); E. Källne and L. A. Jones *ibid*. **25**, 393 (1981).
[39] S. T. Purcell and A. J. Barnard, J. Quant. Spectrosc. Radiat. Transfer **32**, 205 (1984).
[40] J. Purić, A. Srećković, S. Djeniže, and M. Platiša, Phys. Rev. A **36**, 3957 (1987).
[41] S. A. Freudestein and J. Cooper, Astrophys. J. **224**, 1079 (1978).
[42] M. S. Dimitrijević and N. Konjević, Astron. Astrophys. **163**, 297 (1986).
[43] W. C. Martin, R. Zalubas, and A. Musgrove, J. Phys. Chem. Ref. Data **19**, 821 (1990).
[44] J. A. Tully, M. J. Seaton, and K. A. Berrington, J. Phys. B **23**, 3811 (1990).
[45] D. Luo and A. K. Pradham, J. Phys. B **22**, 3377 (1989).
[46] J. D. Hey and Breger, J. Quant. Spectrosc. Radiat. Transfer **24**, 349 (1980); **24**, 427 (1980); and J. D. Hey, S. Afr. J. Phys. **5**, 111 (1982).
[47] J. Purić, S. Djeniže, J. Labat, M. Platiša, A. Srećković, and M. Ćuk, Z. Phys. D **10**, 431 (1988).

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The Complex Structure of the Mg II λλ 2795.523, 2802.698 Å Regions of 64 Be Stars

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Abstract

Here we consider the presence of absorption components shifted to the violet or red side of the main spectral line (satellite or discrete absorption components, i.e., SACs or DACs) in the regions of the Mg II resonance lines in Be stars as well as their kinematical characteristics. Namely, our objective is to check whether there exists a common physical structure for the atmospheric regions creating SACs or DACs of the Mg II resonance lines. In order to do this, a statistical study of the Mg II λλ 2795.523, 2802.698 Å lines in the spectra of 64 Be stars of all spectral subtypes and luminosity classes was performed. We found that the atmospherical absorption regions where the Mg II resonance lines originated may be formed of several independent density layers of matter that rotate with different velocities. It was also attempted to separate SACs and DACs according to low or high radial velocity. The emission lines were detected only in the earliest and latest spectral subtypes.

Key words: stars: atmospheres — stars: early type — stars: emission-line, Be — stars: kinematics

1. Introduction

The Mg II resonance lines have a peculiar profile in the Be stellar spectra, which indicates a multicomponent nature of their origin region. Many researchers have observed the existence of absorption components shifted to the violet or red side of the main spectral line (Underhill 1970; Marlborough et al. 1978; Dachs 1980; Doazan 1982; Danezis 1983, 1987; Sahade et al. 1984; Sahade & Brandi 1985; Hutsemékers 1985; Danezis et al. 1991; Doazan et al. 1991; Laskarides et al. 1992; Cidale 1998; Lyratzi et al. 2003). These components — Discrete Absorption Components (DACs: Bates & Halliwell 1986) or Satellite Absorption Components (SACs: Danezis et al. 2003; Lyratzi & Danezis 2004) — probably originate in separated regions that have different rotational and radial velocities. Especially in the case of very narrow DACs and SACs, they cannot be photospheric; rather, they have a circumstellar or interstellar origin (Slettebak & Snow 1978). For example, Kondo, Morgan, and Modisette (1976) found that the shell absorption becomes stronger in intermediate to late B stars, and suggested that "it might be due to the rising temperature in the gaseous shell which converts Mg II to Mg III and to the weakening of the outward-driving mechanisms of the atmosphere". In any case, the whole feature of the Mg II resonance lines is not the result of a uniform atmospherical region, but the components are created in different regions, which rotate and move radially with different velocities. As de Jager et al. (1979) proposed in their study of 33 stellar spectra of all the spectral types, variable mass loss in the late B supergiants occurs due to "occasional stellar 'puffs' superposed on a more or less regular wind". They proposed that "there are concentrations of low-ionization species in the stellar wind as a result of the occurrence of significant density variations". Also, in order to explain the complex profiles of the Mg II resonance lines, Cidale (1998) proposed that the Be stellar atmospheres are composed of a classical photosphere, an extending high-temperature chromosphere, and a cool envelope. There is a question about the contributions of different atmospherical layers, especially in the case of SAC and/or DAC phenomena, in constructing profiles of the Mg II resonance lines.

The aim of this work is to statistically investigate the presence of SACs and/or DACs in regions of Mg II resonance lines in Be stars and their kinematical characteristics. Also, we would like to search some conclusion about the limits of the rotational and radial velocities ($V_{\rm rot}$, $V_{\rm rad}$), as well as to check whether there exists a common physical structure for the atmospherical regions that create the SACs of the Mg II resonance lines in the spectra of all the Be stars. To do that, a statistical study of the UV Mg II resonance lines λλ 2795.523, 2802.698 Å in the spectra of 64 Be stars (all the spectral subtypes and luminosity classes) was performed. The study was based on a model proposed by Danezis et al. (2003) and Lyratzi and Danezis (2004).

We decided to study the Mg II resonance lines, because they are characteristic of the cool envelope in Be stellar atmospheres and very intense features in the spectra of Be stars and they mostly present a complex and peculiar structure. Besides, since they are resonance lines, they give us a possibility to test the validity of the proposed model. Because we have to

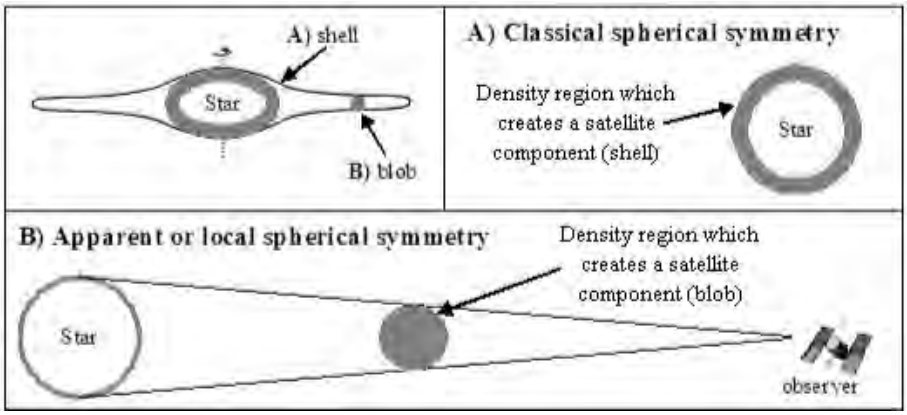

Fig. 1. Density regions that create the observed SACs or DACs in the stellar spectra.

adhere to all of the necessary physical criteria and techniques (Danezis et al. 2003). Our purpose here was to study spectral lines that are created in cool regions (Mg II) in Be stellar atmospheres. Danezis (1987), Sahade, Brandi, and Fontenla (1984), and Sahade and Brandi (1985) detected multistructures in the regions where Fe II lines (I.P.=7.870 eV) are created in the spectra of Be stars, which are characterized as iron stars. One of our purposes was to investigate whether the multistructure appears only in the Fe II spectral lines, or in also other spectral lines with a similar ionization potential (I.P.), as Mg II (I.P.=7.646 eV). This is another reason why we chose to study the Mg II resonance lines and not some other resonance lines of the cool envelope, as N II (I.P.=14.490 eV), C II (I.P.=11.260 eV), Si II (I.P.=8.110 eV), or Al II (I.P.=5.986 eV). The study of Mg II resonance lines provides us information not only about the cool envelope, but also about the multistructure of another ion that lies in the same region where the Fe II spectral lines are created.

In section 2, we describe the method of analysis, in section 3 the observational data, and in section 4 the results along with a discussion. In section 5 we give our conclusions.

2. Method of Spectral Line Analysis

Before describing the method used in our study, let us explain the differences between DACs and SACs. The DACs are components of a spectral line of a specific ion, shifted at different $\Delta\lambda$ from the transition wavelength of a line, because they are created in different density regions that rotate and move radially with different velocities (Lyratzi & Danezis 2004). The DACs are discrete lines, easily observed, in the spectra of some Be stars of luminosity class III, in the case of the Mg II doublet. However, if the layers that give rise to such lines rotate with quite large velocities and move radially with small velocities, then the produced lines are quite broadened and slightly shifted. As a result, they are blended among themselves as well as with the main spectral component, and thus they do not appear as being discrete; consequently, they cannot be resolved. In such a case, the name Discrete Absorption Component is inappropriate. Besides, as Peton (1974) first pointed out, these components appear as "satellites" in the violet or in the red side of the main spectral

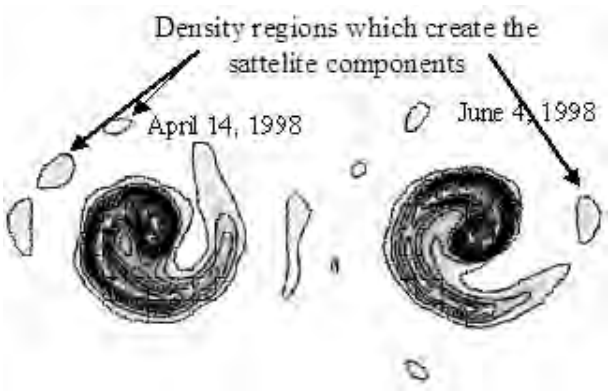

Fig. 2. Due to rotation of the star, the ejected matter forms spiral streams that produce blobs that create the observed SACs or DACs in the stellar spectra. This figure is taken from Tuthill, Monnier, and Danchi (1999).

line's component as a function of the time or the phase in the case of a binary system. For these two reasons, and in order to give a unique name to all of these lines that are components of the line profile whether they are discrete or not, it has been proposed (Lyratzi & Danezis 2004) that they should be named Satellite Absorption Components (SACs) as a general expression, because the Discrete Absorption Components (DACs) are "Satellites" of a main spectral line, while the SACs are not always discrete, and cannot be easily resolved.

An additional peculiar phenomenon is that all of the lines of a specific ion have not DACs. The DAC phenomenon is not a general one, but is present in the case of some lines that have a low excitation potential. For example, while the Mg II resonance lines at 2795.523, 2802.698 Å (multiplet 1) have DACs in the spectra of some Be stars, their subordinate lines at 2790.768, 2797.989 Å (multiplet 3) do not present the same phenomenon. Therefore, we decided to study the Mg II resonance lines, since they are the only Mg II doublet having DACs.

In order to obtain a qualitative picture, we will use the spherical geometry. According to it, there are two possibilities (see figure 1).

A) The region that creates the SACs or DACs may be an envelope around and near to a rapidly rotating star. In such a case, the spherical model could give only a rough approximation, but would allow us to obtain some qualitative results. We note that such an assumption is valid for some earlier models like, e.g., Doazan and Thomas (1982), which cannot explain the observed free-free emission or polarization, but we are interested here only in the kinematic characteristics. In this case, the calculated values of the radial velocity correspond to the component of the expansion or contraction velocity of the shell, which is projected to the observational axis.

B) The region which creates the SACs or DACs may be an independent density region (blob), which is spherically symmetric around its own center. Such density regions have been observed around stars that eject mass. In figure 2, we can see this phenomenon in WR 104, observed by Tuthill, Monnier, and Danchi (1999). Such a region may be one that creates the Mg II resonance lines, and that lies in a cool envelope of the stellar atmosphere. Such a blob may have three different motions: a) it may rotate around the star, b) it may expand or contract, and c) it may move radially. This means that the calculated values of the radial velocity consist of three different components: a) the component of the rotational velocity of the blob around the star, projected to the observational axis, b) the component of the expansion or contraction velocity of the blob, projected to the observational axis, and c) the component of the velocity of the blob's radial motion, projected to the line of sight.

In principle, as known, the star ejects mass with a specific radial velocity. The stream of matter is twisted, forming density regions, such as the interaction of fast and slow wind components, corotating interaction regions (CIRs), and structures due to magnetic fields or spiral streams as a result of the stellar rotation (Underhill & Fahey 1984; Mullan 1984a, 1984b, 1986; Prinja & Howarth 1988; Cranmer & Owocki 1996; Kaper et al. 1996, 1997, 1999; Fullerton et al. 1997; Cranmer et al. 2000). Consequently, hydrodynamic and magnetic forces act as centripetal forces, causing the outward moving matter to twist and move around the star (see figure 2). This motion of the matter is responsible for the formation of high-density regions (shells, blobs, puffs, and spiral streams), that are either spherically symmetric with respect to the star or with respect to their own center (Danezis et al. 2003; Lyratzi & Danezis 2004) (see figure 1).

In order to study the physical structure and the existence of SAC phenomena in the regions where these lines are created, we used a model proposed by Danezis et al. (2003) and Lyratzi and Danezis (2004). This model allowed us to calculate the rotational ($V_{\rm rot}$) and radial velocities ($V_{\rm rad}$) of independent density layers of matter in these regions, as well as the optical depth (τ) and the column density (n). If the considered SACs or DACs originate from "puffs" or "blobs" created by stellar winds in a cool extended envelope, the real shape of the envelope is not crucial. If the considered features are created in the envelope's layers, we could also reach some qualitative conclusions, since we are interested only in the kinematical properties here. Moreover, because there is no sophisticated or rough model of a Be star that could fit the observed profiles, considering their complex structure, there are no results of similar investigations for comparison.

Let us consider that the area of gas that creates a specific spectral line consists of i independent absorbing density regions, followed by j independent regions that both absorb and emit and by an outer absorbing region. Such a structure produces DACs or SACs in the observed spectra (Danezis et al. 2003). The final line function which can describe the complex line profiles of the observed spectral lines is (Danezis et al. 2003; Lyratzi & Danezis 2004)

$$F_\lambda = [F_{\lambda 0} \prod_i e^{-L_i \xi_i} + \sum_j S_{\lambda ej}(1 - e^{-L_{ej}\xi_{ej}})] e^{-L_g \xi_g} \qquad (1)$$

where F_λ is the observed flux, $F_{\lambda 0}$ the initial flux, $S_{\lambda ej}$ the source functions of each emitting density region, ξ the optical depth in the center of the line, and L_i, L_{ej}, L_g the distribution functions of the absorption coefficients ($k_{\lambda i}$, $k_{\lambda ej}$, $k_{\lambda g}$), respectively. Each L depends on the values of the rotational and the radial velocities of the density region, which forms each component of the spectral line ($V_{\rm rot}$, $V_{\rm rad}$) (Danezis et al. 2003; Lyratzi & Danezis 2004). The product of L and ξ is the optical depth of each region.

This function does not depend on the geometry of the regions creating the observed feature. The considered geometry of the regions is taken into account in order to define the distribution function, L. This means that L may represent any distribution which decides a certain geometry (see the Appendix), without changing anything in F_λ.

Each component of the spectral line, which is formed by the $i^{\rm th}$ density region of matter, must be accurately reproduced by the function $e^{-L_i \xi_i}$ by applying appropriate values of $V_{{\rm rot}_i}$, $V_{{\rm rad}_i}$ and ξ_i. Using the best model fit for a complex spectral line, we can calculate the apparent radial and rotational velocities ($V_{{\rm rad}_i}, V_{{\rm rot}_i}$) and the optical depth (ξ_i) in the center of the line of the region where the main spectral line and its SACs are created.

In the case where we want to consider that some other physical parameters are responsible for the line broadening, and not the rotation of the region that produces the studied spectral lines, we may replace the exponential $e^{-L\xi}$ with another classical distribution.

In the case of emission lines, each emission component, which is formed by the $j^{\rm th}$ density region of matter, must be accurately reproduced by the function $S_{\lambda ej}(1 - e^{-L_{ej}\xi_{ej}})$, by applying the appropriate values of $V_{{\rm rot}_i}$, $V_{{\rm rad}_i}$, ξ_i, and S. Using the best model fit for a complex spectral line, we can calculate the apparent radial and rotational velocities ($V_{{\rm rad}_i}, V_{{\rm rot}_i}$), the optical depth ($\xi_i$) at the center of the line, and the source function, S, of the region where the emission component is created.

The proposed model is relatively simple, aiming to describe the regions where the spectral lines that present SACs are created. With this model we can study the regions of a specific ion that creates a specific spectral line.

This model presupposes that the main reason for the line broadening is rotation of the region that gives rise to the

Table 1. The list of Be stars.

Star	Spectral type	Camera	ref.	Star	Spectral type	Camera	ref.
HD 5394	B0 IV : evar	Lwr 07861	1	HD 25940	B3 V e	Lwr 05950	2
HD 53367*	B0 IV : e	Lwr 09286	1	HD 45725*	B3 V e	Lwp 10041	2
HD 203374†	B0 IV pe	Lwp 07400	1	HD 183362	B3 V e	Lwp 11044	2
HD 206773	B0 V : pe	Lwr 14808	1	HD 208057	B3 V e	Lwp 29221	2
HD 200310	B1 V e	Lwr 09544	1	HD 205637	B3 V : p	Lwr 05947	4
HD 212571	B1 V e	Lwr 05948	2	HD 217543	B3 V pe	Lwp 13326	2
HD 44458*	B1 V pe	Lwp 30173	1	HD 217050†	B4 III pe	Lwr 05933	2
HD 200120	B1.5 V nne	Lwr 11035	2	HD 89884	B5 III	Lwp 29529	6
HD 193237	B2 pe	Lwr 07990	2	HD 22192	B5 V e	Lwr 06898	2
HD 45910*	B2 III e	Lwr 12138	3	HD 23302	B6 III e	Lwr 09071	2
HD 37202	B2 IV p	Lwr 05888	4	HD 45542	B6 III e	Lwp 07631	2
HD 36576	B2 IV – V e	Lwp 14029	2	HD 109387	B6 III pe	Lwr 04132	2
HD 212076	B2 IV – V e	Lwr 03406	2	HD 23480	B6 IV e	Lwr 05219	2
HD 32991*	B2 V e	Lwr 11426	2	HD 217891	B6 V e	Lwr 09069	2
HD 58050	B2 V e	Lwr 14810	2	HD 138749	B6 V nne	Lwr 07858	2
HD 164284	B2 V e	Lwr 11038	2	HD 23630	B7 III	Lwr 09060	2
HD 41335	B2 V ne	Lwr 07384	2	HD 209409	B7 IV e	Lwp 15464	2
HD 52721	B2 V ne	Lwp 05462	5	HD 6811	B7 V e	Lwr 09070	7
HD 58343	B2 V ne	Lwr 07363	6	HD 192044*	B7 V e	Lwp 08135	8
HD 148184	B2 V ne	Lwr 06744	6	HD 210129	B7 V ne	Lwp 23173	7
HD 202904	B2 V e	Lwr 07343	2	HD 142983	B8 Ia/Iab	Lwr 07359	6
HD 65079	B2 V ne	Lwp 30119	5	HD 29866	B8 IV ne	Lwr 08745	2
HD 28497	B2 V ne	Lwr 07337	6	HD 47054	B8 V e	Lwp 13074	9
HD 45995*	B2 V nne	Lwr 08648	1	HD 183914*	B8 V e	Lwr 04609	9
HD 10516	B2 V pe	Lwr 07335	2	HD 50138	B8 V e	Lwr 09358	11
HD 187567*	B2.5 IV e	Lwp 14025	2	HD 58715	B8 V var	Lwp 10104	10
HD 191610	B2.5 V e	Lwr 07342	2	HD 23552†	B8 V ne	Lwr 08744	7
HD 32343*	B2.5 V e	Lwr 05890	2	HD 185037	B8 V ne	Lwp 08136	9
HD 65875	B2.5 V e	Lwr 05616	2	HD 199218	B8 V nne	Lwp 09903	7
HD 60855†	B2/B3 V	Lwp 15477	6	HD 91120	B8/B9 IV/V	Lwp 07475	6
HD 37490*	B3 III e	Lwr 07361	1	HD 142926	B9 pe	Lwr 05768	7
HD 50820	B3 IV e+...	Lwr 16776	2	HD 144	B9 III e	Lwr 08997	7

The list of Be stars with spectral type (columns 2, 6) and the type of the camera used during observations (columns 3, 7).
* Double system.
† Triple system.
References: (1) Morgan, Code, and Whitford (1955); (2) Lesh (1968); (3) Sahade, Brandi, and Fontenla (1984); (4) Herbig and Spalding (1955); (5) Guetter (1968); (6) Houk and Smith-Moore (1988); (7) Cowley (1972); (8) Osawa (1959); (9) Cowley et al. (1969); (10) Slettebak (1954); (11) Houziaux and Andrillat (1976).

spectral line (Doazan 1982). We can accept this assumption when we deal with the inner layers to the post coronal regions. Thus, for these atmospheric layers the model gives satisfactory results.

3. Observational Data and Fitting Procedure

The data that we used are the Mg II resonance lines of 64 Be stars taken from the International Ultraviolet Explorer (IUE) Archive Search database.[1] The stellar spectra were observed with the IUE satellite using the Long Wavelength range Prime and Redundant cameras (LWP, LWR) at high resolution (0.1 to 0.3 Å). In table 1, we give a list of stars, their spectral type, and the type of camera used during observations.

Our first step is to identify the spectral lines in the studied wavelength range, in order to determine which lines may be blended with the Mg II doublet, and thus may contribute to the observed features. The identification was made by using the NIST Atomic Spectra Database[2] as well as the catalogues of Moore (1968) and Kelly (1979). In this specific spectral range the adjacent features of the Mg II profiles are intense, but they are away from the Mg II spectral features, so that, in spite of their important influence on the wings, their much smaller influence in the central parts is not important for our discussion. Moreover, because we deal with resonance lines, we know that if one line of the doublet is well fitted, we should apply the same parameters to the other one, even if the fit is not very good. In this case, the unfitted regions correspond to blends.

[1] ⟨http://archive.stsci.edu/cgi-bin/iue⟩.

[2] ⟨http://physics.nist.gov/cgi-bin/AtData/lines_form⟩.

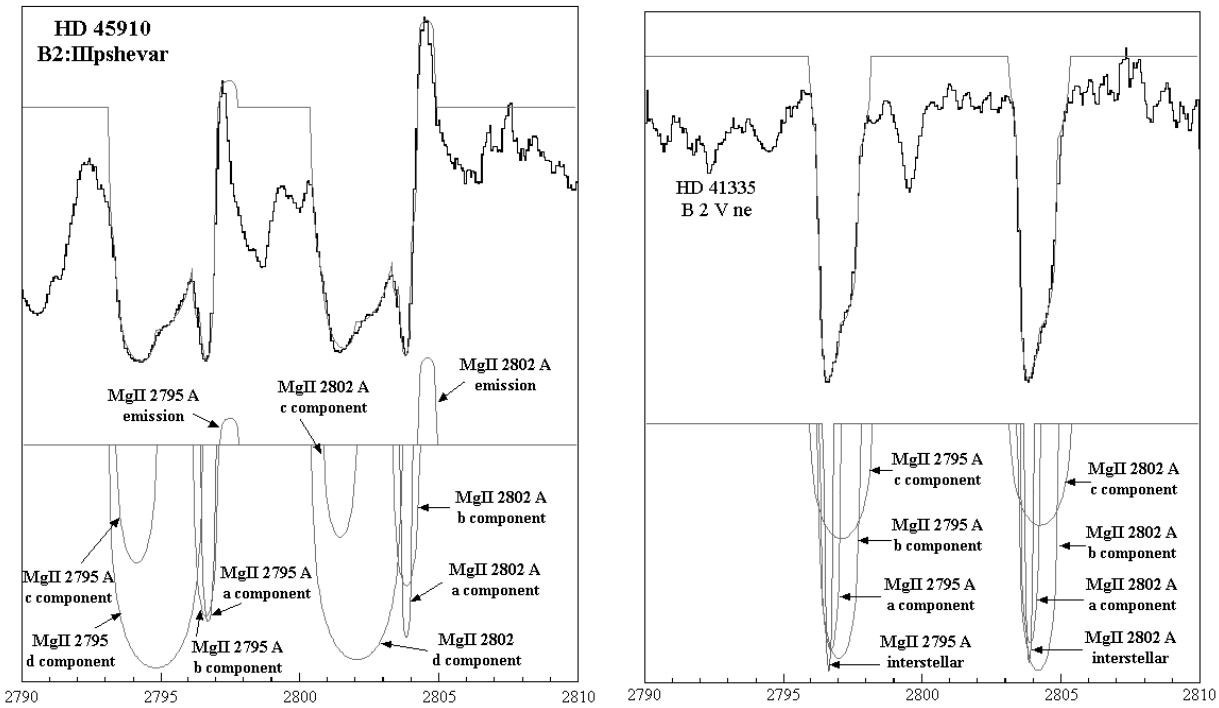

Fig. 3. Mg II resonance line profiles fitted with the model for HD 45910 and HD 41335. The thick lines present observations, and the thin lines present the best fit. The DACs (HD 45910) and SACs (HD 41335) are present below.

Also, the level of the continuum is calculated for the whole spectrum taken by IUE. This means that its suppression by the blends does not affect our calculations.

The procedure that we followed for decomposition of the lines is described in Danezis et al. (2003). The way, criteria, and discussion about the model that we used to fit the observed spectral lines are presented in Danezis et al. (2003). They are explained in more detail in Lyratzi and Danezis (2004) and an application of the method is given in Popović et al. (2004). This means that we tried to fit the observed profiles of the Mg II resonance lines with fewer possible components. We at first tried to fit the observed spectral feature with one component. If this was not possible, we added one more component and then another, until we accomplished the best fit with fewer possible components. This means that we fitted the observed Mg II features with one to four components, for different stars. Our results are given in tables 2 and 3.

In order to be certain that we accomplished the best fit, we performed an F-test, between the fit that we accepted as being the best, and a fit with one component less. We present the results of the F-test in table 4, where we give the values of the confidence with which the accepted fit is better than the fit with one component less. We did not perform an F-test between the best fit and a fit with one component more, because this last one fit presented extreme differences with the observed spectral line profiles, or because the values of the measured parameters go against the classical theory for resonance lines (Danezis et al. 2003; Lyratzi & Danezis 2004).

4. Results and Discussion

The DAC phenomenon is quite common in O- and early B-type stars. However, we found that the DAC phenomenon is also observed in late B-type stars (as in the case of HD 144). Moreover, many researchers (Underhill 1975; Morgan et al. 1977; Marlborough et al. 1978; de Jager et al. 1979; Doazan 1982; Sahade et al. 1984; Sahade & Brandi 1985; Hutsemékers 1985), even if they did not use the name DACs, observed the same phenomenon. We also point out that in Underhill (1970), Marlborough, Snow, and Slettebak (1978), Dachs (1980), Doazan (1982), Sahade, Brandi, and Fontenla (1984), Sahade and Brandi (1985), Hutsemékers (1985), Doazan et al. (1991), and Cidale (1998) only the known DAC phenomenon was investigated. However, in the present paper a similar phenomenon of SACs is introduced, and we investigate whether this phenomenon is able to explain the complex structure of the Mg II resonance lines in the stellar spectra of all the Be spectral subtypes. Our result is that the SAC phenomenon is able to explain this complex structure.

Using the model described above, we find the best fit for the Mg II resonance lines of 64 Be stars given in table 1. In figure 3, we give the best fit of the Mg II resonance lines for two stars (HD 45910 and HD 41335). The first one (HD 45910) presents DACs, where the decomposition of the three different components is easy, while the second one (HD 41335) presents SACs, where it is hard to decompose the three different components without a convenient model. One can thus see that the model conveniently describes the Mg II complex profiles and the complex structure of the regions where these lines are created. In the studied IUE spectra, the interstellar lines are

Table 2. The kinematical parameters for absorption regions for considered stars.

Star	Spectral type	$V_{\rm rot1}$	$V_{\rm rad1}$	$V_{\rm rot2}$	$V_{\rm rad2}$	$V_{\rm rot3}$	$V_{\rm rad3}$	$V_{\rm rot4}$	$V_{\rm rad4}$
HD 5394	B0 IV evar	25	8.8	50	12.3				
HD 53367	B0 IV e	24	−18.0	37	−12.0	7l	−7.0		
HD 203374	B0 IV pe	24	4.5	36	3.5	60	2.0		
HD 206773	B0 V pe	28	15.5	46	18.5				
HD 200310	B1 V e	25	10.1						
HD 212571	B1 V e	22	−2.5	40	−11.0				
HD 44458	B1 V pe	22	−17.5	37	−19.5	83	−29.0		
HD 200120	B1.5 V nne	28	−0.4						
HD 193237	B2 pe	30	−18.6	45	−18.1	86	(DAC) −200.6	115	(DAC) −200.1
HD 45910	B2 III e	24	13.0	42	11.0	60	(DAC) −229.5	170	(DAC) −182.0
HD 37202	B2 IV p	29	−18.0	48	−21.0			125	−33.0
HD 36576	B2 IV–V e	29	−43.0			80	−21.0		
HD 212076	B2 IV–V e	20	−1.0	34	−1.5				
HD 32991	B2 V e	19	−15.4	38	−21.9				
HD 58050	B2 V e	25	−35.9	49	−28.4				
HD 164284	B2 V e	28	13.3			63	33.8		
HD 41335	B2 V ne	22	−9.5	38	−1.5	80	27.0	100	40.0
HD 52721	B2 V ne	18	12.3	34	11.3	65	31.3		
HD 58343	B2 V ne	21	−1.8	50	−5.2				
HD 148184	B2 V ne	17	19.9	30	20.9				
HD 202904	B2 V e	20	4.0	31	4.5				
HD 65079	B2 V ne	29	8.0			74	−12.5		
HD 28497	B2 V ne	8	−45.0	37	−34.5	60	−35.0		
HD 45995	B2 V nne	29	−17.0	45	−20.0	69	−24.0		
HD 10516	B2 V pe	22	−1.0	37	−2.3	50	−5.8		
HD 187567	B2.5 IV e	19	23.6	32	24.6	50	26.1		
HD 32343	B2.5 V e	20	8.4			78	17.9		
HD 65875	B2.5 V e	17	14.0	35	18.0				
HD 191610	B2.5 V e	20	−45.6	45	−53.6				
HD 60855	B2/B3 V			45	−14.6	71	22.9	139	−29.6
HD 37490	B3 III e	20	−5.3	35	−8.3	54	−18.8	98	−10.3
HD 50820	B3 IV e+...	24	−13.0	50	−9.5				
HD 25940	B3 V e	22	0.7	42	−2.3				
HD 45725	B3 V e	18	−9.5	34	−10.5	65	−13.0		
HD 183362	B3 V e	24	24.2	34	24.2	68	19.7		
HD 208057	B3 V e	23	12.3			75	9.8		
HD 205637	B3 V p	22	17.5	39	15.5			115	9.0
HD 217543	B3 V pe	26	16.5	51	15.5			130	23.5
HD 217050	B4 III pe	35	14.3	54	17.8	84	32.3		
HD 89884	B5 III			33	−9.5	60	1.5		
HD 22192	B5 V e	16	−2.0	32	−1.0	52	−7.0		
HD 23302	B6 III e	21	−9.9			86	−8.9		
HD 45542	B6 III e	15	−24.4	33	−24.9	58	−15.4		
HD 109387	B6 III pe	18	−11.4			66	−28.4		
HD 23480	B6 IV e	20	−7.7	32	0.3				
HD 217891	B6 V e	18	−0.8						
HD 138749	B6 V nne	27	22.5	47	14.5				
HD 23630	B7 III	20	−9.0	45	−9.0				
HD 209409	B7 IV e	21	−9.0	38	−9.0	83	−5.0		

Table 2. (Continued.)

Star	Spectral type	$V_{\rm rot1}$	$V_{\rm rad1}$	$V_{\rm rot2}$	$V_{\rm rad2}$	$V_{\rm rot3}$	$V_{\rm rad3}$	$V_{\rm rot4}$	$V_{\rm rad4}$
HD 6811	B7 V e	19	3.3	35	1.8			169	12.8
HD 192044	B7 V e	25	19.5	52	8.5				
HD 210129	B7 V ne	21	62.6	52	43.1				
HD 142983	B8 Ia/Iab	21	−7.0	39	8.0	60	11.5	95	16.5
HD 29866	B8 IV ne	26	−42.0			85	41.5		
HD 47054	B8 V e	24	−30.0	42	−31.5				
HD 183914	B8 V e	17	16.8	37	20.8				
HD 50138	B8 V e	27	−36.0						
HD 58715	B8 V var	22	−21.5	44	−9.0				
HD 23552	B8 V ne			33	24.7				
HD 185037	B8 V ne	26	12.0	45	18.0				
HD 199218	B8 V nne	17	4.7	35	4.2			95	7.7
HD 91120	B8/B9 IV/V	23	−13.5	39	−15.0				
HD 142926	B9 pe	18	−12.9	50	2.1	67	7.6	165	3.6
HD 144	B9 III e	28	−30.6	53	(DAC) −188.6	80	(DAC) −187.1	178	(DAC) −129.6

The rotational ($V_{\rm rot}$) and the radial ($V_{\rm rad}$) velocities in $\rm km\ s^{-1}$.

systematically shifted to the red for $+99\pm16\ \rm km\ s^{-1}$. We used the Hipparcos catalogues,[3] and we applied the corrections for the systemic velocity of individual stars (Smith 2001) and for the orbital motion of the those stars that are members of binary systems. Our results, given in tables 2 and 3 as well as in figures 4–8, are correspondingly corrected.

We should note that in our sample, 15 binary and multiple systems are present (see table 1). Considering that the origin of DACs and SACs might in principle be different than in single stars, at the beginning we separately analyzed this kind of star (presented with open circles in figures 4–6). However, we found that there is no systematic difference between single and binary/multiple stars. Consequently, in a further analysis we will not treat binary/multiple systems in a different way.

From the fit we obtained the rotational ($V_{\rm rot_i}$) and radial ($V_{\rm rad_i}$) velocities for each Mg II resonance line originating within the region.

In tables 2 and 3, we present the kinematical parameters for the absorption Mg II resonance line forming regions (table 2), as well as for the emission ones (table 3). As one can see, not all of the studied stars have an emission component, but only those listed in table 3. One could assume that these emission components are the emission part of P Cygni profiles formed by scattering. In that case, their wavelength and width do not represent the radial and rotational velocities. This could explain the majority of positive radial velocities since, in such a case as outflowing wind, lines will be widened and red-shifted. However, two cases with large negative radial velocities indicate that the real picture may be more complicated. We know that disk models, in many cases, may produce theoretically only the shape of the line profiles, but they are not able to fit them. Thus, in such cases, we may consider that the observed profile results from a different mechanism. In table 2, we give a list of stars, their spectral subtype (columns 1 and 2, respectively) and the values of the rotational velocities (columns 3, 5, 7, and 9) and the radial velocities (columns 4, 6, 8, and 10) of the respective components. Also, in table 3, we present the kinematical parameters of the emission component. In column 1 we present a list of stars, in column 2 their spectral subtype and in columns 3 and 4 values of the rotational and radial velocities, respectively. Let us point out, here, that the calculated values correspond to the regions that create the SACs or DACs. Especially, the obtained rotational velocities correspond to the rotation of the region around itself and not around the star.

Table 3. The same as in table 2, but for the emission component where it is present.

Star	Spectral type	$V_{\rm rot,e}$	$V_{\rm rad,e}$
HD 203374	B0 IV pe	20	72
HD 45910	B2 III e	34	81
HD 32991	B2 V e	57	13
HD 164284	B2 V e	120	−1
HD 148184	B2 V ne	50	33
HD 45995	B2 V nne	46	102
HD 65875	B2.5 V e	30	53
HD 50820	B3 IV e+...	59	−87
HD 217891	B6 V e	50	6
HD 192044	B7 V e	94	7
HD 210129	B7 V ne	97	−29
HD 47054	B8 V e	81	0
HD 50138	B8 V e	53	120
HD 199218	B8 V nne	131	15

In figures 4 and 5, we present, separately, the rotational velocities and the radial velocities, respectively, of all the SACs as a function of the spectral subtype. In figure 5, the radial velocity's values that correspond to the DACs are clearly shown. In figure 6, we present the radial velocities of all the SACs as a function of the respective rotational velocities. In figure 7, we present mean values of the rotational and radial velocities of the two resonance lines of the emission component as a function of the spectral subtype. Each point

[3] ⟨http://vizier.u-strasbg.fr/viz-bin/VizieR-3⟩.

Table 4. Values of the confidence with which the accepted fit is better than the fit with the one less component.

Star	4–3 comps	3–2 comps	2–1 comps	Star	4–3 comps	3–2 comps	2–1 comps
HD 5394		0.9132		HD 25940		0.9972	
HD 53367	1.0000			HD 45725		1.0000	
HD 203374	0.9483			HD 183362	0.9807		
HD 206773		1.0000		HD 208057		1.0000	
HD 200310			0.9993	HD 205637	1.0000		
HD 212571		0.9826		HD 217543	1.0000		
HD 44458	0.9981			HD 217050	1.0000		
HD 200120			1.0000	HD 89884		1.0000	
HD 193237	1.0000			HD 22192		1.0000	
HD 45910	0.1609			HD 23302		1.0000	
HD 37202	1.0000			HD 45542		0.9998	
HD 36576		0.9931		HD 109387	0.9996		
HD 212076		1.0000		HD 23480		0.9998	
HD 32991		0.6737		HD 217891			
HD 58050		0.9978		HD 138749		0.9936	
HD 164284		0.7826		HD 23630		0.9986	
HD 41335	1.0000			HD 209409		0.9954	
HD 52721		0.9767		HD 6811	1.0000		
HD 58343		0.9928		HD 192044		0.8070	
HD 148184		0.9396		HD 210129		0.8927	
HD 202904		0.9475		HD 142983	1.0000		
HD 65079	1.0000			HD 29866		1.0000	
HD 28497	1.0000			HD 47054		0.9086	
HD 45995	0.1169			HD 183914		0.9975	
HD 10516	0.9981			HD 50138			0.6758
HD 187567		0.9747		HD 58715		0.9189	
HD 191610		0.9990		HD 23552			1.0000
HD 32343		0.7793		HD 185037		0.9500	
HD 65875		1.0000		HD 199218		0.9693	
HD 60855	0.9800			HD 91120		0.9778	
HD 37490	1.0000			HD 142926	1.0000		
HD 50820		0.6221		HD 144	1.0000		

refers to the mean value extracted for each spectral subtype. Finally, the radial velocities of the emission component as a function of the respective rotational velocities are shown in figure 8.

The values that we calculated lie within a small range, and we can obtain only the mean values of the radial and rotational velocities and their standard deviations. The points in the diagrams correspond to the mean values of the velocities for each spectral subtype, and the error bars that appear in some of the diagrams to the standard deviation. This standard deviation is not only a statistical error, but it also includes any possible variation of the inclination axis and the error of the spectral classification, since the spectral classification that was based in the optical range could not be appropriate for the UV range. This means that the error bars that appear in the diagrams include the statistical error as well as the dispersion of the values due to a different axis inclination.

The reproduction of the Mg II resonance lines $\lambda\lambda$ 2795.523, 2802.698 Å, using the model where SACs are present, suggests that the atmospherical regions where the Mg II doublet is created may be described in a unique way for all of the studied Be stars. This result confirms the suggestion given by de Jager et al. (1979) that in Be stellar atmospheres there exists a concentration of low-ionization species in the stellar wind, which is due to the occurrence of significant density variations. This result is also in agreement with the results of Morgan, Kondo, and Modisette (1977), who proposed that there are "significant absorption features" on the left side of each resonance line, which are attributed to "additional absorption within the stellar extended atmosphere". These "significant absorption features" can be the SACs that appear in the spectra of the early-type stars. Danezis et al. (2003) and Lyratzi and Danezis (2004) suggested that the peculiar phenomena observed in the spectra of Oe and Be stars, such as the SACs, are due to independent density regions in the stellar environment. Such regions may be structures that cover all, or a significant part, of the stellar disk (shells, blobs, puffs, and bubbles) (Underhill 1975; de Jager et al. 1979; Lamers et al. 1980; Henrichs 1984; Underhill & Fahey 1984; Bates & Halliwell 1986; Grady et al. 1987; Waldron et al. 1992; Cranmer & Owocki 1996; Kaper et al. 1996, 1997, 1999; Rivinius et al. 1997; Markova 2000), interaction

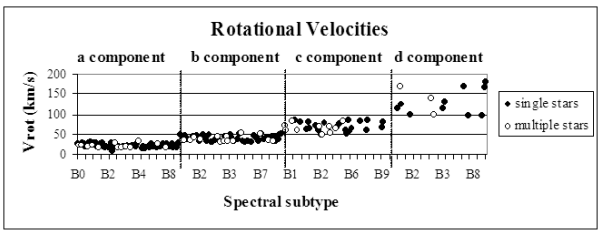

Fig. 4. Mean values for each spectral subtype of the rotational velocities of all the SACs as a function of the spectral subtype.

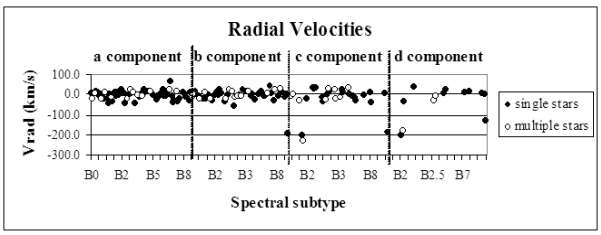

Fig. 5. Mean values for each spectral subtype of the radial velocities of all the SACs as a function of the spectral subtype.

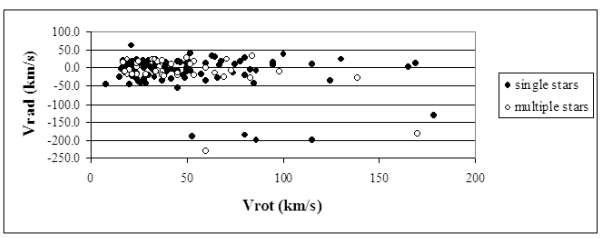

Fig. 6. Radial velocities of all the SACs as a function of the respective rotational velocities.

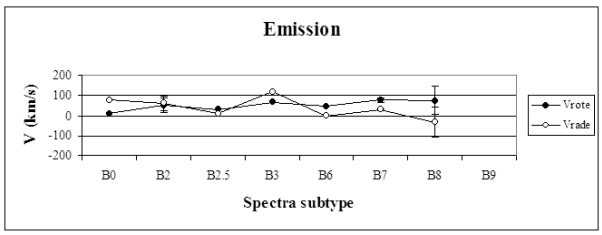

Fig. 7. Mean values for each spectral subtype of the rotational and radial velocities of the emission component as a function of the spectral subtype.

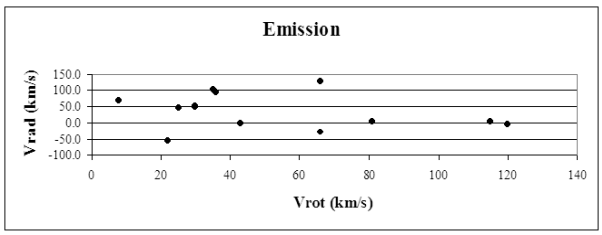

Fig. 8. Radial velocities of the emission component as a function of the respective rotational velocities.

regions of fast and slow wind components, CIRs, structures due to magnetic fields or spiral streams as a result of the stellar rotation (Underhill & Fahey 1984; Mullan 1984a, 1984b, 1986; Prinja & Howarth 1988; Cranmer & Owocki 1996; Kaper et al. 1996, 1997, 1999; Fullerton et al. 1997; Cranmer et al. 2000). This is the common theory that explains the DAC phenomenon in early-type stars. We found DAC phenomena in early B-type stars (e.g., HD 45910), as well as in late B-type stars (e.g., HD 144).

As one can see from table 2, the SAC phenomenon appears to be a classical one for the Be stars. In figure 3 and in table 2 one can see that all of the studied stars present discernible (DACs) or indiscernible (SACs) components of the Mg II resonance lines. The indiscernible components appear in the spectra of all of the stars of luminosity classes IV and V, and most of the stars of luminosity class III. It is very interesting that the SACs are observed as discrete lines (DACs) in the spectra of the three stars, HD 193237 (B2 pe), HD 45910 (B2 III e), and HD 144 (B9 III e), because they present quite different radial shifts. This means that the regions that create these lines move radially with relatively large velocities, producing lines shifted enough to be easily observed in the spectra. On the other hand, in the case of all of the other studied stars, the SACs of the Mg II resonance lines present similar radial velocities, resulting in the SACs being blended among themselves. In this case, we can distinguish these lines by systematic differentiations of the rotational velocities.

The decomposition of the observed profiles for the Mg II regions in Be stellar atmospheres confirms the existence of independent density regions, since by using such a structure, we were able to reproduce the resonance lines of Mg II in all of the studied stars. This decomposition is physically meaningful, since it enables us to detect kinematically different regions with different rotational and radial velocities, as well as the optical depth and the column density, for each of the Mg II independent density regions, which produce DACs or SACs.

Our analysis shows that regions where the considered Mg II resonance lines originate ("blobs" and "puffs" created by winds or cool extended envelopes) may consist of more independent density layers of matter with different kinematical properties (one to four in the analyzed cases). We identified them by the decomposition of observed Mg II lines in the number of components that best fit the observed profile. Namely, depending on particular stars, we obtained that SACs or DACs may be divided in several rotational velocity groups (average values for rotational velocity groups found to be present at 64 considered stars are 22 ± 5 km s^{-1}, 41 ± 7 km s^{-1}, 69 ± 11 km s^{-1}, and 130 ± 31 km s^{-1}). The corresponding radial velocities are near zero (-3.3 ± 20.3 km s^{-1} for the first density region, -3.6 ± 20.6 km s^{-1} for the second one, -1.0 ± 21.8 km s^{-1} for the third one, and $+4.0\pm22.7$ km s^{-1} for the fourth one). In the spectra of the stars HD 193237 (B2 pe), HD 45910 (B2 III e), and HD 144 (B9 III e) the SACs appear as discrete components (DACs), and the radial velocities of the

third and the fourth density regions are -205.7 ± 21.7 km s^{-1} and -170.6 ± 36.6 km s^{-1}, respectively. In the case of the star HD 144, the second component also appears as a discrete component. The radial velocity of the region that creates this component is -188.6 km s^{-1} (figures 4, 5, and 6). The observed velocity dispersion may be due to the different values of the rotational axis inclination of the regions where the SACs are created. The results presented above confirm that the Mg II doublet is more or less stable for a given spectral type as Gurzadyan (1975) suggested. We did not find any variation of the velocities in the Mg II regions with the luminosity class, except in the case of the peculiar stellar spectra, where the SACs appear as discrete lines (DACs), while Kondo, Morgan, and Modisette (1976) proposed that, apart from the difference among spectral subtypes, there is probably difference among luminosity classes too.

We assume that independent density regions corresponding to particular components of considered Mg II lines (one to four components corresponding to one to four regions in the case of 64 stars analyzed here) lie all in the cool stellar envelope. Depending on the temperature, different ions with different ionization potential are created in different regions at different distances from the star. This means that the spectral lines observed in the spectra of Be stars are derived from specific atmospherical regions, different among themselves. The ions that are created very close to the star lie in regions that present spherical symmetry around the star (case A in figure 1). On the other hand, the ions that are created at long distance from a star lie in regions that present spherical symmetry around their own center, and not around the star (case B in figure 1). As the ionization potential of the Mg II ions is I.P.=7.646 eV, the Mg II ions can be created only at great distance from the center of the star, i.e., in the disk, where spherical symmetry around the star cannot be accepted. This means that the Mg II ions lie at regions which present topical or apparent spherical symmetry (case B in figure 1). As a result, the Mg II spectral lines and their SACs/DACs may be derived only from such regions (case B in figure 1), and not from classically spherical regions around the star (case A in figure 1). This kind of density regions (blobs) has been proposed by many researchers (Underhill 1975; de Jager et al. 1979; Lamers et al. 1980; Henrichs 1984; Underhill & Fahey 1984; Mullan 1984a, 1984b, 1986; Bates & Halliwell 1986; Grady et al. 1987; Prinja & Howarth 1988; Waldron et al. 1992; Cranmer & Owocki 1996; Kaper et al. 1996, 1997, 1999; Fullerton et al. 1997; Rivinius et al. 1997; Markova 2000; Cranmer et al. 2000) and are detected in many other cases, as in active stars (WR 104, see figure 2) and many quasars, as we observe DACs/SACs in their UV spectra (Danezis et al. 2006). This means that the density regions are a common phenomenon, observed at different levels. The fact that we found one to four components is accidental. In principle, there could be more or less. Although the number of components is different in different stars, we may conclude that the Mg II resonance lines forming regions present a complex structure.

Our proposition that the SAC phenomenon is responsible for the structure of Mg II lines means that we theoretically expect that the Mg II components have similar radial velocities, within the range of the statistical error (~ 10 km s^{-1}). The problem was how to distinguish them. The common idea (Doazan 1982) is that the radial velocity of the kinematically independent regions is a function of the distance from the rapidly rotating Be star. Accordingly, our first thought was to distinguish these regions according to their rotational velocities, which was confirmed by our calculations. Namely, the regions that create the Mg II lines have similar radial velocities and different rotational velocities.

In our sample we could not detect high radial velocities, no matter what method we used (the proposed model or any other classical method). The radial velocities of all the SACs, in all the studied stars, are about 0 km s^{-1}, and only in the case of the stars HD 193237 (B2 pe), HD 45910 (B2 III e), and HD 144 (B9 III e), where we observed DACs, did we calculate radial velocities with values between -130 km s^{-1} and -230 km s^{-1}. We could detect the same phenomenon in the case of Si IV in a sample of 68 Be stars (values of radial velocities between -116 km s^{-1} and $+25$ km s^{-1}) (Lyratzi et al. 2006), as well as in the case of Hα in 120 Be stars (values of radial velocities around 0 km s^{-1}) (Lyratzi et al. 2005). These results indicate that in the atmospherical layers from the photosphere (very broad components of Hα) to the cool envelope (Mg II resonance lines) we cannot detect very high radial velocities. However, as we expected, the presence of DACs in three stars of our sample indicated that from the regions near to the star toward the ones away from the star, the radial velocity increases, but it does not reach high values, as happens in the case of Oe stars. In the case of specific Be stars that present the DACs with high radial velocities in some of their spectra, e.g., 59 Cyg and γ Cas (Doazan et al. 1989; Telting & Kaper 1994), we should study each one of them as an exception of the classical rule. This proposition is based on the fact that the spectral classification was made in the optical range, and may not apply in the UV spectral range (Walborn 1971; Walborn & Panek 1984; Walborn & Nichols-Bohlin 1987) (see also the SIMBAD database[4]). This means that the spectral classifications in the optical and the UV ranges are not always in accord. As a result, some early Be stars could be late Oe stars, and we know that it is a common phenomenon to observe high radial velocities of SACs/DACs in Oe stars. However, in the case of Be stars, we have not observed the same phenomenon. This difference in the behavior of density regions in Oe and Be stars is very interesting and requires further investigation. Finally, we should pay attention to the way that the radial velocities are calculated. The classical method considered that the whole observed feature corresponds to only one spectral line, meaning that the radial velocity was calculated by the displacement of the deeper point of the observed feature. Considering the SAC idea, the observed feature consists of a number of spectral line components. As a result, the deeper point of the observed feature is only the result of the synthesis of all the SACs. In this case we should calculate the radial velocity of every one of these components.

An emission component is present in the spectra of B0, B2, B2.5, B3, B6, B7, B8, and B9 type stars (figure 7). This means that emission does not appear in the spectra of the middle spectral subtypes of Be stars (Kondo et al. 1975). The radial

[4] ⟨http://simbad.u-strasbg.fr/sim-fid.pl⟩.

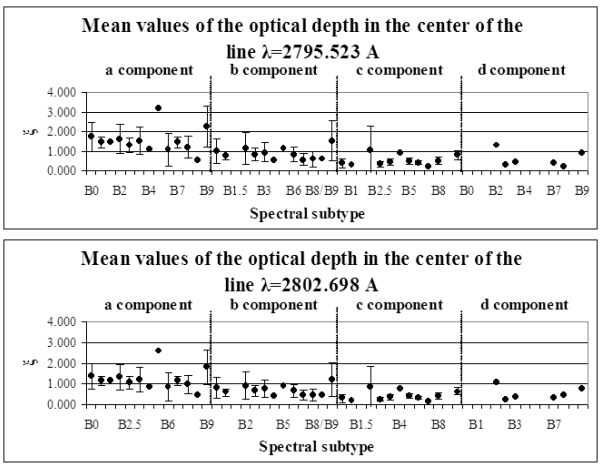

Fig. 9. Mean values of the optical depth, ξ, in the center of the line for all kinematically separated components of each resonance line, as a function of the spectral subtype.

velocity of the emission component decreases as the rotational velocity increases. The emission component presents positive or negative radial velocity. If one takes into account that negative radial velocities exist, which is not in agreement with the assumption that all emission components are the emission part of P Cygni profiles formed by scattering, one can assume the following. The obtained velocities correspond to the regions where the emission component is created as, e.g., strings, blobs, puffs, bubbles. This means that the emission region may approach, or move away from, the observer, and its different position and motion around the star is responsible for whether this value is positive or negative. In figures 7 and 8, one can see that as the rotational velocity increases the radial velocity decreases, in contrast to the relation of the two velocities of the absorption components. A problem with the emission component is that it is blended with the absorption lines of other ions, and thus it is difficult to evaluate the rotational and radial velocities. As a result, the calculated values present greater statistical error than in the case of the absorption components.

According to the criteria described in Danezis et al. (2003), the same components of the two resonance lines should have the same values of rotational and radial velocities and the ratio of the optical depth (ξ) should be the same as the respective ratio of the relative intensities. In figure 9, we present the mean values of the optical depth (ξ) in the center of the line for all kinematically separated components of each resonance line, as a function of the spectral subtype. As one can see, the value of ξ of the first kinematical region is obviously higher than in the other three. It tends to decrease from the first kinematical region to the fourth. That, also, may indicate physically separated regions.

5. Conclusions

We applied a method developed in Danezis et al. (2003) and Lyratzi and Danezis (2004) to the Mg II resonance line of 64 Be stars in order to investigate the kinematical properties of the Mg II resonance line forming region. We obtained the rotational and radial velocities, which allowed us to extract some general physical properties concerning the Mg II regions of Be stars. Some interesting results inferred from the investigations are the following: (i) The proposed rotation model gives satisfactory results for the region of the Mg II $\lambda\lambda$ 2795.523, 2802.698 Å resonance lines. (ii) The atmospherical absorption region where the Mg II resonance lines are created presents a complex structure. It tends to be composed by more than one kinematically independent region (only four stars present a simple structure). We found that the kinematically independent regions rotate with different velocities: 22 $\mathrm{km\ s^{-1}}$, 41 $\mathrm{km\ s^{-1}}$, 69 $\mathrm{km\ s^{-1}}$, and 130 $\mathrm{km\ s^{-1}}$. The respective radial velocities are near to zero for all of these regions. These calculated values lead us to accept that the Mg II resonance lines of the Be stellar spectra present Satellite Absorption Components (SACs). (iii) The rotational velocities of the found independent regions present a uniform fluctuation with the spectral subtype. (iv) The emission lines were detected for the earliest and latest spectral subtypes with positive radial velocities with several exceptions; i.e., they have negative radial velocities ranging from 0 to -87 km $\mathrm{s^{-1}}$. If lines are formed by scattering, the positive values are not radial velocities.

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Appendix. Calculation of the Distribution Function L

As we know, the distribution function (L) of the absorption coefficient (k_λ) has the same form as the distribution function of each component of the spectral line. This means that we can replace the distribution function of the absorption coefficient, L_i, with another expression for the distribution function of each component.

It is also known that Be and Oe stars are rapid rotators. This means that we accept that the main reason for the line broadening is rotation of the regions that produce each satellite component of the whole observed spectral feature. These rapidly rotating density regions may also present radial motion. For these two reasons, we seek another expression for the distribution function of the spectral line's components that has as parameters the rotational and radial velocities of the spherical density regions.

For a spherical density region, we assume the following hypotheses: i) the natural broadening of the spectral lines follows the Lorentz distribution; ii) Lambert's sinus law stands for each point of the spherical region; iii) the angular velocity of rotation is constant.

In order to calculate the total radiation, we divide the

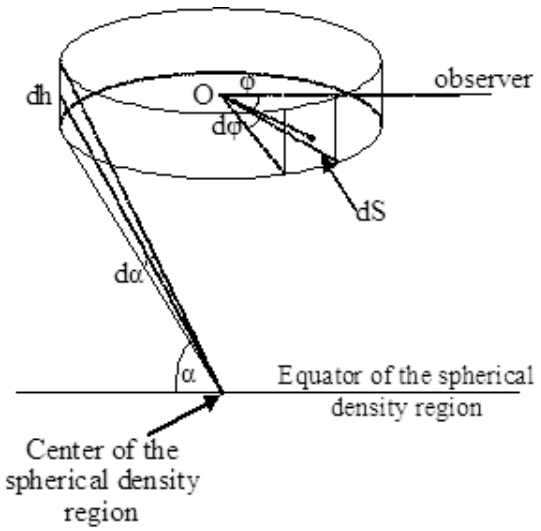

Fig. 10. Elementary ring of the spherical density region.

spherical layer in very thin cylindrical surfaces that are perpendicular to the rotational axis. Lambert's law allows us to consider that the luminosity from each point on the sphere is the same.

On the above cylindrical surface we also consider the surface dS. According to Lambert's law, when this surface rotates with an angular velocity ω, its radiation intensity is

$$dI(\omega) = Q(\omega) dS \cos\theta, \tag{A1}$$

where θ is the angle between the vertical on dS and the line of sight and

$$Q(\omega) = C_1 \frac{\gamma}{(\omega-\omega_k)^2 + \left(\frac{\gamma}{2}\right)^2}. \tag{A2}$$

C_1 is a constant and γ is the Lorentzian full width at half maximum, which in the case of natural broadening has a value of $\gamma \cong 10^8$ Hz.

When the surface dS does not rotate, the center of the formed spectral line has the observed wavelength, λ_0, which corresponds to a frequency, ν_0. Thus,

$$\omega_0 = 2\pi\nu_0 = 2\pi\frac{c}{\lambda_0}. \tag{A3}$$

When the surface dS rotates with a rotational velocity $V_{\rm rot}$, the center of the formed line has the wavelength λ_k, and in this case $\omega_k = \omega_0(1 - z\sin\varphi)$, where $z = V_{\rm rot}/c$.

We also have $\cos\theta \cong \cos\alpha\cos\varphi$. The angles α and φ are shown in figure 10.

The surface dS can be written as $dS = rdhd\varphi$, where r is the radius of the cylinder, $d\varphi$ the angle under which the observer sees dS, and dh the height of dS.

Making the above substitutions in equation (A1), we have

$$dI(\omega) = \frac{C_1 r dh\gamma\cos\alpha\cos\varphi d\varphi}{[\omega-\omega_0(1-z\sin\varphi)]^2 + \left(\frac{\gamma}{2}\right)^2}. \tag{A4}$$

Thus, the radiation intensity from the semicylinder is

$$I(\omega) = \int_{-\pi/2}^{\pi/2} \frac{C_1 r dh\gamma\cos\alpha\cos\varphi d\varphi}{[\omega-\omega_0(1-z\sin\varphi)]^2 + \left(\frac{\gamma}{2}\right)^2} \tag{A5}$$

or

$$I(\omega) = \frac{4C_1 r dh}{\gamma} \times \int_{-\pi/2}^{\pi/2} \frac{\cos\alpha d(\sin\varphi)}{\{[\omega/(\gamma/2)] - [\omega_0/(\gamma/2)](1-z\sin\varphi)\}^2 + 1}. \tag{A6}$$

If we take that $\tilde{\omega} = \omega/(\gamma/2)$, $\tilde{\omega}_0 = \omega_0/(\gamma/2)$, $x = \sin\varphi$, we have

$$I(\tilde{\omega}) = \frac{4C_1 r\cos\alpha dh}{\gamma} \int_{-1}^{1} \frac{dx}{[\tilde{\omega}-\tilde{\omega}_0(1-zx)]^2 + 1}. \tag{A7}$$

Taking that $y = \tilde{\omega} - \tilde{\omega}_0(1-zx)$, the above integral becomes

$$I(\tilde{\omega}) = \frac{4C_1 r\cos\alpha dh}{\gamma\tilde{\omega}_0 z} \int_{\tilde{\omega}-\tilde{\omega}_0(1+z)}^{\tilde{\omega}-\tilde{\omega}_0(1-z)} \frac{dy}{y^2+1}. \tag{A8}$$

Finally, we have

$$I(\tilde{\omega}) = \left(\frac{4C_1 r\cos\alpha dh}{\gamma}\right) \times \left(\frac{\arctan[\tilde{\omega}-\tilde{\omega}_0(1-z)] - \arctan[\tilde{\omega}-\tilde{\omega}_0(1+z)]}{\tilde{\omega}_0 z}\right). \tag{A9}$$

The above function describes the radiation intensity from a visual semicylinder with radius r and height dh.

Under the angle $d\alpha$ is seen dh from the center of the spherical region. This cylinder rotates with a rotational velocity, $z = V_{\rm rot}/c$, and a constant angular velocity, $\tilde{\omega}$.

We consider the function

$$P(\tilde{\omega}, z) = \frac{\arctan[\tilde{\omega}-\tilde{\omega}_0(1-z)] - \arctan[\tilde{\omega}-\tilde{\omega}_0(1+z)]}{\tilde{\omega}_0 z}. \tag{A10}$$

We study the limit of this function in the case that the density layer does not rotate, i.e., when $z \to 0$. In such a case,

$$\lim_{z\to 0} P(\tilde{\omega}, z) = \lim_{z\to 0} \frac{\arctan[\tilde{\omega}-\tilde{\omega}_0(1-z)] - \arctan[\tilde{\omega}-\tilde{\omega}_0(1+z)]}{\tilde{\omega}_0 z}. \tag{A11}$$

We apply L' Hospital's theorem and we obtain

$$\lim_{z\to 0} P(\tilde{\omega}, z) = \lim_{z\to 0} \frac{\frac{d}{dz}\{\arctan[\tilde{\omega}-\tilde{\omega}_0(1-z)]\} - \frac{d}{dz}\{\arctan[\tilde{\omega}-\tilde{\omega}_0(1+z)]\}}{\frac{d}{dz}(\tilde{\omega}_0 z)}, \tag{A12}$$

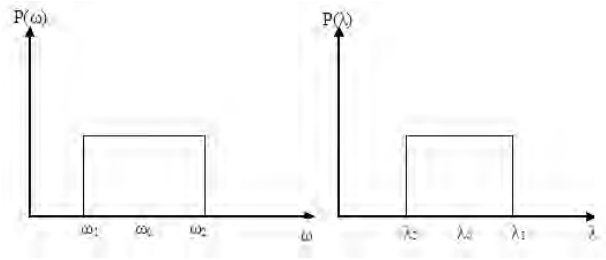

Fig. 11. Quadratic pulsation.

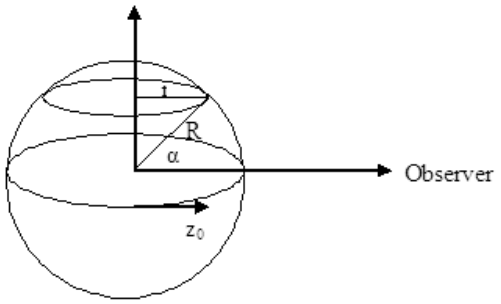

Fig. 12. Rotating spherical density region that produces SACs or DACs.

$$\lim_{z\to 0} P(\tilde{\omega}, z) = \lim_{z\to 0}\left[\frac{1}{1+[\tilde{\omega}-\tilde{\omega}_0(1-z)]^2}+\frac{1}{1+[\tilde{\omega}-\tilde{\omega}_0(1+z)]^2}\right] = \frac{2}{(\tilde{\omega}-\tilde{\omega}_0)^2+1}. \quad \text{(A13)}$$

It is obvious that in the nonrotating case this form corresponds to the Lorentz's distribution for the naturally broadened spectral lines.

In the case where the rotation broadening, $|\lambda_1-\lambda_2|$ (or $|\omega_1-\omega_2|$), is much larger than the natural broadening (the natural broadening of a spectral line is of an order of 10^{-3}–10^{-4}Å), the above function, $P(\tilde{\omega}, z)$, presents the form of one quadratic pulsation (see figure 11)

For each ω with $\omega_1 < \omega < \omega_2$, the relative shift is $z = |\Delta\omega|/\omega_0$. For a point ω_1 we have $(\omega_0-\omega_1)/\omega_0 = z$, so that $\omega_1 = \omega_0(1-z)$. Likewise, for a point ω_2 we have $\omega_2 = \omega_0(1+z)$. But, $\omega = 2\pi\nu = 2\pi c/\lambda$. Thus, $\lambda_1 = \lambda_0/(1-z)$ and $\lambda_2 = \lambda_0/(1+z)$ with $\lambda_1 > \lambda_2$.

This means that $\Delta\lambda_{\text{total}} \equiv \lambda_1-\lambda_2 = 2\lambda_0 z/(1-z^2)$ and so $\lambda_{\min} \equiv \lambda_2 = \lambda_0 - \Delta\lambda_{\text{total}}/2 = \lambda_0 - \lambda_0 z/(1-z^2)$ and $\lambda_{\max} \equiv \lambda_1 = \lambda_0 + \Delta\lambda_{\text{total}}/2 = \lambda_0 + \lambda_0 z/(1-z^2)$.

We set $\rho = \lambda_0 z/(1-z^2)$ and normalize to 1. In this way, the function $P(\tilde{\omega}, z)$ could be approximated by the function $f(\lambda)$ where:

$$f(\lambda) = \begin{cases} 1 & |\lambda-\lambda_0| < \rho \\ 0 & \text{otherwise} \end{cases}. \quad \text{(A14)}$$

We now assume that the spherical density region rotates with equatorial velocity $z_0 = V_0/c$ (figure 12).

The points of the circle with radius r rotate with a velocity V_{rot} and for $r = R\cos\alpha$ we take $V_{\text{rot}} = \omega r = \omega R\cos\alpha$.

We set $V_0 = \omega R$. Also, $\omega = \text{const}$. Thus, $V_{\text{rot}} = (V_0/R)\, R\cos\alpha = V_0\cos\alpha$ and $z = z_0\cos\alpha$. We also have $dh = Rd\alpha$ and equation (A1) becomes

$$dI(\tilde{\omega}) = \frac{4C_1R}{\gamma} \times \frac{\arctan[\tilde{\omega}-\tilde{\omega}_0(1-z_0\cos\alpha)] - \arctan[\tilde{\omega}-\tilde{\omega}_0(1+z_0\cos\alpha)]}{\tilde{\omega}_0 z_0\cos\alpha} \times \cos\alpha d\alpha. \quad \text{(A15)}$$

The integral of this equation is

$$I(\tilde{\omega}) = \frac{4C_1R}{\gamma} \times \int_{-\pi/2}^{\pi/2} \frac{\arctan[\tilde{\omega}-\tilde{\omega}_0(1-z_0\cos\alpha)] - \arctan[\tilde{\omega}-\tilde{\omega}_0(1+z_0\cos\alpha)]}{\tilde{\omega}_0 z_0\cos\alpha} \times \cos\alpha d\alpha. \quad \text{(A16)}$$

When we take into account the function $P(\tilde{\omega}, z)$, the above function becomes

$$I(\tilde{\omega}) = \frac{4C_1R}{\gamma}\int_{-\pi/2}^{\pi/2} P(\tilde{\omega}, z_0\cos\alpha)\cos\alpha d\alpha. \quad \text{(A17)}$$

We approximate $P(\tilde{\omega}, z_0\cos\alpha)$ at $f(\lambda)$ and take the integral for the observation angle $\theta \in [-\theta_0, \theta_0]$ from the equatorial plane.

We have

$$I(\tilde{\omega}) \cong I_1 = \frac{4C_1R}{\gamma}\int_{-\theta_0}^{\theta_0} 1\cdot\cos\theta d\theta, \quad \text{(A18)}$$

$$I_1 = \frac{4C_1R}{\gamma}\int_{-\theta_0}^{\theta_0}\cos\theta d\theta = \frac{4C_1R}{\gamma}[\sin\theta]_{-\theta_0}^{\theta_0} = \frac{8C_1R}{\gamma}\sin\theta_0. \quad \text{(A19)}$$

If we normalize the constant, we have

$$I_1 = \sin\theta_0 = \sqrt{1-\cos^2\theta_0}. \quad \text{(A20)}$$

For angle θ_0 we have

$$|\lambda-\lambda_0| \le \rho_0 = \frac{\lambda_0 z_0\cos\theta_0}{1-z_0^2\cos^2\theta_0}. \quad \text{(A21)}$$

For a wavelength λ or for a shift of $\Delta\lambda = |\lambda-\lambda_0|$ from the center of the spectral line, the absorbing (or emitting) regions are those with angular distance θ from the equatorial plane, with $|\theta| \le \theta_0$.

For the equatorial plane we have

$$\Delta\lambda = \frac{\lambda_0 z_0\cos\theta_0}{1-z_0^2\cos^2\theta_0}. \quad \text{(A22)}$$

From this equation we can calculate the angle θ_0 as

$$\cos\theta_0 = \frac{-\lambda_0 \pm \sqrt{\lambda_0^2+4\Delta\lambda^2}}{2\Delta\lambda z_0}. \quad \text{(A23)}$$

Since θ_0 is between $-\pi/2$ and $\pi/2$, we have $\cos\theta_0 \geq 0$, and so

$$\cos\theta_0 = \frac{-\lambda_0 + \sqrt{\lambda_0^2 + 4\Delta\lambda^2}}{2\Delta\lambda z_0}. \quad \text{(A24)}$$

Thus, the distribution function I_1 takes its final form:

$$I_1 = \sqrt{1-\cos^2\theta_0} \quad \text{if} \quad \cos\theta_0 = \frac{-\lambda_0 + \sqrt{\lambda_0^2 + 4\Delta\lambda^2}}{2\Delta\lambda z_0} < 1 \quad \text{(A25)}$$

and

$$I_1 = 0 \quad \text{otherwise.} \quad \text{(A26)}$$

It is obvious that the distribution function I_1 is a function of the wavelength (λ). This means that $I_1 = I_1(\lambda)$. This distribution function has the same form as the distribution function of the absorption coefficient, L, and may replace it (in $e^{-L\xi}$), when the main reason of the line broadening is rotation. We name it the rotation distribution function.

The spectral line profile, which is formed by a spherical density region, is reproduced by the function $e^{-L\xi}$ by applying an appropriate value of the rotational velocity, $V_{\rm rot}$ (from z_0), the radial velocity, $V_{\rm rad}$ [from $V_{\rm rad}/c = (\lambda_0 - \lambda_{\rm lab})/\lambda_{\rm lab}$], and the optical depth, ξ, in the center of the line.

References

Bates, B., & Halliwell, D. R. 1986, MNRAS, 223, 673
Cidale, L. S. 1998, ApJ, 502, 824
Cowley, A. 1972, AJ, 77, 750
Cowley, A., Cowley, C., Jaschek, M., & Jaschek, C. 1969, AJ, 74, 375
Cranmer, S. R., & Owocki, S. P. 1996, ApJ, 462, 469
Cranmer, S. R., Smith, M. A., & Robinson, R. D. 2000, ApJ, 537, 433
Dachs, J. 1980, Second European IUE Conf. (ESA SP-157), (Paris: ESA), 139
Danezis, E. 1983, PhD Thesis, University of Athens
Danezis, E. 1987, in Physics of Be Stars, ed. A. Slettebak & T. P. Snow (Cambridge: Cambridge University Press), 445
Danezis, E., et al. 2003, Ap&SS, 284, 1119
Danezis, E., Popović, L. Č., Lyratzi, E., & Dimitrijević, M. S. 2006, in The Physics of Ionized Gases, ed. L. Hadzievski, B. Marinkovic, & N. Simonovic (AIP), 373
Danezis, E., Theodossiou, E., & Laskarides, P. G. 1991, Ap&SS, 179, 111
de Jager, C., Kondo, Y., Hoekstra, R., van der Hucht, K. A., Kamperman, T. M., Lamers, H. J. G. L. M., Modisette, J. L., & Morgan, T. H. 1979, ApJ, 230, 534
Doazan, V. 1982, in B Stars With and Without Emission Lines, ed. A. Underhill & V. Doazan (Washington, D. C. : NASA), 279
Doazan, V., Barylak, M., Rusconi, L., Sedmak, G., Thomas, R. N., & Bourdonneau, B. 1989, A&A, 210, 249
Doazan, V., Sedmak, G., Barylak, M., & Rusconi, L. 1991, A Be Star Atlas of Far UV and Optical High-Resolution Spectra (ESA SP-1147), (Noordwijk: ESA Publications Division)
Doazan, V., & Thomas, R. N. 1982, in B Stars With and Without Emission Lines, ed. A. Underhill & V. Doazan (Washington, D. C. : NASA), 409
Fullerton, A. W., Massa, D. L., Prinja, R. K., Owocki, S. P., & Cranmer, S. R. 1997, A&A, 327, 699
Grady, C. A., Sonneborn, G., Wu, C.-C., & Henrichs, H. F. 1987, ApJS, 65, 673
Guetter, H. H. 1968, PASP, 80, 197
Gurzadyan, G. A. 1975, PASP, 87, 289
Henrichs, H. F. 1984, Fourth European IUE Conf. (ESA SP-218), (Noordwijk: ESA), 43
Herbig, G. H., & Spalding, J. F., Jr. 1955, ApJ, 121, 118
Houk, N., & Smith-Moore, M. 1988, Michigan Catalogue of Two-Dimensional Spectral Types for HD Stars, vol.4
Houziaux, L., & Andrillat, Y. 1976, IAU Symp., 70, 87
Hutsemékers, D. 1985, A&AS, 60, 373
Kaper, L., et al. 1997, A&A, 327, 281
Kaper, L., Henrichs, H. F., Nichols, J. S., Snoek L. C., Volten, H., & Zwarthoed G. A. A. 1996, A&AS, 116, 257
Kaper, L., Henrichs, H. F., Nichols, J. S., & Telting, J. H. 1999, A&A, 344, 231
Kelly, R. L. 1979, Atomic Emission Lines in the Near Ultraviolet (NASA TM 80268), (Washington, D. C. : NASA)
Kondo, Y., Modisette, J. L., & Wolf, G. W. 1975, ApJ, 199, 110
Kondo, Y., Morgan, T. H., & Modisette, J. L. 1976, ApJ, 209, 489
Lamers, H. J. G. L. M., Faraggiana, R., & Burger, M. 1980, A&A, 82, 48
Laskarides, P. G., Theodossiou, E., & Danezis, E. 1992, Ap&SS, 179, 13
Lesh, J. R. 1968, ApJS, 17, 371
Lyratzi, E., & Danezis, E. 2004, AIP Conf. Proc., 740, 458
Lyratzi, E., Danezis, E., Antoniou, A., Nikolaidis, D., Popović, L. Č., & Dimitrijević, M. S. 2006, IAU Joint Discussion 4
Lyratzi, E., Danezis, E., Nikolaidis, D., Popović, L. Č., Dimitrievć, M. S., Theodossiou, E., & Antoniou, A. 2005, Mem. Soc. Astron. Ital. Suppl., 7, 114
Lyratzi, E., Danezis, E., Stathopoulou, M., Theodossiou, E., Nikolaidis, D., Drakopoulos, C., & Soulikias, A. 2003, Publ. Astron. Obs. Belgrade, 76, 27
Markova, N. 2000, A&AS, 144, 391
Marlborough, J. M., Snow, T. P., Jr., & Slettebak, A. 1978, ApJ, 224, 157
Moore, C. E. 1968, National Bureau of Standard Circ., 488
Morgan, T. H., Kondo, Y., & Modisette, J. L. 1977, ApJ, 216, 457
Morgan, W. W., Code, A. D., & Whitford, A. E. 1955, ApJS, 2, 41
Mullan, D. J. 1984a, ApJ, 283, 303
Mullan, D. J. 1984b, ApJ, 284, 769
Mullan, D. J. 1986, A&A, 165, 157
Osawa, K. 1959, ApJ, 130, 159
Peton, A. 1974, Space Sci. Rev., 30, 481
Popović, L. Č., et al. 2004, AIP Conf. Proc., 740, 497
Prinja, R. K., & Howarth, I. D. 1988, MNRAS, 233, 123
Rivinius, T., et al. 1997, A&A, 318, 819
Sahade, J., & Brandi, E. 1985, Rev. Mex. Astron. Astrofis., 10, 229
Sahade, J., Brandi, E., & Fontenla, J. M. 1984, A&AS, 56, 17
Slettebak, A. 1954, ApJ, 119, 146
Slettebak, A., & Snow, T. P., Jr. 1978, ApJ, 224, L127
Smith, M. A. 2001, PASP, 113, 882
Telting, J. H., & Kaper, L. 1994, A&A, 284, 515
Tuthill, P. G., Monnier, J. D., & Danchi, W. C. 1999, Nature, 398, 487

Underhill, A. B. 1970, in Spectrum Formation in Stars With Steady-State Extended Atmospheres, ed. H. G. Groth & P. Wellman (Washington, D. C. : National Bureau of Standards), 3
Underhill, A. B. 1975, ApJ, 199, 691
Underhill, A. B., & Fahey, R. P. 1984, ApJ, 280, 712
Walborn, N. R. 1971, ApJS, 23, 257
Walborn, N. R., & Nichols-Bohlin, J. 1987, PASP, 99, 40
Walborn, N. R., & Panek, R. J. 1984, ApJ, 280, L27
Waldron, W. L., Klein, L., & Altner, B. 1992, ASP Conf. Ser., 22, 181

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A New Model for the Structure of the DACs and SACs Regions in the Oe and Be Stellar Atmospheres

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Abstract

We present a new mathematical model for the density regions where a specific spectral line and its SACs/DACs are created in the Oe and Be stellar atmospheres. In calculations of final spectral line function we consider that the main processes for the line broadening are the rotation of the density regions creating the spectral line and its DACs/SACs, as well as the random motions of the ions. This line function is able to reproduce the spectral feature, which enables us to calculate some important physical parameters, such as the rotational, radial, and random velocities, the full width at half maximum, the Gaussian deviation, the optical depth, the column density, and the absorbed or emitted energy. Additionally, we can calculate the percentage of the contribution of the rotational velocity and the ions' random motions of the DACs/SACs regions to the line broadening. Finally, we present two tests and three short applications of the proposed model.

Key words: stars: early type, emission-line — ultraviolet: stars

1. Introduction

When we study the UV lines of hot emission stars we have to deal with two problems: (i) The presence of a very complex structure of many spectral lines in the UV region, such as the resonance lines of Si IV, C IV, N V, Mg II, and the N IV spectral line. (ii) The presence of Discrete Absorption Components (DACs, Bates & Halliwell 1986).

DACs are discrete, but not unknown, absorption spectral lines. They are spectral lines of the same ion and the same wavelength as a main spectral line, shifted at different $\Delta\lambda$, since they are created in different density regions, which rotate and move radially with different velocities (Danezis 1983, 1987; Danezis et al. 2003; Lyratzi et al. 2007). DACs are lines, easily observed in the case that the regions that give rise to them rotate with low velocities and move radially with high velocities.

Many suggestions have been made to explain the DACs phenomenon. Most researchers have suggested mechanisms that allow the existence of structures which cover all or a significant part of the stellar disk, such as shells, blobs, or puffs (Underhill 1975; Henrichs 1984; Underhill & Fahey 1984; Bates & Halliwell 1986; Grady et al. 1987; Lamers et al. 1988; Waldron et al. 1992, 1994; Cranmer & Owocki 1996; Rivinius et al. 1997; Kaper et al. 1996, 1997, 1999; Markova 2000). Some researchers have also suggested interaction of fast and slow wind components, Corotation Interaction Regions (CIRs), and structures due to magnetic fields or spiral streams as a result of the stellar rotation (Underhill & Fahey 1984; Mullan 1984a, 1984b, 1986; Prinja & Howarth 1988; Cranmer & Owocki 1996; Fullerton et al. 1997; Kaper et al. 1996, 1997, 1999; Cranmer et al. 2000). Though we do not yet know the mechanism responsible for the formation of such structures, it is positive that DACs result from independent high-density regions in the stellar environment.

An important question is whether there is a connection between the observed complex structure of the above-mentioned spectral lines and the presence of DACs. A possible answer is that if the regions that create the DACs rotate with large velocities and move radially with small velocities, the produced lines would have large widths and small shifts. As a result, they are blended among themselves as well as with the main spectral line, and thus they are not discrete. In such a case the name Discrete Absorption Components is inappropriate, and we use only the name Satellite Absorption Components (SACs) (Lyratzi & Danezis 2004; Danezis et al. 2005, 2006; Nikolaidis et al. 2006; D. Nikolaidis et al. 2006, presentation in 26th IAU General Assembly). A very important question is whether it is possible that the existence of SACs may be responsible for the complex structure of the observed spectral feature.

As is clear, for a future study of the mechanisms responsible for the creation of density regions that produce the complex profiles of the above-mentioned spectral lines, as well as for a study of their structure and evolution, we need to calculate the values of some physical parameters of these regions.

In order to calculate these parameters, it is necessary to construct a line function, based on the idea of DACs

and SACs phenomena able to reproduce, in the best way, the observed spectral feature.

Danezis et al. (2003) presented such a line function in the case that the process of the line broadening is only the rotation of the regions that create the observed spectral lines and their components and when these regions present spherical symmetry around their own center or the center of the star (see also Lyratzi et al. 2007). With this line function we can calculate some important physical parameters, such as the rotational and the radial velocities, the optical depth, the column density (Danezis et al. 2005) and the absorbed/emitted energy. However, in some cases the chaotic motion of emitters/absorbers inside the dense layers can be significant (see e.g., Danezis et al. 2006) and the estimated rotation might be overestimated. Therefore, a modification of the previously given model (Danezis et al. 2003) is needed, in sense that the possible contribution of random velocities to the line broadening can be taken into account.

Here, we present a new model that also includes the random motions of the ions, since in the case of hot emission stars one can expect a significant contribution of random motion of the emitters/absorbers to the line profile. Based on this idea, besides the above-mentioned physical parameters of the regions that create the complex spectral lines, we can calculate the mean random velocity of the ions, but also the percentage of the contribution of the rotational velocity and emitter/absorber random motions of the DACs/SACs regions to the line broadening, as well as the Gaussian deviation for each DAC/SAC profile.

This paper is organized as follows: In section 2 we give a description of the model. In section 3 we discuss it, in section 4 we give two tests, and in section 5 we present applications. Finally, in section 6 we outline our conclusions.

2. Description of the Model — the Line Function

As was already mentioned above, Danezis et al. (2003) presented a line function that is able to accurately reproduce the observed spectral lines and their SACs/DACs at the same time. The proposed line function is

$$F_{\lambda\mathrm{final}} = \left[F_0(\lambda) \prod_i e^{-L_i \xi_i} + \sum_j S_{\lambda \mathrm{e}j} \left(1 - e^{-L_{\mathrm{e}j} \xi_{\mathrm{e}j}}\right) \right] e^{-L_g \xi_g}, \tag{1}$$

where: $F_0(\lambda)$ is the initial radiation flux; L_i, $L_{\mathrm{e}j}$, and L_g are the distribution functions of the absorption coefficients ($k_{\lambda i}$, $k_{\lambda \mathrm{e}j}$, and $k_{\lambda g}$, respectively). Each L depends on the values of the apparent rotational velocity as well as of the radial velocity of the density shell, which forms the spectral line (V_{rot}, V_{rad}); ξ_i is the optical depth in the center of the line; $S_{\lambda \mathrm{e}j}$ is the source function, which, at the moment when the spectrum is taken, is constant.

In equation (1), the functions $e^{-L_i \xi_i}$, $S_{\lambda \mathrm{e}j} \left(1 - e^{-L_{\mathrm{e}j} \xi_{\mathrm{e}j}}\right)$, $e^{-L_g \xi_g}$ are the distribution functions of each satellite component; we can replace them with a known distribution function (Gauss, Lorentz, Voigt, or disk model). An important fact is that in the calculation of $F(\lambda)$ we can include different geometries (in the calculation of L) of the absorbing or emitting independent density layers of matter.

A decision concerning the geometry is essential to calculate the distribution function that we use for each component; i.e. for different geometries we have different line shapes, representing the considered SACs.

Equation (1) gives a function of the complex profile of a spectral line, which presents SACs or DACs. This means that equation (1) is able to reproduce not only the main spectral line, but its SACs as well.

The main hypotheses when we constructed the rotation distribution function were that the line width, $\Delta\lambda$, is only due to rotation of the regions that create the observed spectral lines and their components, and that these regions present spherical symmetry around their own center, or the center of the star (see also Lyratzi et al. 2007). Consequently, the random velocities of the emitters/absorbers in the density region are assumed to be negligible, i.e., they do not significantly contribute to the line profile. Here, we consider that the random velocities may have a significant contribution to the distribution function, L (see Appendix). In this case the final form of L is given as

$$L(\lambda) = \frac{\sqrt{\pi}}{2\lambda_0 z} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \left[\mathrm{erf}\left(\frac{\lambda - \lambda_0}{\sigma\sqrt{2}} + \frac{\lambda_0 z}{\sigma\sqrt{2}} \cos\theta \right) - \mathrm{erf}\left(\frac{\lambda - \lambda_0}{\sigma\sqrt{2}} - \frac{\lambda_0 z}{\sigma\sqrt{2}} \cos\theta \right) \right] \cos\theta \, d\theta, \tag{2}$$

where λ_0 is the transition wavelength of a spectral line that arises from a specific point of the equator of a spherical density region that produces one satellite component, $z = \dfrac{V_{\mathrm{rot}}}{c}$ (V_{rot} is the rotational velocity of the specific point) and $\mathrm{erf}(x) = \dfrac{2}{\pi} \displaystyle\int_0^x e^{-u^2} du$ is the function that describes the Gaussian error distribution.

3. Discussion and Way of Application of the Proposed Model

Introducing the previous final function of a complex spectral line [equation (1)], in combination with the distribution function, L, given in equation (2), we note the following:

1. The proposed line function [equation (1)] can be used for any number of absorbing or emitting regions. This means that it can also be used in the simple case that $i = 1$ and $j = 0$ or $i = 0$ and $j = 1$, meaning when we deal with simple, classical absorption or emission spectral lines, respectively. This allows us to calculate all of the important physical parameters, such as the rotational, radial, and random velocities, the full width at half maximum, the Gaussian deviation, the optical depth, the column density (Danezis et al. 2005), and the absorbed or emitted energy, for all simple and classical spectral lines in all spectral ranges.

2. For each group of parameters (V_{rot_i}, V_{rad_i}, V_{rand_i}, and ξ_i), the function $I_{\lambda i} = e^{-L_i \xi_i}$ reproduces the spectral line profile formed by the i density region of matter, meaning that for each group we have a totally different profile. This results

in the existence of only one group of V_{rot_i}, V_{rad_i}, V_{rand_i}, and ξ_i giving the best fit of the i component. In order to accept that as the best fit of the observed spectral line, given by the groups (V_{rot_i}, V_{rad_i}, V_{rand_i}, ξ_i) of all calculated SACs, one has to adhere to all physical criteria and techniques, such as:

i) To make a complete identification of spectral lines in the region around the studied spectral line and to have the superposition of the spectral region that we study with the same region of a classical star of the same spectral type and luminosity class, in order to identify the existence of spectral lines that blend with the studied ones, as well as the existence of SACs.

ii) The resonance lines as well as all lines originating in a particular region should have the same number of SACs, depending on the structure of this region, without any influence of the ionization stage or ionization potential of the emitters/absorbers. As a consequence, the respective SACs should have similar values of the radial and rotational velocities.

iii) The ratio of the optical depths of two resonance lines must be the same as the ratio of the respective relative intensities.

3. In order to decide which group of parameters gives the best fit, we propose a model according to the following two steps:

(i) In the first step we consider that the main process for line broadening of the main line and satellite components is rotation of the region that creates the components of the observed feature; a secondary cause is thermal Doppler broadening. This means that we start fitting the line using the maximum V_{rot}. We then include Doppler broadening, in order to accomplish the best fit (rotation case). (ii) In the second step, we consider the opposite. In this case the main process of line broadening of the main line and satellite components is supposed to be Doppler broadening; a secondary process is rotation of the regions that create the components of the observed feature. This means that we start fitting the line using the maximal Doppler broadening. We then include V_{rot}, in order to accomplish the best fit (Doppler case).

In both cases (rotation case and Doppler case) we check the correct number of satellite components that construct the whole line profile. At first we fit using the number of components that give the best difference graph between the fit and the real spectral line. We then make a fit using one component less than in the previous fit. The F-test between them allows us to take the correct number of satellite components that construct in the best way the whole line profile. The F-test between these two cases indicates the best way to fit spectral lines. When the F-test cannot give a definite conclusion on which case we should use, we can still obtain information about the limits of V_{rot} and σ. If the F-test gives similar values, then the rotation case defines the maximal V_{rot} and the minimal σ and the Doppler case defines the minimal V_{rot} and the maximal σ.

4. The profiles of each main spectral line and its SACs are fitted by the function $e^{-L_i\xi_i}$ in the case of an absorption component, or $S_{\lambda \mathrm{e}j}\left(1-e^{-L_{\mathrm{e}j}\xi_{\mathrm{e}j}}\right)$ in the case of an emission component. These functions produce symmetrical line profiles. However, most of the spectral lines are asymmetric. This fact is interpreted as being a systematical variation of the apparent radial velocities of the density regions where the main spectral line and its SACs are created. In order to approximate those asymmetric profiles we have chosen a classical method. This is the separation of the region that produces asymmetric profiles of the spectral line, into a small number of sub-regions, and each of them is treated as an independent absorbing shell. In this way we can study the variation of the density, the radial shift and the apparent rotation as a function of the depth in every region that produces a spectral line with an asymmetric profile. Everything mentioned above must be taken into account during an evaluation of our results; also, one should not consider that the evaluated parameters of those sub-regions correspond to independent regions of matter, which form the main spectral line or its SACs.

5. We suggest that the width of the blue wing is the result of the composition of profiles of the main spectral line and its SACs. Thus, the blue wing of each SAC gives the apparent rotational velocity of the density shell, in which it forms. In order to conduct measurements with physical meaning, we should not calculate the width of the blue wing of the observed spectral feature, but the width of the blue wing of each SAC.

6. We would like to point out that the final criterion to accept or reject a best fit is the ability of the calculated values of the physical parameters to give us a physical description of the events developing in the regions where the spectral lines presenting SACs are created.

7. In the proposed distribution function an important factor is $m = \dfrac{\lambda_0 z}{\sqrt{2}\sigma}$. This factor indicates the kind of the distribution function that is able to fit in the best way each component's profile.

i) If $m \simeq 3$, we have equivalent contributions of the rotational and random motions to the line widths.

ii) If $m \simeq 500$, the line broadening is only an effect of the rotational velocity, and the random velocity is negligible. In this case, the profile of the line is the same as the theoretical profile derived from the rotation distribution function.

iii) Finally, if $m < 1$, the line broadening is only an effect of random velocities and the line distribution is Gaussian.

4. Testing the Model

In order to check the validity of our model we perform two tests:

I) In order to check the above spectral line function, we calculated the rotational velocity of He I λ 4387.928 Å absorption line for five Be stars, using two methods, the classical Fourier analysis and our model. In figure 1 we present five He I λ 4387.928 Å fittings for the studied Be stars and the measured rotational velocities with both methods. The obtained rotational velocities from our model are in good agreement with ones obtained with Fourier analysis.

The values of the rotational velocities, calculated with Fourier analysis, some times, may present small differences compared to those calculated with our method, because in Fourier analysis the total broadening of the spectral lines is assumed to represent the rotational velocity. On the contrary, our model accepts that a part of this broadening arises from the random motion of the ions.

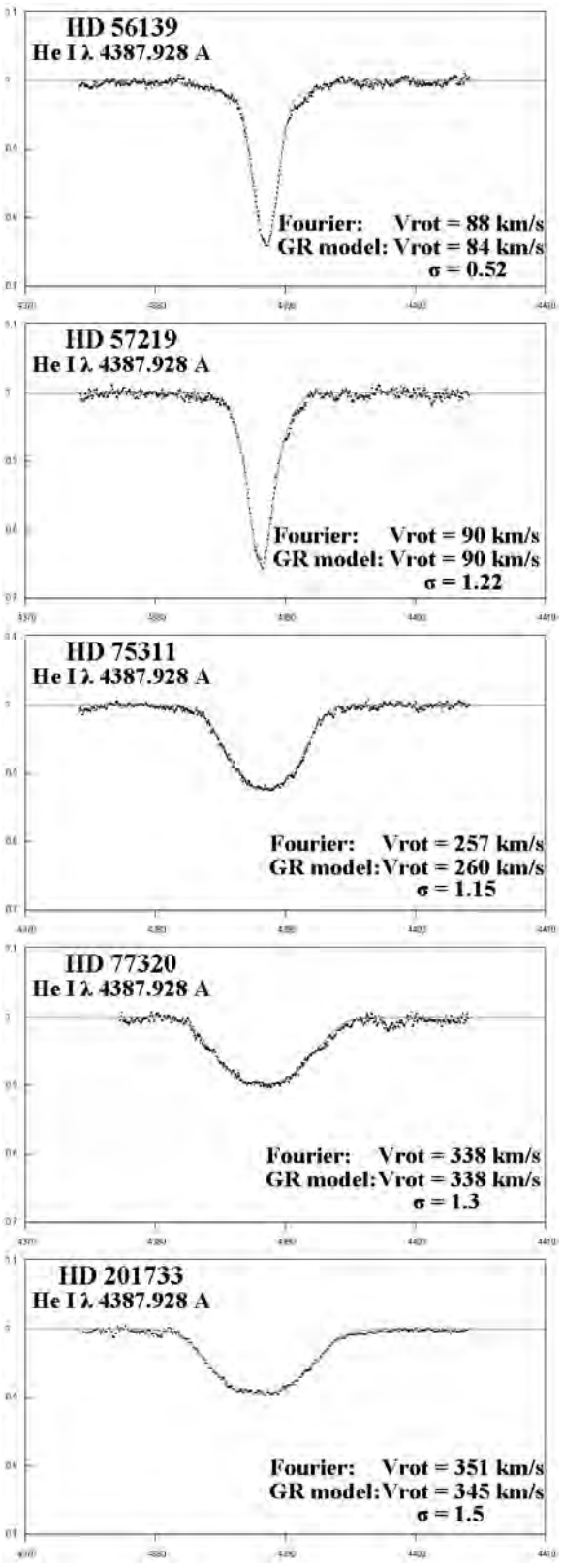

Fig. 1. Five He I λ 4387.928 Å fittings for the studied Be stars with the GR model and the measured rotational velocities with Fourier analysis and the GR model. The differences between the observed and reproduced spectral lines are hard to see, as we have accomplished the best fit.

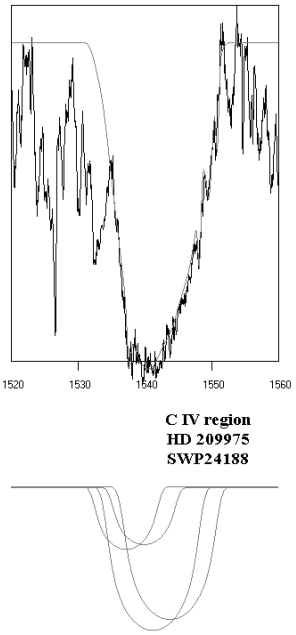

Fig. 2. C IV resonance lines (λλ 1548.155, 1550.774 Å) best fit with the GR model for the star HD 209975. The components obtained from the best fit are shown at the bottom.

We point out that with our model, apart from the rotational velocities, we can also calculate some other parameters, such as the standard Gaussian deviation, σ, the velocity of random motions of emitters/absorbers, the radial velocities of the regions producing studied spectral lines, the full width at half maximum (FWHM), the optical depth, the column density, and the absorbed or emitted energy.

II) An additional test of our model is to calculate the random velocities of layers that produce the C IV satellite components of 20 Oe stars with different rotational velocities.

We analyzed the C IV line profiles of 20 Oe stars, the spectra of which were observed with the IUE - satellite (IUE Archive Search database[1]). We examined the complex structure of the C IV resonance lines (λλ 1548.155, 1550.774 Å). Our sample included the subtypes O4 (one star), O6 (four stars), O7 (five stars), O8 (three stars), and O9 (seven stars). The values of the photospheric rotational velocities were taken from the catalogue of Wilson (1963) (see also Antoniou et al. 2006).

In the composite C IV line profiles we detect two components in 9 stars, three in 7 stars, four in 3 stars, and five in one star.

In figure 2 we present the C IV resonance lines best fit for the star HD 209975.

In figure 3 we present random velocities ($V_{\rm rand}$) of each SAC as a function of the photospheric rotational velocity ($V_{\rm phot}$) for all of the studied stars.

As one can see in figure 3, the obtained values for random velocities are in accordance with classical theory; the values of the random velocities do not depend on the inclination angle

[1] ⟨http://archive.stsci.edu/iue/search.php⟩.

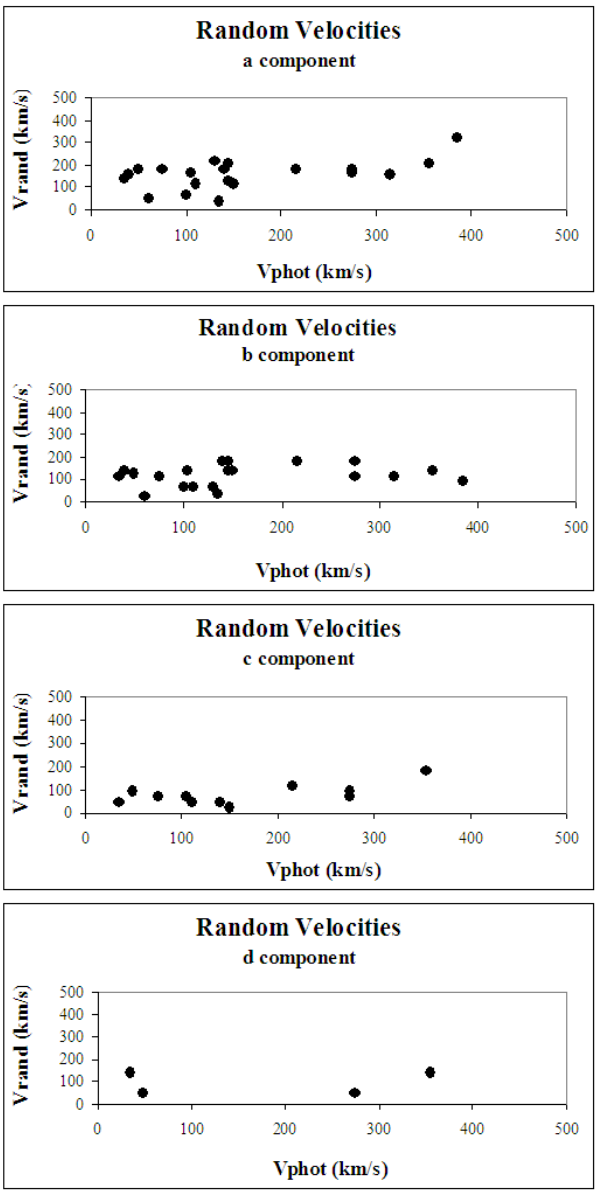

Fig. 3. Random velocities ($V_{\rm rand}$) of the four SACs as a function of the photospheric rotational velocity ($V_{\rm phot}$) for all of the studied Oe stars.

of the rotational axis. Because the ionization potential of the regions where satellite components are created is the same for all studied stars, one can expect similar average values of the random velocities for each absorbing region (here denoted as the a–d components; see figure 3) for all studied stars, as we obtained by using the model.

Both of the tests, described above, support our new approach to investigating the regions around hot stars, implying that besides rotation of the regions, one should also consider the random motion of emitters/absorbers.

5. Applications of the Model: Rotation – Density Regions vs. Photosphere

Here, we give some examples of applications of the model. We apply the model to study the complex structure of C IV and Si IV spectral lines in Oe and Be stars, as well as the rotational velocities of different components, in order to find a more precise rotational component.

5.1. C IV Density Regions of 20 Oe Stars

In this application we use the previously mentioned C IV IUE spectra of the second test. We study the relation between the ratio $V_{\rm rot}/V_{\rm phot}$ of the first, second, third, and fourth detected components with the photospheric rotational velocity ($V_{\rm phot}$). This ratio indicates how much the rotational velocity of the specific C IV layer is higher than the apparent rotational velocity of a star (see also Antoniou et al. 2006). In figure 4 we present our results.

In each region and for each component we can conclude that there exists an exponential relation between the ratio $V_{\rm rot}/V_{\rm phot}$ and the photospheric rotational velocity, $V_{\rm phot}$. The maximum ratio, $V_{\rm rot}/V_{\rm phot}$, varies from 40 for the first to 5 for the fourth component (figure 4). A possible explanation of this situation is the inclination of the stellar axis.

5.2. Si IV Density Regions of 27 Be Stars

This study was based on an analysis of 27 Be stellar spectra taken with the IUE-satellite. We examined the complex structure of the Si IV resonance lines ($\lambda\lambda$ 1393.755, 1402.77 Å). Our sample included all subtypes from B0 to B8. The values of the photospheric rotational velocities were taken from the catalogue of Chauville et al. (2001).

We found that the Si IV spectral lines consist of three components in 7 stars, four in 15 stars, and five in 5 stars. We studied the relation between the ratio $V_{\rm rot}/V_{\rm phot}$ of the first, second, third, fourth, and fifth detected components with the photospheric rotational velocity ($V_{\rm phot}$). This ratio indicates how much the rotational velocity of the specific Si IV layer is higher than the apparent rotational velocity of the star (see also Lyratzi et al. 2006). In figure 5 we present our results.

The Si IV resonance lines are composed of three, four, or five components. The difference from the case of the C IV resonance lines in the spectra of 20 Oe stars is that they are composed of two, three, or four components. However, in both cases, in each region and for each component there exists an exponential relation between the ratio $V_{\rm rot}/V_{\rm phot}$ and the photospheric rotational velocity, $V_{\rm phot}$. For the satellite components of the Si IV resonance lines, the maximum ratio, $V_{\rm rot}/V_{\rm phot}$, varies from 19 for the first, to 1 for the fifth component (figure 5).

5.3. Rotation in Photosphere vs. Rotation of Density Regions

As one can see in figures 4 and 5, there is a good correlation between the rotational velocities of the density regions and the photosphere. In both cases (Be and Oe stars) for rotational velocity of the photosphere, $V_{\rm phot} > 200$ km s^{-1}, the rotation of the photosphere correlates with the rotation of the density regions ($V_{\rm rot} \approx {\rm const.} \times V_{\rm phot}$). On the other hand, for $V_{\rm phot} < 200$ km s^{-1}, the ratio $V_{\rm rot}/V_{\rm phot}$ decreases with the

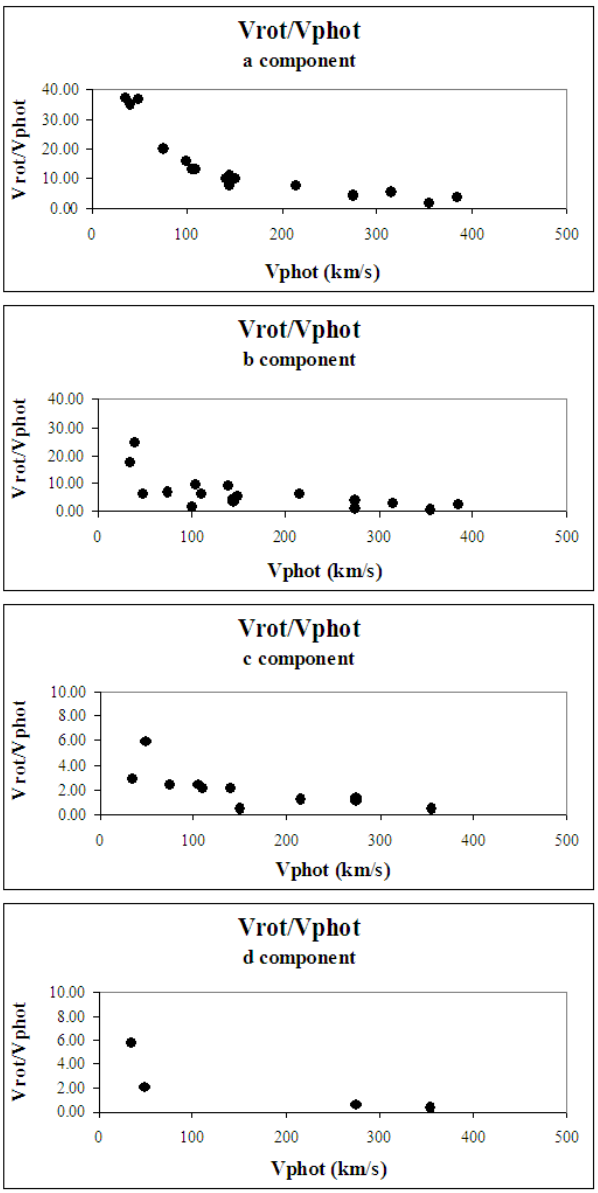

Fig. 4. Ratio $V_{\rm rot}/V_{\rm phot}$ of the four SACs as a function of the photospheric rotational velocity ($V_{\rm phot}$) for all of the studied Oe stars.

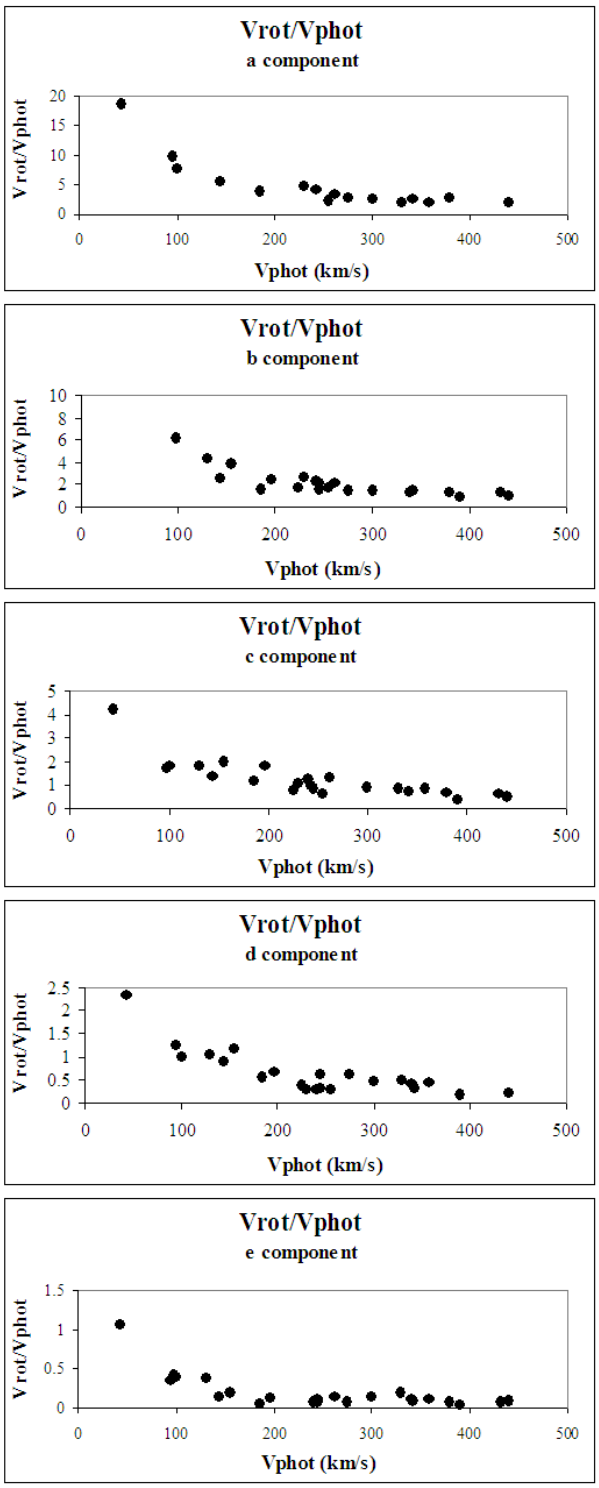

Fig. 5. Ratio $V_{\rm rot}/V_{\rm phot}$ of the five SACs as a function of the photospheric rotational velocity ($V_{\rm phot}$) for all of the studied Be stars.

rotation in the photosphere. This can be explained by the inclination effect and the fact that the density regions are extensive around the star, i.e., for a high inclination angle the projected photospheric rotational velocity is small, but in a density region (that lies extensively around the star), one can detect faster rotation.

6. Conclusions

Here we present a new model for fitting the complex UV lines of Be and Oe stars, where we take into account the possibility that the random motion of ions can significantly contribute to the line widths. The proposed model can be applied to the spectral photospherical lines as well as the UV lines originating in the post-coronal regions. Concerning our work, we can make the following conclusions:

(i) The proposed model can accurately reproduce the complex UV lines of Be and Oe stars.

(ii) Using the proposed model one can very well separate the contribution of the rotational and radial velocities in the density region by fitting the complex line profiles.

(iii) The proposed model provides an opportunity to investigate the physical parameters of the regions creating the UV complex line profiles.

(iv) The proposed model allows us to use the photospheric lines, in order to determine the photospheric rotation.

At the end, let us point out that in spite of the fact that today there exists a number of models that are able to reproduce the spectra from stellar atmospheres, there is a problem to find an appropriate model that can fit the complex UV line profiles that are created not only in the photosphere, but also in the density regions. On the other hand, the proposed model is able to provide information about the physical parameters of density regions as well as the rotation of the photosphere. We hope that the proposed model will be useful first of all to allow a first impression about the physics of density layers.

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Appendix. Including the Random Motion in the Calculation of L — The Gauss-Rotation model (GR model)

We consider a spherical shell and a point A_i in its equator. If the laboratory wavelength of a spectral line that arises from A_i is $\lambda_{\rm lab}$, the observed wavelength is: $\lambda_0 = \lambda_{\rm lab} \pm \Delta\lambda_{\rm rad}$. If the spherical density region rotates, we observe a displacement $\Delta\lambda_{\rm rot}$ and the new wavelength of the center of the line is $\lambda_i = \lambda_0 \pm \Delta\lambda_{\rm rot}$, where $\Delta\lambda_{\rm rot} = \lambda_0 z \sin\varphi$, $z = \dfrac{V_{\rm rot}}{c}$, $V_{\rm rot}$ is the rotational velocity of point A_i.

This means that $\lambda_i = \lambda_0 \pm \lambda_0 z \sin\varphi = \lambda_0 (1 \pm z \sin\varphi)$ and if $-\dfrac{\pi}{2} < \varphi < \dfrac{\pi}{2}$, then $\lambda_i = \lambda_0 (1 - z \sin\varphi)$.

If we consider that the spectral line profile is a Gaussian distribution, $I(\lambda) = \dfrac{1}{\sqrt{2\pi}\sigma} e^{-\left[\frac{\lambda-\kappa}{\sigma\sqrt{2}}\right]^2}$, where κ is the mean value of the distribution and in the case of the line profile it indicates the center of the spectral line that arises from A_i. This means that

$$I(\lambda) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\left[\frac{\lambda-\lambda_0(1-z\sin\varphi)}{\sigma\sqrt{2}}\right]^2} = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{[\lambda-\lambda_0(1-z\sin\varphi)]^2}{2\sigma^2}}. \tag{A1}$$

The distribution function for all of the semi-equator is

$$I_1(\lambda) = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{[\lambda-\lambda_0(1-z\sin\varphi)]^2}{2\sigma^2}} \cos\varphi d\varphi. \tag{A2}$$

If $\sin\varphi = x$, then $dx = \cos\varphi d\varphi$, $-1 \le x \le 1$, and equation (A2) takes the form

$$I_1(\lambda) = \int_{-1}^{1} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{[\lambda-\lambda_0(1-zx)]^2}{2\sigma^2}} dx. \tag{A3}$$

If we set $u = \dfrac{\lambda - \lambda_0(1-zx)}{\sqrt{2}\sigma}$, we have

$$I_1(\lambda) = \frac{1}{\lambda_0 z\sqrt{\pi}} \int_{\frac{\lambda-\lambda_0(1+z)}{\sigma\sqrt{2}}}^{\frac{\lambda-\lambda_0(1-z)}{\sigma\sqrt{2}}} e^{-u^2} du. \tag{A4}$$

We consider the function $\operatorname{erf}(x) = \dfrac{2}{\pi}\displaystyle\int_0^x e^{-u^2} du$. It is a known function that describes the Gaussian error distribution.

If we take into account this function, $I_1(\lambda)$ takes the form

$$I_1(\lambda) = \frac{1}{\lambda_0 z\sqrt{\pi}} \left[\int_0^{\frac{\lambda-\lambda_0(1-z)}{\sigma\sqrt{2}}} e^{-u^2} du - \int_0^{\frac{\lambda-\lambda_0(1+z)}{\sigma\sqrt{2}}} e^{-u^2} du \right], \tag{A5}$$

$$I_1(\lambda) = \frac{1}{\lambda_0 z\sqrt{\pi}} \left\{ \frac{\pi}{2} \operatorname{erf}\left[\frac{\lambda-\lambda_0(1-z)}{\sigma\sqrt{2}}\right] - \frac{\pi}{2} \operatorname{erf}\left[\frac{\lambda-\lambda_0(1+z)}{\sigma\sqrt{2}}\right] \right\}. \tag{A6}$$

Thus, we finally have

$$I_1(\lambda) = \frac{\sqrt{\pi}}{2\lambda_0 z} \left[\operatorname{erf}\left(\frac{\lambda-\lambda_0(1-z)}{\sigma\sqrt{2}}\right) - \operatorname{erf}\left(\frac{\lambda-\lambda_0(1+z)}{\sigma\sqrt{2}}\right) \right], \tag{A7}$$

and the distribution function from the semi-spherical region is

$$I_{\rm final}(\lambda) = \frac{\sqrt{\pi}}{2\lambda_0 z} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \left[\operatorname{erf}\left(\frac{\lambda-\lambda_0}{\sigma\sqrt{2}} + \frac{\lambda_0 z}{\sigma\sqrt{2}}\cos\theta\right) - \operatorname{erf}\left(\frac{\lambda-\lambda_0}{\sigma\sqrt{2}} - \frac{\lambda_0 z}{\sigma\sqrt{2}}\cos\theta\right) \right] \cos\theta d\theta, \tag{A8}$$

(Method Simpson).

In equation (A8), from λ_0 we can calculate the value of the radial velocity ($V_{\rm rad}$); from z we calculate the rotational velocity ($V_{\rm rot}$), and from σ we calculate the random velocity ($V_{\rm rand}$).

This distribution function, $I_{\rm final}(\lambda)$, has the same form as the distribution function of the absorption coefficient, L, and may replace it in the line functions $e^{-L\xi}$ or $S_{\lambda e}\left(1 - e^{-L_{ej}\xi_{ej}}\right)$, in the case when the line broadening is an effect of both the rotational velocity of the density region as well as the random velocities of the ions. This means that we now have a new distribution function to fit each satellite component of a complex line profile that represents DACs or SACs. We name this function the Gauss-Rotation distribution function (GR distribution function).

References

Antoniou, A., Danezis, E., Lyratzi, E., Nikolaidis, D., Popović, L. Č., Dimitrijević, M. S., & Theodossiou, E. 2006, in Proc. 23rd Summer School and International Symposium on the Physics of Ionized Gases, ed N. S. Simonović, B. P. Marinković, & L. Hadžievski (Melville, NY: AIP)

Bates, B., & Halliwell, D. R. 1986, MNRAS, 223, 673

Chauville, J., Zorec, J., Ballereau, D., Morrell, N., Cidale, L., & Garcia, A. 2001, A&A, 378, 861

Cranmer, S. R., & Owocki, S. P. 1996, ApJ, 462, 469

Cranmer, S. R., Smith, M. A., & Robinson, R. D. 2000, ApJ, 537, 433

Danezis, E. 1983, PhD Thesis, University of Athens

Danezis, E. 1987, in IAU Colloq. 92, Physics of Be Stars, ed A. Slettebak & T. P. Snow (Cambridge, UK: Cambridge University Press), 445

Danezis, E., et al. 2003, Ap&SS, 284, 1119

Danezis, E., Lyratzi, E., Nikolaidis, D., Antoniou, A., Popović, L. Č., & Dimitrijević, M. S. 2006, in Proc. 23rd Summer School and International Symposium on the Physics of Ionized Gases, ed. N. S. Simonović, B. P. Marinković, & L. Hadžievski (Melville, NY: AIP)

Danezis, E., Nikolaidis, D., Lyratzi, E., Popović, L. Č., Dimitrijević, M. S., Theodossiou, E., & Antoniou, A. 2005, Mem. Soc. Astron. Ital., 7, 107

Fullerton, A. W., Massa, D. L., Prinja, R. K., Owocki, S. P., & Cranmer, S. R. 1997, A&A, 327, 699

Grady, C. A., Sonneborn, G., Wu, C.-C., & Henrichs, H. F. 1987, ApJS, 65, 673

Henrichs, H. F. 1984, in ESA SSSP-218, Proc. 4th European IUE Conf., ed E. Rolfe & B. Battrick (Noordwijk: ESA), 43

Kaper, L., et al. 1997, A&A, 327, 281

Kaper, L., Henrichs, H. F., Nichols, J. S., Snoek L. C., Volten, H., & Zwarthoed G. A. A. 1996, A&AS, 116, 257

Kaper, L., Henrichs, H. F., Nichols, J. S., & Telting, J. H. 1999, A&A, 344, 231

Lamers, H. J. G. L. M., Snow, T. P., de Jager, C., & Langerwerf, A. 1988, ApJ, 325, 342

Lyratzi, E. & Danezis, E. 2004, in AIP Conf. Proc., 740, 458

Lyratzi, E., Danezis, E., Nikolaidis, D., Antoniou, A., Popović, L. Č., & Dimitrijević, M. S., & Theodossiou, E. 2006, in Proc. 23rd Summer School and International Symposium on the Physics of Ionized Gases, ed. N. S. Simonović, B. P. Marinković, & L. Hadžievski (Melville, NY: AIP)

Lyratzi, E., Danezis, E., Popović, L. Č., & Dimitrijević, M. S., Nikolaidis, D., & Antoniou, A. 2007, PASJ, 59, 357

Markova, N. 2000, A&AS, 144, 391

Mullan, D. J. 1984a, ApJ, 283, 303

Mullan, D. J. 1984b, ApJ, 284, 769

Mullan, D. J. 1986, A&A, 165, 157

Nikolaidis, D., Danezis, E., Lyratzi, E., Popović, L. Č., Antoniou, A., Dimitrijević, M. S., & Theodossiou, E. 2006, in Proc. 23rd Summer School and International Symposium on the Physics of Ionized Gases, ed. N. S. Simonović, B. P. Marinković, & L. Hadžievski (Melville, NY: AIP)

Prinja, R. K., & Howarth, I. D. 1988, MNRAS, 233, 123

Rivinius, Th. et al. 1997, A&A, 318, 819

Underhill, A. B. 1975, ApJ, 199, 691

Underhill, A. B., & Fahey, R. P. 1984, ApJ, 280, 712

Waldron, W. L., Klein, L., & Altner B. 1992, ASP Conf. Series, 22, 181

Waldron, W. L., Klein, L., & Altner B. 1994, ApJ, 426, 725

Wilson, R. E. 1963, General Catalogue of Stellar Radial Velocities (Washington: Carnegie Institution of Washington), 601

Proceedings of the VIII Serbian-Bulgarian Astronomical Conference (VIII SBAC)
Leskovac, Serbia, May 8-12, 2012,
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Publ. Astron. Soc. "Rudjer Bošković" No 12, 2013, 15-19

CORRELATIONS BETWEEN SPECTRAL PROPERTIES IN AGN TYPE 1: INFLUENCE OF STARBURSTS

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Abstract. The possible influence of starbursts to AGN (Active Galactic Nucleus) spectra is investigated in the case of a sample of AGNs Type 1. We divided the AGN sample into two subsamples according to dominant source of ionization. It is assumed that objects with R=log([O III]/Hβ NLR) < 0.5 have a predominant starburst contribution in narrow emission lines, and objects with R=log([O III]/Hβ NLR) > 0.5 are pure AGNs. We performed correlations between different spectral properties within these two subsamples and found some significant differences: the correlations between FWHM broad Hβ vs. FWHM [O III], and FWHM broad Hβ vs. L_{5100}, as well as EW Hβ broad vs. L_{5100}, are seen only for the starburst subsample. The possible influence of starbursts on the emission of the broad lines in AGN spectra is discussed.

1. INTRODUCTION

In some cases, the kinematical or physical characteristics of AGNs may be reflected in the correlations between different AGN spectral properties. Many authors investigated these correlations, trying to find and explain their physical background (see Popović and Kovačević 2011 and references therein).

On the other hand, there are some indications that evolution of AGNs is probably related with starburst regions (see Lípari and Terlevich 2006; Mao et al. 2009; Sani et al. 2010). Namely, it is possible that AGNs in an earlier phase of their evolution are composed of starburst (star-forming) regions and the cental engine, that is AGN, and, during evolution, the starburst contribution becomes weaker and/or negligible (Wang and Wei 2006, 2008; Mao et al. 2009).

In this paper we analyse how the presence/absence of the starburst contribution to the AGN spectra influences to the correlations between different spectral properties.

2. THE SAMPLE AND ANALYSIS

For this investigation we use the sample of 302 AGNs Type 1, selected with criteria described in paper Kovačević et al. (2010).

The sample has approximately an uniform redshift distribution in the range of z=0–0.7 and negligible host galaxy contribution.

As it is described in Kovačević et al. (2010), the emission lines within the 4400 – 5500 Å range are fitted with multiple Gaussians, where each Gaussian represent contribution from different emission region. For spectra with z<0.4, we also fitted the Hα and forbidden [N II] lines. The Balmer lines are fitted with three components: a narrow, an intermediate and a very broad component (Hβ NLR, ILR and VBLR, respectively). We assume that all narrow lines originate from the same emission region, and consequently they have the same width and shift. The Hβ broad component is taken as the sum of the Hβ ILR and Hβ VBLR components, and FWHM (Full Width Half Maximum) of Hβ line is measured only for the Hβ broad line. The iron lines within 4400 – 5500 Å range are fitted with template given in Kovačević et al. (2010).

In order to estimate in which objects there is a significant contribution of starbursts, we plot "BPT diagram" (Baldwin, Phillips and Terlevich 1981), which use the ratio of the narrow lines for diagnostic of starburst contribution. Since we have line measurements of the Hα and [N II] lines only for objects with z<0.4, the BPT diagram is performed for the 137 objects from our sample, as shown in Fig 1. As it can be seen from Fig. 1, a number of AGNs from the sample show a significant starburst contribution in narrow lines. It is interesting that these AGNs are mostly with the FWHM Hβ broad < 3000 km s^{-1} (open circles), while in the AGN part of the BPT diagram, both fractions (with FWHM Hβ broad < 3000 km s^{-1} and FWHM Hβ broad > 3000 km s^{-1}), are present. the objects with the FWHM Hβ broad > 3000 km s^{-1} are denoted with full circles.

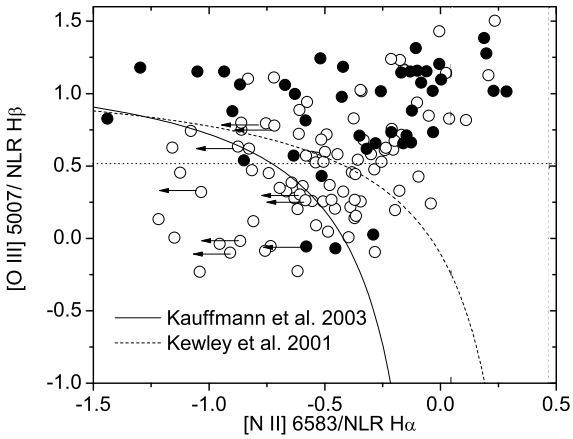

Figure 1: The BPT diagram for 137 objects from the sample. Open circles: objects with FWHM Hβ broad < 3000 km s^{-1}, full circles: with FWHM Hβ broad > 3000 km s^{-1}. Dashed line: R=log([O III]/Hβ NLR) = 0.5 (Popović and Kovačević, 2011).

The possible contribution of starbursts in AGN Type 1 spectra has been also reported (using the BPT diagnostic) in some other investigations: Popović et al. (2009) found that in the case of NLSy1 galaxy Mrk 493, the narrow-line ratios correspond to starbursts rather than to an AGN origin. Similar result is found in paper of Mao

et al. 2009 for the three AGN Type 1, which are mainly excited from starburst in narrow lines, since they belong to the H II part of BPT diagram.

Since we have complete measurements of line parameters only for the narrow Hβ and [O III] lines in the whole sample (302 AGNs), we accepted a criteria of R=log([O III]/Hβ NLR) = 0.5 (horizontal dashed line in Fig. 1) as an indicator of the predominant starburst emission contribution to the narrow emission lines. We divided our sample into two subsamples: R $<$ 0.5 (91 AGNs, hereafter starburst dominant) and R $>$ 0.5 (210 AGNs, hereafter AGN dominant). Then, we perform correlations between measured spectral properties for two subsamples, in order to check if there are some significant differences in correlation coefficients, which may be signature of different physical properties of emission regions.

3. RESULTS

Since our division of sample according to the dominant source of ionization (in narrow lines) into the AGN dominant and starburst dominant subsamples is very approximate (we use only the ratio of R=log([O III]/Hβ NLR), we need some additional tests, in order to check its accuracy. We perform correlation between FWHM [O III] and continuum luminosity (at 5100 Å) for which one may expect to be significant for the subsample with starburst contribution (Brungardt 1988). Indeed, as it can be seen in Fig 2., there is a significant correlation between these parameters for the starburst dominant subsample, but no correlation is seen for the AGN dominant one.

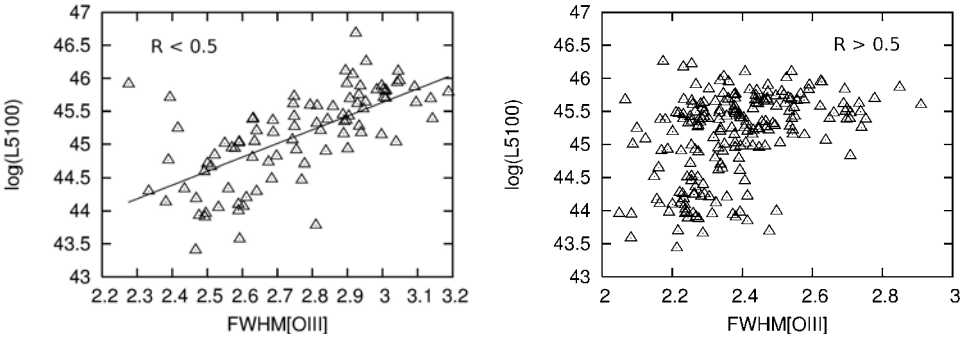

Figure 2: The correlation between FWHM [O III] and continuum luminosity (at 5100 Å) is significant for starburst dominant (R $<$ 0.5) subsample, while for AGN dominant (R $>$ 0.5), no correlation is seen (Popović and Kovačević, 2011).

We performed correlations between spectral properties (continuum luminosity, broad and narrow line widths, equivalent widths of lines) for two subsamples and found significant differences in some correlations. We found that the width of the broad Hβ is in a significant correlation with the FWHM of narrow [O III] lines and with the continuum luminosity (L_{5100}) for the starburst dominant subsample, while there are no any correlations between these parameters for the AGN dominant subsample. Correlations are shown in Fig 3 and 4. Also, we found correlation between the EW (equivalent width) of Hβ broad and L_{5100} for the starburst dominant subsam-

ple (r=0.56, P=9E-9), while there is no correlation for the AGN dominant subsample (r=- 0.03, P=0.67). This correlation is very interesting since anticorrelations between EWs of the emission lines and continuum luminosity are commonly called the Baldwin effect (see Baldwin 1977), and their physical cause is still unclear, because they can not be explained by simple photoionization model. Additionaly, in this case there is opposite trend, e.i. EW of the broad Hβ increases, as continuum luminosity increases (Inverse Baldwin effect).

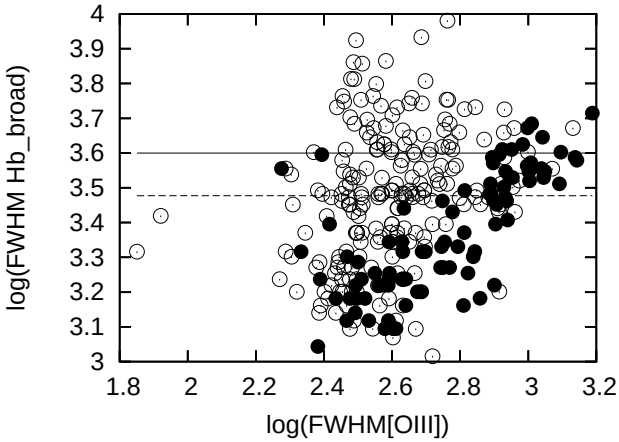

Figure 3: FWHMs of the broad Hβ vs. the narrow [O III] lines (which corresponds to the narrow Hβ). Filled circles denote the sample with R $<$ 0.5, and open circles, sample with R $>$ 0.5. The solid line denotes a border of FWHM Hβ = 4000 km/s, while the dashed line denotes FWHM Hβ = 3000 km/s (Popović and Kovačević, 2011).

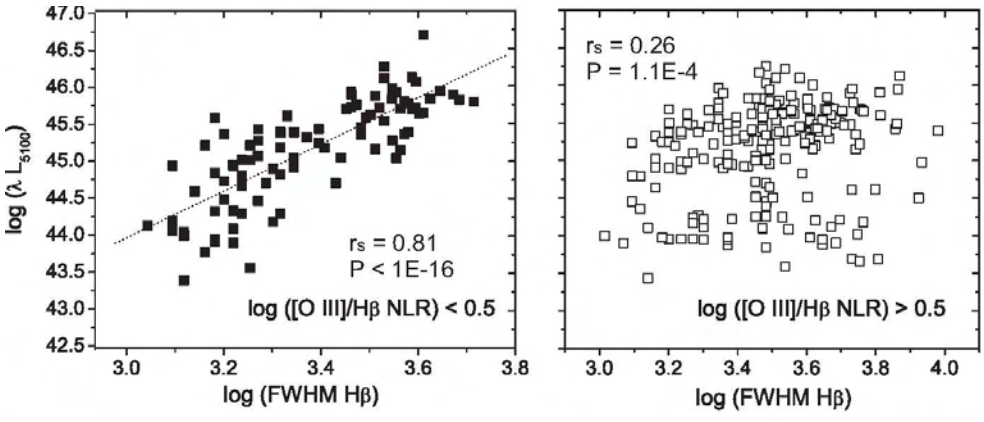

Figure 4: Correlations between continuum luminosity and FWHM Hβ for starburst dominant (left) and AGN dominant subasmple (right).

Since we found significant correlations of some spectral parameters and the broad component (ILR+VBLR) of Hβ only for starburst dominant subsample, one may ask interesting question: is it possible that starbursts may have contribution, not only in emission of narrow lines, but also partly in the emission of the broad lines in AGN spectra? In that case, part of the flux of the broad Balmer emission lines may arise in the stellar envelopes of Wolf- Rayet and OB stars associated with multiple SN events (see Izotov et al. 2007, and references therein) and emission gas could be randomly accelerated in several bursts.

References

Baldwin, J. A.: 1977, *Astrophysical Journal*, **214**, 679.
Baldwin, J. A., Phillips, M. M., Terlevich, R.: 1981, *Astronomical Society of the Pacific, Publications*, **93**, 5.
Brungardt, C. L.: 1988, *Astrophysical Journal Letters*, **327**, 51.
Izotov, Y. I., Thuan, T. X., Guseva, N.G.: 2007, *Astrophysical Journal*, **671**, 1297.
Kovačević, J., Popović, L. Č., Dimitrijević, M. S.: 2010, *Astrophysical Journal Supplement*, **189**, 15.
Lípari, S. L., Terlevich, R. J.: 2006, *Monthly Notices of the Royal Astronomical Society*, **368**, 1001.
Mao, Y-F. Wang, J., Wei, J.-Y.: 2009, *Astronomy and Astrophysics*, **9**, 529.
Popović, L. Č., Smirnova, A., Kovačević, J., Moiseev, A., Afanasiev, V.: 2009, *Astronomical Journal*, **137**, 3548.
Popović, L. Č., Kovačević, J.: 2011, *Astrophysical Journal*, **738**, 68.
Sani, E., Lutz, D., Risaliti, G., Netzer, H., Gallo, L. C., Trakhtenbrot, B., Sturm, E., Boller, T.: 2010, *Monthly Notices of the Royal Astronomical Society*, **403**, 1246.
Wang, J., Wei, J.: 2006, *Astrophysical Journal*, **648**, 158.
Wang, J., Wei, J.: 2008, *Astrophysical Journal*, **679**, 86.

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SOCIETY OF ASTRONOMERS OF SERBIA 2008-2011

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Abstract: The review of activities of the Society of Astronomers of Serbia within the period 2008-2011 is presented.

1. INTRODUCTION

Society of astronomers of Serbia (SAS) is founded on 25. 02. 1981, and author of this contribution was elected for president on Assembly held in October 2008. Activities of the Society from October 2008 up to the end of 2011 are:

International Year of Astronomy 2009;
Olympiads in astronomy;
Mobile planetarium and project "Popularization of astronomy in educational and cultural institutions and schools";
Scientific meetings organized by DAS;
Publishing activity of SAS;
Foreign scientists – guests of Society of Astronomers of Serbia;
Links with the European Astronomical Society;
Links with the International Astronomical Union;

2. INTERNATIONAL YEAR OF ASTRONOMY 2009

On the proposition of UNESCO, in December 2007, the United Nations General Assembly adopted a resolution, that 2009 was declared the International Year of Astronomy, in order to mark the anniversary of the start of the telescopic era, the 400th anniversary of the first astronomical observation through a telescope made by Galileo Galilei.

IYA 2009 was a global celebration of astronomy and its contributions to society and culture, with the following objectives:

Popularization of astronomy and related sciences;

Strengthening of the astronomical communities and of the international cooperation;

Astronomical education (formal and informal);

Promotion of the importance and attraction of the scientific work;

Strengthening of amateur community and improvement of the cooperation of amateurs and professionals;

Preservation and protection of world cultural and natural heritage of dark skies and historical astronomical sites.

Preparations for the marking of IYA in Serbia began in 2007, and since September 2008 until the end of IYA, national coordinator and president of the National Organizing Committee for the marking of IYA in Serbia was Nikola Božić. Beside him, from October 2008 (after the Assembly of the Society of Astronomers of Serbia), other members of the National Organizing Committee (NOC of IYA) are Ištvan Vince, Predrag Jovanović, Nadežda Pejović, Slobodan Ninković, Milan Dimitrijević, Dejan Urošević, Zoran Knežević, Nataša Stanić and Aleksandar Bogojević. Ministry of Science and Technological Development approved to SAS 600 000 RSD for projects for marking IYA 2009 in Serbia. With these funds disposed NOC of IYA and Nikola Božić reported to Directional Board of SAS on NOC of IYA activities. In celebration of IYA in Serbia, besides SAS, and all other astronomical institutions and society of amateur astronomers took part.

Coordinators of global projects were:

100 Hours of Astronomy - Janko Mravik;
Galileoscops - Goran Pavičić;
Cosmic Diary - Milan Ćirković;
Gates of the Universe - Aleksandar Zorkić;
She is an astronomer - Tijana Prodanović;
Conscience on dark sky - Nikola Božić;
Astronomical Heritage - Zorica Cvetković;
Galilean Ambassadors - Slobodan Ninković;
Conscience on the Universe - Nataša Stanić;
The universe as seen by eyes of Earth - Dragana Ilić;
Global development of astronomy - Olga Atanacković.

The most important activities realized during International Year of Astronomy, ordered chronologically, are:

Student’s seminar "Architecture in Space", Research Station Petnica, January;

Series of lectures "The universe yours to discover" Kolarac Foundation, January / February:

Milutin Milanković - Canon of insolation, Zoran Knežević;
Great astronomical discoveries from Galileo until now, Nikola Božić;

Galileo Galilei - the beginning of modern astronomy, Milan Ćirković;
Radio Astronomy, Dr Jelena Milogradov-Turin;

Ceremony of the proclamation of IYA in Serbia, Faculty of Science, February;

Publishing of a brochure dedicated to IYA, March;

Public telescopic observations in, at least, around fifteen cities throughout the year;

The popular lectures, in at least two dozen cities throughout the year;

Workshops for preschoolers, 7 Children's Theatre Festival "Zvezdarište", Municipality of Zvezdara, April;

Program for preschool and primary school children, Children's Fair, Belgrade Fair, April;

Participation at the manifestation "Night of Museums", Faculty of Science, AS "R. Bošković", Belgrade, May;

Organization of participation in the international competition "Be astronomer of the Integral", May-June;

Participation in the realization of the international photo competition "Earth and Sky", Summer; Media activity in *Politika*, *Novosti*, *Blic*, *24 sata*, *Borba*, B92, RTS, Radio Beograd, Radio 021, *Prosvetni pregled*, *Vreme*, *Mikro*, *Playboy*, *Planeta*, *Astronomija*, *Glas javnosti*, *National Geography*, RTV, Pink, E-newspapers...;

The third workshop of students of astronomy, Faculty of Science, June;

Seventh Serbian Conference on spectral line shapes in astrophysics, Zrenjanin 15-19. June;

Lecture for prisoners in the Prison for Juveniles in Valjevo, June;

International Astronomical camp "Letenka" Fruška Gora, with more than 220 astronomers from around the region. The central activity of IYA in Serbia, July;

International cooperation with countries of the region, but also with distant Ethiopia, the whole year;

Public discussion of the phenomenon of concealment during the total solar eclipse, ten years later, in August;

The projection of the popular science television series of Milan S . Dimitrijević, the Cinematheque, Autumn (organized by Andjelka Kovačević);

Projections of science fiction films in the Cinematheque, Autumn (organized Anđelka Kovačević);

Exhibition dedicated to the cooperation between Serbia and France in the field of astronomy, the French Cultural Center, September;

Astronomy and the arts, debates, exhibition of paintings and installations, Belgrade City Library, Youth Center, September;

Series of lectures "In honor to Milanković", AS "R. Bošković", in September:

Milan S. Dimitrijević: *Milanković and astronomy*;

Jelena Milogradov-Turin: *How we repaid to Milutin Milanković*;

Goran Pavičić: *On the Life and Work of Milutin Milanković*;

Nataša Stanić: *Milanković as a popularizer of science: "Through Space and Centuries"*.

VI SREAC conference of professional astronomers with the participation of amateur astronomers, under the auspices of UNESCO, the Ministry of Science and Astronomical Observatory of Belgrade, September;

The cycle of lectures on "Women in Astronomy" in Kolarac Foundation, October:

Dragana Ilić: *The Astronomical Instruments – The Sky seen by the eyes of women*;

Olga Atanacković: *Women at Harvard - through Light to the Stars*;

Andjelka Kovačević: *The Stars of Miss Leavitt*;

Tijana Prodanović: *The missing Space - The story of Vera Rubin*;

Exhibition of astronomical photographs, within the frame of the project "From the Earth to the Universe," Education Fair and Book Fair, Belgrade Fair, October;

Art competition for children on topics in astronomy, during whole year;

Conference of Secondary school pupils - participants in programs of Research station “Petnica”, "A Step into Science," November;

Astronomical exhibition and an exhibition of astronomical photos on the III Festival of Science, December;

The competition for primary school children for essays in connection with astronomy. The ceremony of handling the prizes on Belgrade Astronomical Observatory in cooperation with “Mladinska knjiga”, December;

Encouragement of cooperation among amateur societies and professionals with them, during the whole year;

Seminars for teachers of physics, about astronomy, AD "R. Bošković ", autumn;

Encouragement and training for the establishment of school sections in Serbia, RS “Petnica”, during the whole year;

To obtain a donation of 100 galileoscopes for schools in Serbia, December;

The start of the formation of the Museum of Astronomy at Belgrade Astronomical Observatory. the whole year, Vojislav Protić Benišek;

Purchase of a mobile planetarium, with the financial support of UNESCO, in December. The idea and project Nataša Stanić, about the practical realization the most is done by Goran Pavičić.

3. OLYMPIADS IN ASTRONOMY

Competitors from Serbia in this period took part in the following international Olympiads covering astronomy and astrophysics:

XIII International Astronomical Olympiad (International Astronomy Olympiad), Trieste, 13-21 October 2008, eight competitors, three over the quota (the success of the previous year), two seniors, three juniors, team leaders were Ratomirka Miller and Slobodan Ninković; silver medals obtained Nataša Dragović and Filip Živanović, bronze Milena Milošević, Aleksandar Miladinović and Dušan Joksimović.

III International Olympiad on Astronomy and Astrophysics (International Olympiad on Astronomy and Astrophysics) Teheran, 17-26 October 2009, four competitors, team leaders were Slobodan Ninković and Ivan Milić, silver medalists Aleksandar Vasiljković, Nataša Dragović and Filip Živanović, Milena Milošević commended, and Filip Živanović as the best observer received a special award and gift (lap-top) from the organizers.

XIV International Astronomical Olympiad, Hangzhou, 8-16 November 2009, the four contestants, two seniors and two juniors, team leaders were Ratomirka Miller and Slobodan Ninković, bronze medalist Ognjen Marković.

IV International Olympiad on Astronomy and Astrophysics, Beijing, 12-21 September 2010, five competitors, team leaders were Sonja Vidojević and Slobodan Ninković, Aleksandar Vasiljković won the gold medal, Ognjen Marković and Filip Živanović silver, and bronze Stefan Andjelković. Milena Milošević was commended.

XV International Astronomical Olympiad, Sudak in the Crimea, 16-24 of October 2010, five competitors, two seniors and three juniors, team leaders were Slobodan Ninković and Ivan Milić; Ivan Tanasijević won gold, silver Luka Bojović, and bronze Stefan Badža and Djordje Žikelić.

V International Olympiad in astronomy and astrophysics, Katowice, from 25 August to 4 September 2011, five competitors, team leaders Slobodan Ninković and Aleksandar Vasiljković; Stefan Andjelković and Ognjen Marković won the silver medal, bronze Filip Živanović, and Stefan Badža was commended.

XVI International Astronomical Olympiad, Alma-Ata, 22-30 September 2011, the five contestants, two over quota, two senior and one junior, team leaders Nikola Božić and Ivan Milić. The success was the following: Aleksandar Miladinović, Dušan Šobot and Ivan Tanasijević won the bronze medals.

In the period 2008-2011, Society of Astronomers of Serbia took part in eight Olympiads in astronomy, in which participants from Serbia won two gold medals, ten silver and eleven bronze medals, three participants were commended and one received a special award.

Team leaders were: Slobodan Ninković seven times, Ivan Milić three, Ratomirka Miller two and by once Sonja Vidojević, Aleksandar Vasiljković and Nikola Božić.

4. PROJECT "POPULARIZATION OF ASTRONOMY IN EDUCATIONAL AND CULTURAL INSTITUTIONS AND SCHOOLS"

For popularization of astronomy using a mobile planetarium, SAS was applied at the Ministry of Science and Technological Development with the project "Popularization of astronomy in educational and cultural institutions and schools", and for 2010 as well as for 2011 received 300 000 RSD for each year. Program activities are primarily designed to popularize astronomy in the towns in the interior of Serbia and the Republic Srpska. To this end, the lecturers with the mobile planetarium, obtained in 2009 thanks to the donation of UNESCO, visited

particular towns, organizing a day of astronomy, in order to acquaint students, educators and concerned citizens with the phenomena and objects in the night sky and the results and achievements in this science.

Activities achieved during the realization of project in 2010 year are shown here in tables.

Date	*Lecture and Place*	*Attendies*	*Lecturer*
08/04/10	Electromagnetic spectrum and objects which we observe – Kragujevac	50	Luka Č. Popović
08/04/10	The secret of big silence of cosmic civilisations – Kragujevac	50	Milan S. Dimitrijević
08/04/10	Planetarium projection (mobile planetarium) – Kragujevac	120	Goran Pavičić
15/04/11	The secret of big silence of cosmic civilisations - Doboj	50	Milan S. Dimitrijević
15/04/10	Planetarium projection (mobile planetarium) – Doboj	180	Goran Pavičić
16/04/10	Planetarium projection (mobile planetarium) – Banja Luka	240	Goran Pavičić
16/04/10	The secret of big silence of cosmic civilisations - Banja Luka	50	Milan S. Dimitrijević
17/04/10	Planetarium projection (mobile planetarium) – Banja Luka	120	Goran Pavičić
28/04/10	Electromagnetic spectrum and objects which we observe – Vršac	60	Luka Č. Popović
28/04/10	The secret of big silence of cosmic civilisations – Vršac	60	Milan S. Dimitrijević
28/04/10	Planetarium projection (mobile planetarium) – Vršac	180	Goran Pavičić
15/05/2010	Planetarium projection (mobile planetarium)- Avio Museum – Belgrade	690	N. Trajković, A. Zlatanović, N. Radovanović, S. Maćušev
22/05/2010	Planetarium projection (mobile planetarium) – Novi Sad	690	A. Brajović, K. Savić, K. Kaćanski, Goran Pavičić
23/05/2010	Planetarium projection (mobile planetarium) – Novi Sad	690	A. Brajović, K. Savić, K. Kaćanski, Goran Pavičić

26/05/2010	Planetarium projection (mobile planetarium) – Kikinda	180	Goran Pavičić
26/05/2010	Electromagnetic spectrum and objects which we observe – Kikinda	60	Luka Č. Popović
26/05/2010	Astronomy of XXI century – Kikinda	60	Milan S. Dimitrijević
26/05/10	Milutin Milanković - Novi Bečej	60	Petar Vuca
17/09/10	Planetarium projection (mobile planetarium)- Secondary school, Zrenjanin	150	Goran Pavičić
18/09/10	Planetarium projection (mobile planetarium)- Primary school „2 October", Zrenjanin	150	Goran Pavičić
24/09/10	Planetarium projection (mobile planetarium) – Night of researchers, Novi Sad	600	Kristina Kaćanski, Goran Pavičić
27/09/10	Planetarium projection (mobile planetarium), Secondary school „Svetozar Marković", Niš	300	Goran Pavičić
27/09/10	The secret of big silence of cosmic civilisations – where are they?, Faculty of Sciences, Niš	40	Milan S. Dimitrijević
28/09/10	Mobile planetarium – Secondary school, Prokuplje	210	Goran Pavičić
28/09/10	The secret of big silence of cosmic civilisations – where are they?, Secondary school, Prokuplje	40	Milan S. Dimitrijević
09/10/10	The secret of big silence of cosmic civilisations - „Days of Eureka" – Kruševac	60	Milan S. Dimitrijević
09/10/10	„Miraculous astrophysical objects" - „Days of Eureka" – Kruševac	60	Luka Č. Popović
09/10/10	Mobile planetarium - „Days of Eureka" – Kruševac	180	Goran Pavičić
26/10/10	Mobile planetarium - „Fair ZVONCE" - Belgrade	120	A. Brajović, N. Popović, Goran Pavičić
27/10/10	Mobile planetarium - „Fair ZVONCE" - Belgrade	120	A. Brajović, N. Popović, Goran Pavičić

28/10/10	Mobile planetarium - „Fair ZVONCE” - Belgrade	120	A. Brajović, N. Popović, Goran Pavičić
29/10/10	Mobile planetarium - „Fair ZVONCE” - Belgrade	120	A. Brajović, N. Popović, Goran Pavičić
30/10/10	Mobile planetarium - „Fair ZVONCE” - Belgrade	120	A. Brajović, N. Popović, Goran Pavičić
10/11/10	Mobile planetarium – Novi Bečej	120	Goran Pavičić
11/11/10	The secret of big silence of cosmic civilisations – Novi Bečej	60	Milan S. Dimitrijević
11/11/10	Milutin Milanković - Novi Bečej	60	Petar Vuca
12/11/10	Mobile planetarium – Novo Miloševo	120	Goran Pavičić
12/11/10	Mobile planetarium – Novi Kneževac	120	Goran Pavičić
13/11/10	The secret of big silence of cosmic civilisations - Novi Kneževac	60	Milan S. Dimitrijević
13/11/10	Milutin Milanković - Novi Kneževac	60	Petar Vuca
03/12/10	Mobile planetarium, Festival of Science - Belgrade	810	A. Brajović, N. Grubač, F. Čolaković, Goran Pavičić
04/12/10	Mobile planetarium, Festival of Science - Belgrade	810	A. Brajović, N. Grubač, F. Čolaković, Goran Pavičić
05/12/10	Mobile planetarium, Festival of Science - Belgrade	810	A. Brajović, N. Grubač, F. Čolaković, Goran Pavičić
27/12/10	Mobile planetarium, Secondary school - Smederevo	120	Goran Pavičić

To the above listed activities 9250 listeners were present in 2010. On total of 19 lectures were 960 listeners, and 276 planetarium projections with lectures, were attended by 8290 listeners (since in a planetarium projection the number of

listeners is limited to 30, the total number of listeners during the day is shown in the table).

Such "Days of Astronomy" were organized during 2010 in Kragujevac, Doboj, Banja Luka, Vršac, Belgrade, Novi Sad, Kikinda, Zrenjanin, Niš, Prokuplje, Kruševac, Novi Bečej, Novo Miloševo and Novi Kneževac.

Under the program, to schools in Kragujevac, Doboj, Banja Luka, Vršac, Kikinda, Niš, Prokuplje, Kruševac, Novi Bečej, Novo Miloševo and Novi Kneževac, Galileoscops, purchased during IYA with the assistance of the Ministry, were donated.

In the realization of the project were involved Goran Pavičić, Milan S. Dimitrijević, Luka Č. Popović, Darko Jevremović, Petar Vuca, Nenad Trajković, Ana Zlatanović, Nataša Radovanović, Slavica Maćušev, Ana Brajović, Kristina Savić, Kristina Kaćanski, Natalija Popović, Nevena Grubač, and Filip Čolaković.

In 2011, "Days of Astronomy" are organized in Niš, Pančevo, Smederevska Palanka, Leskovac, Rusko Selo, Banatsko Karadjordjevo, Novi Sad, Gradiška, Banja Luka, Modriča, Trebinje, Sutjeska, Subotica, Sečanj, Kruševac, Vršac, Belgrade and Kučevo.



Figure 1: Poster for the lectures in Doboj and Banja Luka.



Figure 2: Dobrivoje Grčak, director of the Secondary school in Kruševac and Milan S. Dimitrijević with Acknowledgement. In front of him, books that he donated to the Secondary school, Kruševac 9. 10. 2010.

Activities on the Project realized during 2011 are presented in the table below.

Date	*Lecture and Place*	*Attendies*	*Lecturer*
25/02/11	Mobile planetarium – Niš	240	Goran Pavičić
26/02/11	Mobile planetarium – Niš	300	Goran Pavičić
26/02/11	Astronomy of XXI century – Niš	60	Milan S. Dimitrijević
16/03/11	Mobile planetarium – Pančevo	180	Goran Pavičić
16/03/11	Astronomy of XXI century – Pančevo	43	Milan S. Dimitrijević
24/03/11	Mobile planetarium – Smederevska Palanka	180	Goran Pavičić
24/03/11	Astronomy of XXI century – Smederevska Palanka	35	Milan S. Dimitrijević
16/04/11	Mobile planetarium – Leskovac	150	Goran Pavičić
16/04/11	Astronomy of XXI century - Leskovac	60	Milan S. Dimitrijević

17/04/11	Mobile planetarium - Leskovac	150	Goran Pavičić
05/05/11	Mobile planetarium – Rusko Selo	60	Goran Pavičić
05/05/11	Astronomy of XXI century – Rusko Selo	60	Milan S. Dimitrijević
05/05/11	Milutin Milanković – Rusko Selo	60	Petar Vuca
06/05/11	Mobile planetarium – Banatsko Karadjordjevo	120	Goran Pavičić
06/05/11	Astronomy of XXI century – Banatsko Karadjordjevo	120	Milan S. Dimitrijević
06/05/11	Milutin Milanković – Banatsko Karadjordjevo	120	Petar Vuca
07/05/11	Mobile planetarium – Novi Sad	240	Goran Pavičić, K. Savić, N. Grubač, R. Džudžar
08/05/11	Mobile planetarium – Novi Sad	240	Goran Pavičić, K. Savić, N. Grubač, R. Džudžar
23/08/11	Mobile planetarium – Kragujevac	120	Goran Pavičić
19/09/11	Mobile planetarium – Gradiška	240	Goran Pavičić
19/09/11	The secret of big silence of cosmic civilisations – where are they? – Gradiška	75	Milan S. Dimitrijević
20/09/11	Mobile planetarium – Banja Luka	180	Goran Pavičić
20/09/11	The secret of big silence of cosmic civilisations – where are they? – Banja Luka	50	Milan S. Dimitrijević
21/09/11	Mobile planetarium – Modriča	180	Goran Pavičić
23/09/11	Mobile planetarium – Subotica	180	Ana Brajović, Nevena Grubač
29/09/11	Astronomy of XXI century – Sečanj	60	Milan S. Dimitrijević
29/09/11	Milutin Milanković – Sečanj	60	Petar Vuca
30/09/11	Astronomy of XXI century – Sutjeska	60	Milan S. Dimitrijević
30/09/11	Milutin Milanković – Sutjeska	60	Petar Vuca

06/10/11	Mobile planetarium – Trebinje	300	Goran Pavičić
06/10/11	Astronomy of XXI century – Trebinje	50	Milan S. Dimitrijević
07/10/11	Mobile planetarium – Trebinje	300	Goran Pavičić
15/10/11	Astronomy of XXI century – Kruševac	80	Milan S. Dimitrijević
15/10/11	Dark matter and Dark energy – Kruševac	80	Slobodan Ninković
15/10/11	A jorney across the Space – Kruševac	80	Luka Č. Popović
15/10/11	Mobile planetarium – Kruševac	240	Ana Brajović, Nevena Grubač
28/10/11	Astronomical theory of climatic changes – Vršac	20	Milan S. Dimitrijević
23-30/10/11	Mobile planetarium – Fair of education „ZVONCE”, Belgrade	1700	N. Radovanović, Lj. Isaković, Goran Pavičić
08/11/2011	Mobile planetarium – Kučevo	150	Nevena Grubač, Goran Pavičić
2-4/12/11	Mobile planetarium – Festival of Science, Belgrade	2000	N. Grubač, N. Radovanović, Goran Pavičić

To the above listed activities 8638 listeners were present in 2011. On total of 19 lectures were 1233 listeners, and 249 planetarium projections with lectures, were attended by 7405 listeners.

In the realization of the project were involved Goran Pavičić, Milan S. Dimitrijević, Luka Č. Popović, Darko Jevremović, Petar Vuca, Slobodan Ninković, Nataša Radovanović, Ana Brajović, Kristina Savić, Nevena Grubač, Robert Džudžar and Ljubisa Isaković.



ГЛАС СРПСКЕ сриједа, 21. септембар 2011. 23

ДОМУ

Ово је "Гласу Српске" изјавила директор овог

коње - казала је Мирко вићева. А. П.

Одушевљење планетаријумом

Виђена симулација ноћног неба ФОТО: С. ЈОКИЋ

Универзитетско астрономско друштво Бањалука већ другу годину заредом уз помоћ београдског астрономског друштва "Руђер Бошковић" довело је мобилни планетаријум помоћу кога су бројни Бањалучани имали прилику да на едукативан начин виде симулацију ноћног неба.

Рекао је ово послије јучерашњег предавања члан бањалучког астрономског друштва Немања Ракић.

- Реализацију овог пројекта подржали су Министарство науке и технологије РС те бројни искусни предавачи из ове области који су корисним информацијама овај необични догађај учинили још интересантнијим. Оно на што смо посебно поносни је предавање професора Милана С. Димитријевића који важи за велико име у астрономији - додао је Ракић. С. Ј.

Figure 3: Article in „Glas Srpske“.



Figure 4: Mobile planetarium. Trebinje 6. 10. 2011.



Figure 5: Trebinje 6. 10. 2011. Lecture of Milan S. Dimitrijević.



Figure 6: Trebinje. Luka Č. Popović and Milan S. Dimitrijević in Church Library with the donated books.



Figure 7: Kruševac „Day of Eureka“ 15th of October 2011.
First row: Milan S. Dimitrijević, Luka Č. Popović, Dobrivoje Grčak, Slobodan Ninković, Danica Milićević.

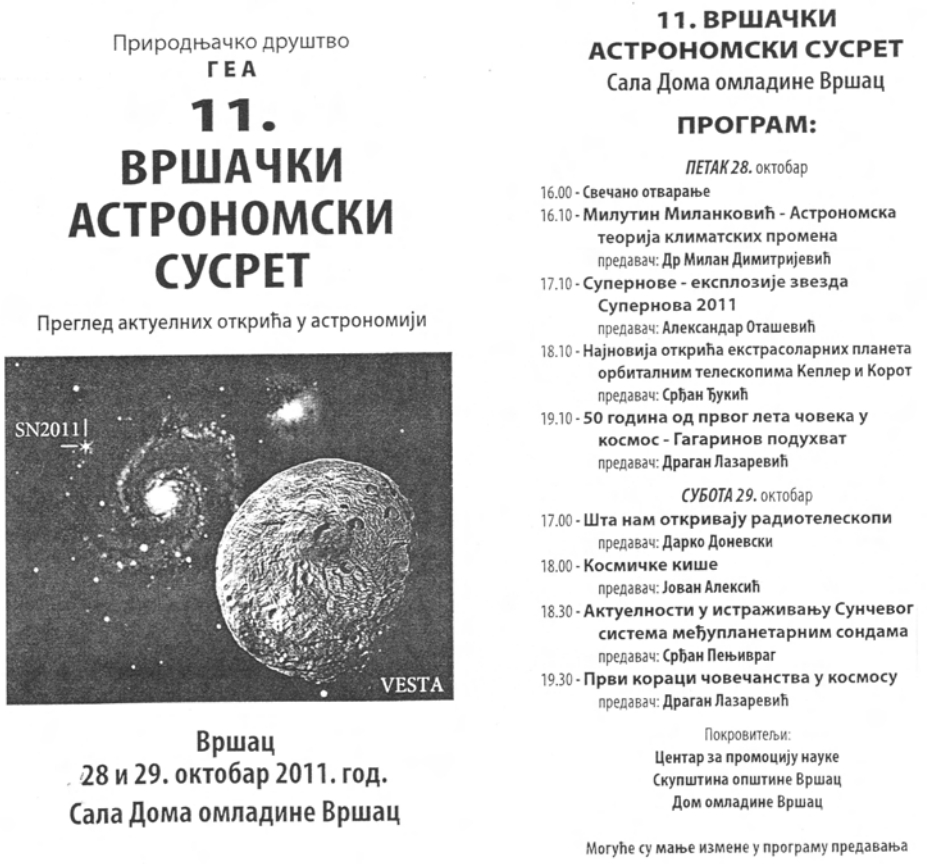

Figure 8: Astronomical Meetings of Vršac**.**

5. SCIENTIFIC CONFERENCES ORGANIZEDV BY SAS

Within the considered period, SAS has expanded its activities and on scientific meetings and for the first time organized two scientific conferences.

First is 1st Workshop "Spectroscopy as a tool to investigate Active Galactic Nuclei and gravitational lenses," Hotel "Kantri club", Babe, Kosmaj, Serbia, 7-11.07. 2010. The meeting was conceived as a workshop, so in the morning were lectures (during the Meeting in total eight lectures), and in the afternoon, participants worked in groups on specific topics or mini projects.

The main conclusions of the meeting are that such work, where three to six researchers are grouped around a well defined topics, enable a quality work. Two papers were finished on the workshop and sent in the days that followed to the leading journals, and seven future papers were considered in different forms.

Second was I Workshop on Astrophysical Spectroscopy, Vila "Alexander", Orašac, 26-30. August 2011, organized by the same principle as the previous one.

In addition, SAS was co-organizer of international conferences VII Serbian Conference on Spectral Line Shapes in Astrophysics, Zrenjanin, 15-19. June 2009 and VIII Serbian Conference on Spectral Line Shapes in Astrophysics, Divčibare, 6-10. Jun 2011, as well as of the National Conference with international participation "Development of astronomy among Serbs V", Belgrade, 18-22 April 2008.

6. PUBLISHING ACTIVITY

Within the considered period, SAS for the first time started and with the publishing activity. Published were a brochure on the International Year of Astronomy, Proceedings of the Sixth Serbian-Bulgarian Astronomical Conference (with the Astronomical Society "Rudjer Bošković"), Book of Abstracts of the Seventh Serbian Conference on Spectral Line Shapes in Astrophysics and four electronic optical DVD discs (two were published together with the Astronomical observatory and one with the Astronomical Society "Rudjer Bošković").

Published bibliographic units are:

1. INTERNATIONALYEAR OF ASTRONOMY (IN SERBIAN)
2. PROCEEDINGS OF THE 6TH SERBIAN-BULGARIAN ASTRONOMICAL CONFERENCE, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9.
3. VII SERBIAN CONFERENCE ON SPECTRAL LINE SHAPES IN ASTROPHYSICS (VII SCSLSA), Zrenjanin 15-19 June 2009, Book of abstracts, eds. L. Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Serbian Astronomical Society and Astronomical Observatory, Belgrade 2009.
4. ABSTRACTS, PROGRAM AND PHOTOS [Electronic Source], 7th Serbian Conference on Spectral Line Shapes in Astrophysics, June 15-19, 2009, Zrenjanin, Serbia; eds. Luka Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Organized by Serbian Astronomical Society and Astronomical Observatory, Belgrade. DVD prepared by Milan S. Dimitrijević, Miodrag Dačić and Tatjana Milovanov - Belgrade: Serbian Astronomical Society: Astronomical Observatory, 2009 (Beograd: Astronomical Observatory). - 1. Electronic optical disk (DVD).
5. PROCEEDINGS, PHOTOS AND VIDEOS [Electronic Source], The 5th Bulgarian-Serbian Conference on Astronomy and Space Science, May 9-12, 2006, Sofia, Bulgaria, edited by M. K. Tsvetkov, L. Filipov, M. S. Dimitrijević, L. Č. Popović, organized by the Space Research Institute of the Bulgarian Academy of Sciences. DVD prepared by Milan S. Dimitrijević and Tatjana Milovanov - Belgrade: Serbian Astronomical Society: Astronomical Observatory, 2009 (Belgrade: Astronomical Observatory). - 1. Electronic optical disk (DVD).
6. DEVELOPMENT OF ASTRONOMY AMONG SERBS V, Belgrade 18-22. April 2008. [Electronic source], editor Milan S. Dimitrijević, organizer

Astronomical Society "Rudjer Bošković", disk prepared by Milan S. Dimitrijević and Tatjana Milovanov, - Belgrade: Astronomical Society "Rudjer Bošković", Society of Astronomers of Serbia 2009 (Belgrade: Astronomical Society "Rudjer Bošković") - 1 electronic optical disc (DVD).

7. ABSTRACTS, PRESENTATIONS AND PHOTOS [Electronic Source], 1st Workshop “Spectroscopy as a Tool to Investigate Active Galactic Nuclei and Gravitational Lenses”, Kosmaj, Babe, July 7-11, 2010; eds. Milan S. Dimitrijević, Luka Č. Popović and Miodrag Dačić, Organized by Serbian Astronomical Society and Astronomical Observatory, Belgrade. DVD prepared by Milan S. Dimitrijević, Miodrag Dačić and Tatjana Milovanov - Belgrade: Astronomical Observatory: Serbian Astronomical Society, 2009 (Beograd: Astronomical Observatory). - 1. Electronic optical disk (DVD).

7. FOREIGN SCIENTISTS – GUESTS OF SOCIETY OF ASTRONOMERS OF SERBIA

For the first time in its history the Society had within the considered period twelve stays of foreign guests, which opened up the possibility for another type of activities and applications to competitions at the Ministry of Education and Science. Guests Scientists from abroad who stayed in Serbia as guests of SAS were:

Magdalena Christova, Bulgaria,
Giovanni La Mura, Italy,
Martin Gaskel, USA,
Piero Rafanelli, Italy,
Ala Shapovalova, Russia,
Aleksandr F. Zakharov, Russia,
Jonathan Francisco Leon Tavares, Finland,
Eduardo Guerras Valera, Spain,
Nebil Ben Nesib, Tunisia.

They were the guests of the Conference *1st Workshop on "Spectroscopy as a tool to investigate Active Galactic Nuclei and gravitational lenses”*, Hotel Kantri club, Babe, Kosmaj, Serbia, 7-11.07.2010. At the meeting *I Workshop on astrophysical spectroscopy*, Orašac, 26-30.08.2011, SAS guests were:

Magdalena Christova, Bulgaria,
Giovanni La Mura, Italy,
Jacopo Fritz, Belgium.

8. OTHER ACTIVITIES

8.1. Links with the European Astronomical Society

Directional Board of SAS regularly collected and paid annual dues for the European Astronomical Society, for those members who wanted to.

Milan S. Dimitrijević and Andjelka Kovačević participated in all meetings of the bodies of the European Astronomical Society and its assembly on JENAM 2009 "European Week of Astronomy and Space Science" in Hatfield, near London, 20-23 April 2009, as representatives of the Society of Astronomers of Serbia, and Dimitrijević and as a Councilor of the European Astronomical Society.

On JENAM 2011 in St. Petersburg, the official representative of the SAS in the EAS was Vojislava Protić Benišek.

8.2. Links with the International Astronomical Union

Links with the International Astronomical Union (IAU) were held from one side through the National Committee for Astronomy, whose president within the period considered was Ištvan Vince, and from the other side the SAS paid the membership fee of Republic of Serbia to IAU.

9. CONCLUSION

We can conclude that in the period since 2008 up to 2011. Society of Astronomers of Serbia successfully participated in activities related to International Year of Astronomy, organized preparation and participation of our competitors at eight international Olympiads in astronomy, where they won two gold medals, ten silver and eight bronze. The Society has purchased portable planetarium and the Ministry accepted its project "Popularization of astronomy in educational and cultural institutions and schools". During its realization a series of popular lectures and planetarium projections were organized in different places in Serbia and Republic Srpska. Only in 2010, to the activities covered by this project, within which was organized "Astronomy Day" in different places, attended 9250 listeners. On that occasion, to schools have been donated Galileoscops, purchased in 2009th. The Society expanded its activities and to the organization of scientific conferences, publishing and inviting scientists from abroad, and also maintained and developed links with the European Astronomical Society and the International Astronomical Union.

References

Božić, Nikola: 2010, *International Year of Astronomy 2009 in Serbia*, Proceedings of the conference "Development of astronomy among Serbs VI", Belgrade, 18-22 April 2008, editor M. S. Dimitrijevic, *Publ. Astr. Soc. "Rudjer Bošković"*, **10**, 367.

Proceedings of the VIII Serbian-Bulgarian Astronomical Conference (VIII SBAC)
Leskovac, Serbia, May 8-12, 2012,
Editors: M. S. Dimitrijević and M. K. Tsvetkov
Publ. Astron. Soc. "Rudjer Bošković" No 12, 2013, 173-188

TEN YEARS OF THE SCIENTIFIC SOCIETY "ISAAC NEWTON" AND OF "YUGOSLAVIA" BRANCH OF THE INTERNATIONAL ASTRONOMICAL INSTITUTE ISAAC NEWTON OF CHILE

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Abstract. On the occasion of ten years from the foundation, activities of Scientific Society "Isaac Newton" and of "Yugoslavia Branch" of the Isaac Newton Institute of Chile in Eastern Europe and Eurasia are reviewed.

Ten years ago, on 11th April 2002, the director of the Astronomical Observatory and the Director and Founder of the International Astronomical Institute "Isaac Newton" from Chile, Gonzalo Alcaino, signed an agreement on establishment of a Branch of this Institute in Yugoslavia (Fig. 1). The circumstances leading up to it are presented in detail in the journal "Vasiona" (Universe - Dimitrijevic, 2002). The initial years of the Branch (2002-2004), are described in the article Dimitrijević et al. (2005).

Associates of the Branch "Yugoslavia", which founded it, were: Edi Bon, Srdjan Z. Bukvić, Zorica Cvetković, Miodrag Dačić, Milan S. Dimitrijević (Branch Director), Stevan. Djeniže, Gojko R. Djurašević, Sanja R. Erkapić, Ljubinko M. Ignjatović, Predrag Jovanović, Aleksandar Dj. Kubičela, Anatolij A. Mihajlov, Vladimir Milosavljević, Nenad Milovanović, Slobodan Ninković, Dragomir Olević, Luka Č. Popović, Srdjan S. Samurović, Zoran Simić, Aleksandar Srećković, Nataša M. Stanic and Dragana Tankosic. They were later joined by: Dejan Urošević (second session of the Assembly – 30th January 2003), Dragan Ilić, Andjelka Kovačević, Jelena Kovačević, Nataša Gavrilović (fourth session of the Assembly on March 5th, 2007), Darko Jevremović (sixth session of the Assembly on 16th July 2008). In 2009, Marko Stalevski was admitted and on 17th November, on the eighth session of the Assembly, Sonja Vidojević, so that, at 1 February 2012, Branch has 29 members.

The first, constitutive meeting was held at the Astronomical Observatory on 8th May 2002. On it is confirmed and adopted the earlier signed agreement, establishing the Branch, and Jovan Grujić photographed participants, according to the wish

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AGREEMENT

AMONG THE
BELGRADE ASTRONOMICAL OBSERVATORY IN YUGOSLAVIA
AND
THE ISAAC NEWTON INSTITUTE OF CHILE

Wishing to contribute to further development of scientific research in observational and theoretical astrophysics, and using the possibilities of international cooperation enhanced by the globalized use of internet, we have decided to open a Branch of the Isaac Newton Institute at the Belgrade Astronomical Observatory in Yugoslavia.

At the Observatory in Belgrade, a group of astronomers from the local staff, have been unified as to create the Isaac Newton Institute Branch in Yugoslavia. The scientists involved will remain in the staff of their observatory and simultaneously become members of the Isaac Newton Institute. Scientists from other astronomical centers in Yugoslavia are as well entitled to join our Branch.

As the results of the research with the Isaac Newton Institute Branch in Yugoslavia, are considered only results submitted to the three most prestigious journals in astronomy, namely, the Astrophysical Journal and the Astronomical Journal in the United States, and Astronomy and Astrophysics, in Europe. The two institutions involved will be explicitely mentioned as the affiliations of the corresponding authors.

The present document officially establishes the creation of the Isaac Newton Institute of Chile Branch in Yugoslavia at the Belgrade Astronomical Observatory.

April 11, 2002

Milan S. Dimitrijević, Ph.D.
Director
Belgrade Astronomical Observatory

Gonzalo Alcaino
President
Isaac Newton Institute

Figure 1: The agreement between Belgrade Astronomical Observatory and Isaac Newton Institute of Chile on establishment of the Branch of this Institute in Yugoslavia.



Figure 2: Members of the Branch of the Institute Isaac Newton of Chile in Yugoslavia. Seated: Dragomir Olević, Dragan Tankosić, Slobodan Ninković, Stevan Djeniže, Milan S. Dimitrijević, Luka Č. Popović, Gojko Djurašević, Aleksandar Kubičela, Srdjan Bukvić. Standing: Zoran Simić, Predrag Jovanović, Miodrag Dačić, Vladimir Milosavljević, Aleksandar Srećković, Zorica Cvetković, Anatolij A. Mihajlov, Ljubinko Ignjatović, Sanja Erkapić.

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of Gonzalo Alcaino, who wanted to publish a picture of the members of the Branch in the publication of the Institute (***, no year, a copy in the library of Matica Srpska within the legacy of M. S. Dimitrijevic). Two images were selected and one published in the said publication and the other is here as Fig. 2. The second meeting was convened for the 25th July (see Fig. 3). Item 3 in the invitation, organizational issues, has been turned into the founding assembly of the as-

sociation of citizens: the Scientific Society "Isaac Newton." The meeting adopted the statute, and for the President of the Managing Board and for director of the Branch was elected Milan. Dimitrijević, for his deputy Stevan Djeniže, for the secretary Miodrag Dačić. In the Managing Board has been elected also Luka Č. Popović and Anatolij A. Mihajlov, and in the Supervisory Board Gojko Djurašević, Aleksandar Srećković and Zorica Cvetković.

In the Register of associations, social organizations and political organizations, led by the Federal Ministry of Justice, the Society was included on the 4th September 2002. It is interesting that the Society has received a copy of the decision that differ from original (Fig. 7), to which we draw attention to future researchers. In the decision, signed by the Minister Savo Marković, is written that the Society "was included in the registry list no. 1645 under the number 4352, and on the copy, signed for the Minister by (illegible) is: "in the registratry list no. 1642 under the number 4344".



У четвртак 25. јула 2002. у
библиотеци АОБ
у 14 часова
одржаће се други састанак
ЈУГОСЛОВЕНСКОГ
ОГРАНКА ИНСТИТУТА
ИСАК ЊУТН

Дневни ред

1. Предавање
   Лука Ч. Поповић
   ОБЛАСТ БАЛМЕРОВЕ ЕМИСИЈЕ У NGC 3516:
   КИНЕМАТИЧКА И ФИЗИЧКА СВОЈСТВА

2. Стеван Ђениже
   ЕКСПЕРИМЕНТАЛНЕ ШТАРКОВЕ ШИРИНЕ И
   ПОМАЦИ У СПЕКТРУ ТРОСТРУКО ЈОНИЗОВАНОГ
   СУМПОРА

3. Организациона питања

Директор
Југословенског огранка
Милан С. Димитријевић

Figure 3: Call for the second meeting of the Yugoslav Branch of the Institute Isaac Newton.



У понедељак 9. септембра
2002. у библиотеци АОЗ
у 11 часова
одржаће се трећи састанак
ЈУГОСЛОВЕНСКОГ
ОГРАНКА ИНСТИТУТА
ИСАК ЊУТН

Дневни ред

1. Предавање
   Profesor Gonzálo Alcaino Barros
   THE ISAAC NEWTON INSTITUTE OF CHILE IN
   EASTERN EUROPE AND EURASIA

Директор Југословенског огранка
Милан С. Димитријевић

Figure 4: Invitation to the lecture of Gonzalo Alcaino.

It should be noted that the Society, on the third General Assembly, held on 30th April 2003, proposed Dimitrijević for a corresponding member of SASA, and also on the seventh General Assembly, held on 10th May 2009. Luka Č. Popović proposed (acts no. 5 and 6/08 of 07.16.2008), that the Society initiates the process for awarding the title of scientist emeritus for M. S. Dimitrijević and A. A. Mihajlov. Both proposals were addopted at the 6 General Assembly, held on 16th July 2008.

The National Council for Science, elected M. S. Dimitrijević for scientist emeritus. According to the new law on associations, the Company has registered on 5th August 2011, in the Agency for Business Registers (Fig. 8).

By 1st January 2012, Branch Associates have published 76 papers in Astronomy and Astrophysics, Astrophysical Journal (including Letters and Supplement Series), Astronomical Journal and the Monthly Notices of the Royal Astronomical Society, and their list is presented here.

At the beginning, Alcaino published annual report of the Isaac Newton Institute of Chile (***, 2003, 2004, Alcaino, 2003, 2004, 2005), where was also the report on the scientific work of the Branch.

ОДЛУКА О ОСНИВАЊУ

На основу члана 10. став 2. Закона о удруживању грађана у удружења, друштвене и политичке организације које се оснивају на територији СРЈ, као и члана 13. Статута, на оснивачкој скупштина одржаној 25. јула 2002. године донета је одлука о оснивању Удружења грађана "ЈУГОСЛОВЕНСКИ ОГРАНАК МЕЂУНАРОДНОГ АСТРОНОМСКОГ ИНСТИТУТА – ИСАК ЊУТН ".

Седиште удружења је у Београду.

Оснивачи Удружења су:

1. Др. Милан С. Димитријевић; астроном
2. Др. Срђан С. Буквић, физичар;
3. Проф. Др. Стеван Ђениже, физичар;
4. Др Лука Ч. Поповић, астроном;
5. Др Анатолиј А. Михајлов, физичар;
6. Др Миодраг Д. Дачић, астроном;
7. Др Александар Ђ. Кубичела, астроном;
8. Др Слободан Нинковић, астроном;
9. Др Александар Срећковић, физичар;
10. Мр. Еди Бон, астроном;
11. Мр. Предраг Јовановић, астроном;
12. Мр Ненад Миловановић, астроном;
13. Мр Драгомир Олевић, астроном;
14. Мр Наташа Станић, астроном ;
15. Зоран Симић, астроном.

Основни задатак Удружења је окупљање заинтересованих грађана и правних лица у циљу развоја Науке, културе, образовања, информатике и грађанског друштва, као и очувања природне средине.

Овлашћује се Др. Милан С. Димитријевић председник Управног одбора Удружења, за извршавање послова уписа у регистар.

Председавајући Оснивачке скупштине

Др Милан С. Димитријевић

Figure 5: The decision on foundation of the Scientific society „Isaac Newton".



Figure 6: Visit of Alcaino to the Astronomical Observatory on 9th September 2002: Aleksandar Kubičela, Milan S. Dimitrijević, Zorica Cvetković, Gonzalo Alcaino.

Following ten years of work, we can conclude that the great merit of Gonzalo Alcaino is that he assembled the most creative scientists in Serbia working in as tronomy, supported and helped their work and stimulated them to publish in most prestigious international journals. If one looks at the list of publications, given below, one can see that the Branch “Yugoslavia” of the Isaac Newton Institute of Chile, created and supported by Gonzalo Alcaino, is scientifically the most productive astronomical institution in Serbia which gave a significant contribution to this Science, and has the richest list of scientific results in Astronomy in Serbia.



Савезна Република Југославија
САВЕЗНО МИНИСТАРСТВО ПРАВДЕ
Број 3/1-1213/2 -2002-07
04. 09 2002. године
Београд

На основу члана 13. Закона о удруживању грађана у удружења, друштвене организације и политичке организације који се оснивају за територију СФРЈ ("Службени лист СФРЈ", бр. 42/90) и члана 192. став 1. Закона о општем управном поступку ("Службени лист СРЈ", бр. 33/97 и 31/2001), по пријави Научног друштва "ИСАК ЊУТН" из Београда за упис у Регистар удружења, друштвених организација и политичких организација, Савезно министарство правде доноси

Р Е Ш Е Њ Е

1. Научно друштво "ИСАК ЊУТН" **уписује се** у Регистар удружења, друштвених организација и политичких организација, који се води код Савезног министарства правде, као **удружење грађана**, на регистарском листу број 1645 под редним бројем 4352.

2. Седиште Научног друштва "ИСАК ЊУТН" налази се у Београду, улица Волгина број 7.

3. Научно друштво "ИСАК ЊУТН" заступа и представља др Милан С. Димитријевић, председник Управног одбора.

О б р а з л о ж е њ е

Научно друштво "ИСАК ЊУТН" из Београда поднело је пријаву за упис у Регистар удружења, друштвених организација и политичких организација, који се води код Савезног министарства правде.

Решавајући по поднетој пријави утврђено је да су испуњени сви услови предвиђени Законом, па је одлучено као у диспозитиву Решења.

Правна поука : Ово решење је коначно у управном поступку и против њега се може покренути управни спор тужбом Савезном суду у року од 30 дана од дана пријема Решења.

Достављено:
- организацији
- у досије
- архиви

САВЕЗНИ МИНИСТАР
Проф. др Сава Марковић

Савезна Република Југославија
САВЕЗНО МИНИСТАРСТВО ПРАВДЕ
Број 3/1-1213/2-2002-07
04. 09 2002. године
Београд

На основу члана 13. Закона о удруживању грађана у удружења, друштвене организације и политичке организације који се оснивају за територију СФРЈ ("Службени лист СФРЈ", бр. 42/90) и члана 192. став 1. Закона о општем управном поступку ("Службени лист СРЈ", бр. 33/97 и 31/2001), по пријави Научног друштва "ИСАК ЊУТН" из Београда за упис у Регистар удружења, друштвених организација и политичких организација, Савезно министарство правде доноси

Р Е Ш Е Њ Е

1. Научно друштво "ИСАК ЊУТН" **уписује се** у Регистар удружења, друштвених организација и политичких организација, који се води код Савезног министарства правде, као **удружење грађана**, на регистарском листу број 1642 под редним бројем 4344.

2. Седиште Научног друштва "ИСАК ЊУТН" налази се у Београду, улица Волгина број 7.

3. Научно друштво "ИСАК ЊУТН" заступа и представља др Милан С. Димитријевић, председник Управног одбора.

О б р а з л о ж е њ е

Научно друштво "ИСАК ЊУТН" из Београда поднело је пријаву за упис у Регистар удружења, друштвених организација и политичких организација, који се води код Савезног министарства правде.

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Достављено:
- организацији
- у досије
- архиви

САВЕЗНИ МИНИСТАР
Проф. др Сава Марковић

Figure 7: Original and copy of the decision of registration with different numbers in the registry and different signatures.

Република Србија
Агенција за привредне регистре

5000049075415

Регистар удружења

Број БУ 13544/2011

Дана 05.08.2011. године
Београд

Агенција за привредне регистре, Регистратор који води Регистар удружења, на основу чланова 26. и 32. Закона о удружењима („Службени гласник РС“ бр. 51/09), поступајући по пријави за упис усклађивања у Регистар удружења друштвених организација, удружења грађана и њихових савеза уписаних у Регистар друштвених организација и удружења грађана и Регистар удружења, друштвених организација и политичких организација, који је поднет од стране **"НАУЧНО ДРУШТВО - ИСАК ЊУТН"**, преко:

Име и презиме: Милан Димитријевић

доноси:

Р Е Ш Е Њ Е

УПИСУЈЕ СЕ у Регистар удружења усклађивање удружења, са следећим подацима:

Облик организовања: Удружење

Назив: "НАУЧНО ДРУШТВО - ИСАК ЊУТН"

Назив у преводу на страни језик:

- Пун назив (енглески језик): „SCIENTIFIC SOCIETY ISAAC NEWTON“

Седиште и адреса: Волгина 7, Београд-Звездара, Србија

Матични број удружења: 28056494

ПИБ: 107192151

Датум оснивања: 25.07.2002

Датум доношења Статута: 05.11.2010

Делатност удружења: 9412 - Делатности струковних удружења

Подаци о заступнику:

Име и презиме: Милан Димитријевић
ЈМБГ: 2408947710415
Адреса: Булевар Краља Александра 126, Београд-Звездара, Србија

Страна 1 од 2



Предвиђено време на које се удружење оснива: Неограничено

Област остваривања циљева:

Рад на популаризацији и унапређењу астрономских наука.

О б р а з л о ж е њ е

Подносилац пријаве број БУ 13544/2011, поднео је дана 20.07.2011. године, усаглашену пријаву за упис усклађивања:

"НАУЧНО ДРУШТВО - ИСАК ЊУТН"

у Регистар удружења, и документацију заведену у потврди о примљеној пријави број БУ 13544/2011.

Како су испуњени услови прописани одредбом члана 79. Закона о удружењима („Сл.гласник РС" бр.51/09.) и члана 30. Правилника о садржини, начину уписа и вођења Регистра удружења („Сл.гласник РС" број 80/09), Регистратор је одлучио као у диспозитиву.

Упис усклађивања у Регистар удружења, врши се без накнаде.

Поука о правном средству:

Против овог решења може се изјавити жалба министру надлежном за људска и мањинска права, послове државне управе и локалне самоуправе, у року од 15 дана од дана пријема решења. Жалба се предаје преко Агенције за привредне регистре, уз доказ о уплати таксе од 500,оо динара, прописану тарифним бројем 7., Закона о републичким административним таксама на рачун број:840-742221843-57, прималац Буџет Републике Србије.

РЕГИСТРАТОР

Нинса Чулић

Figure 8: The decision on the registration of Scientific Society "Isaac Newton" in the Register of Associations.

PUBLISHED SCIENTIFIC WORKS OF ASSOCIATES OF THE SCIENTIFIC SOCIETY „ISAAC NEWTON“

1. Djeniže S., Srecković A., Jelisavčić M., Bukvić S.: 2002, „Experimental Stark widths and shifts in the triply ionized Sulphur spectrum", Astronomy and Astrophysics, **389**, 1086-1089.
2. Popović L. Č., Mediavilla E. G., Kubičela, A., Jovanović, P.: 2002, "Balmer lines emission region in NGC 3516: Kinematical and physical properties" Astronomy and Astrophysics, **390**, 473-480.
3. Milosavljević V., Djeniže S.: 2002, “Ion contribution to the astrophysical important 447.15, 587.6 and 667.82 nm He I spectral lines broadening", Astronomy and Astrophysics, **393**, 721-726.
4. Djeniže, S., Dimitrijević, M. S., Srećković, A., Bukvić, S.: 2002, "Stark shifts and transition probabilities in Si III and Si IV spectra", Astronomy and Astrophysics, **396**, 331-336.

5. Milosavljević, V., Djeniže, S.: 2003, "Ion contribution to the prominent NeI, ArI and KrI spectral lines broadening", Astronomy and Astrophysics, 398, 1179-1184.
6. Popović L. Č., Mediavilla E. G., Jovanović P., Munoz J. A.: 2003, "The influence of microlensing on the shape of the AGN Fe K alpha line", Astronomy and Astrophysics, 398, 975-982.
7. Tankosić, D. Popović, L. Č., Dimitrijević, M. S.: 2003, "The electron-impact broadening parameters for Co III spectral lines", Astronomy and Astrophysics, 399, 795-797.
8. Dimitrijević, M. S., Dacić, M., Cvetković, Z., Sahal-Bréchot, S.: 2003, "Stark broadening of spectral lines of multicharged ions of astrophysical interest. XXIII. Be III", Astronomy and Astrophysics, 400, 791-793.
9. Srecković, A., Dimitrijević, M. S., Djeniže, S., Bukvić, S.: 2003, "Stark broadening parameters in the S III spectrum", Astronomy and Astrophysics, 400, 1155-1159.
10. Djurašević, G., Rovithis-Livaniou, H., Rovithis, P., Georgiades, N., Erkapić, S., Pavlović, R.: 2003, "Gravity-darkening coefficients in semi-detached binary systems from their photometric observations: Part I", Astronomy and Astrophysics, 402, 667-682
11. Mihajlov A. A., Jevremović D., Hauschildt P., Dimitrijević M. S. Ignjatović Lj. M., Alard, F.: 2003, "The influence of chemi-ionization and chemi-recombination processes on the Rydberg states populations of the hydrogen atoms in low-temperature layers of M type red dwarf atmospheres", Astronomy and Astrophysics, 403, 787-791.
12. Dimitrijević, M. S., Ryabchikova, T., Popović, L. C., Shulyak, D., Tsymbal, V.: 2003, "On the influence of Stark broadening on Si I lines in stellar atmospheres", ASTRONOMY AND ASTROPHYSICS 2003, Djeniže 404, 1099-1106.
13. Mihajlov A. A., Ignjatović Lj. M., Dimitrijević M. S., Djuric, Z.: 2003, "Symmetrical chemi-ionization and chemi-recombination processes in low-temperature layers of helium rich DB white dwarf atmospheres", ApJs 2003, Djeniže 147, 369-377.
14. Milosavljević V., Djeniže S.: 2003, "Astrophysical plasma diagnostics through analysis Ar I line shape characteristics", ASTRONOMY AND ASTROPHYSICS 2003, Djeniže 405, 397-403.
15. Popović, L. Č.: 2003, "Balmer Lines as Diagnostics of Physical Conditions in AGN Broad Emission Line Region", ApJ 2003, Djeniže 599, 140-146.
16. Zboril, M., Djurasević, G.: 2003, "SV Cam spot activity in February 2001 - March 2002", ASTRONOMY AND ASTROPHYSICS 2003, Djeniže 406, 193-201.
17. Djeniže, S., Bukvić, S., Srecković, A., Kalezic, S.: 2003,"Experimental transition probabilities and Stark shifts in O III and OIV spectra", ASTRONOMY AND ASTROPHYSICS 2003, Djeniže 406, 759-764.

18. Cakirh, O., Ibanoglu, C., Djurasević, G., Erkapic, S., Evren, S., Tas, G.: 2003, "Long-term photometric behaviour of the RS CVn binary RT Lacertae", ASTRONOMY AND ASTROPHYSICS 2003, Djeniže 405, 733-745.
19. Dimitrijević, M. S., Jovanović, P., Simić, Z.: 2003, "Stark broadening of neutral germanium spectral lines", Astronomy and Astrophysics, **410**, 735-739.
20 Djeniže, S., Bukvić, S., Srećković, A.: 2003, "On the Bowen fluorescence mechanism in the helium-oxygen plasmas", Astronomy and Astrophysics, **411**, 637-640.
21. Popović, L. Č., Mediavilla, E. G., Bon, E. Stanić, N., Kubičela, A.: 2003, "The Line Emission Region in III Zw 2: Kinematics and variability", Astrophysical Journal, **599**, 185-192..
22. Olević, D., Cvetković, Z.: 2004, "Orbits for 10 interferometric binary systems calculated by using the improved Koval'Skij's method", Astronomy and Astrophysics, **415**, 259-264.
23. Milovanović, N., Dimitrijević M. S., Popović, L. Č., Simić Z.: 2004, "Importance of Collisions with Charged Particles for Stellar UV Line Shapes: Cd III" Astronomy and Astrophysics, **417**, 375-380.
24. Djurašević, G., Albayrak, B., Tanriverdi, T., Erkapić, S.: 2004, "A Photometric Study of NN Virginis", Astronomy and Astrophysics, **415**, 283-287.
25. Mihajlov, A. A., Ermolaev, A. M., Ignjatović, Lj. M.: 2004, "H+ + H(1s) collisions at intermediate impact velocities as a new source of UV and VUV radiation", Astronomy and Astrophysics, **419**, 1-5.
26. Srecković, A., Bukvić, S., Djeniže, S., Dimitrijević, M. S.: 2004, "Stark broadening parameters in singly and doubly ionized fluorine spectra", Astronomy and Astrophysics, **420**, 769-774.
27. Zakharov, A. F., Popović, L. Č., Jovanović, P.. 2004, "On the contribution of microlensing to X-ray variability of high-redshifted QSOs", Astronomy and Astrophysics, **420**, 881-888.
28. Albayrak, B., Djurašević, G., Erkapić, S., Tanriverdi, T.: 2004, "Modeling the changing spot features of SW Lacertae: A three year study", Astronomy and Astrophysics, **420**, 1039-1045.
29. Ben Nessib, N., Dimitrijević, M. S., Sahal-Bréchot, S.: 2004, "Stark broadening of the four times ionized silicon spectral lines", Astronomy and Astrophysics, **423**, 397-400.
30. Dimitrijević, M. S., Dačić, M., Cvetković, Z., Simić, Z.: 2004, "Stark broadening of Ga I spectral lines", Astronomy and Astrophysics, **425**, 1147-1152.
31. Popović, L. Č., Mediavilla, E., Bon, E., Ilić. D.: 2004, "Contribution of the Disk Emission to the Broad Emission Lines in AGNs: Two-component model", Astronomy and Astrophysics, **423**, 909-918.
32. Djeniže, S., Bukvić, S., Srećković, A., Platiša, M.: 2004, "Mg II spectral line broadening in helium, oxygen and argon-helium plasmas", Astronomy and Astrophysics, **424**, 561-564.

33. Mahmoudi, W. F., Ben Nessib, N., Dimitrijević, M. S.: 2004, "Modified semiempirical electron width calculations of singly-ionized oxygen spectral lines", Astronomy and Astrophysics, **423**, 397-400.
34. Urošević, D., Pannuti, T. G., Duric, N., Theodorou, A.: 2005, "The Sigma-D Relation for Supernova Remnants in Nearby Galaxies", Astronomy and Astrophysics, 435, 437-447.
35. Dimitrijević, M. S., Ryabchikova, T., Popović, L. Č., Shulyak, D., Khan, S.: 2005, "On the influence of Stark broadening on Cr I lines in stellar atmospheres", Astronomy and Astrophysics, **435**, 1191-1198.
36. Mihajlov, A. A., Ignjatović, Lj. M., Dimitrijević, M. S.: 2005, "Processes of (n-n')-mixing in collisions of Rydberg H*(n) atoms with H(1s) in the Solar atmosphere", Astronomy and Astrophysics, **437**, 1023-1028.
37. Simić, Z., Dimitrijević, M. S., Milovanović, N., Sahal-Bréchot, S.: 2005, "Stark broadening of Cd I spectral lines”, Astronomy and Astrophysics, **441**, 391-393.
38. Djurašević, G., Rovithis-Livaniou, H., Rovithis, P., Georgiades, N., Erkapić, S., Pavlović, R.: 2006, "Gravity-Darkening exponents in Semi-Detached Binary Systems from their photometric observations: Part II", Astronomy and Astrophysics, **495**, 291-303.
39. Popović, L. Č., Jovanović, P., Mediavilla, E., Zakharov, A. F., Abajas, C., Muñoz, J. A., Chartas, G.: 2006, "A study of the correlation between the amplification of the Fe K alpha line and the X-ray continuum of quasars due to microlensing", Astrophysical Journal, **637**, 620-630.
40. Urošević, D., Pannuti, T. G., Leahy, D. : 2007, "An analysis of the broadband (22-3900 MHZ) radio spectrum of HB3 (G132.7+1.3): The detection of thermal radio emission from an evolved supernova remnant?", Astrophysical Journal Letters, **655**, L41.
41. Hamdi, R., Ben Nessib, N., Dimitrijević, M. S., Sahal-Bréchot, S.: 2007, "Stark broadening of the four times ionized neon lines", Astrophysical Journal Supplement Series, **170**, 243-250.
42. Dimitrijević, M. S., Ryabchikova, T., Simić, Z., Popović, L. Č., Dačić, M.: 2007, "The influence of Stark broadening on Cr II spectral line shapes in stellar atmospheres", Astronomy and Astrophysics, 469, 681-686.
43. Mihajlov, A. A., Ignjatović, Lj. M., Sakan, N. M., Dimitrijević, M. S.: 2007, "The influence of H2+ - photo-dissociation and (H + H+) - radiative collisions on the solar atmosphere opacity in UV and VUV regions", Astronomy and Astrophysics, **469**, 749-754.
44. Mihajlov, A. A., Jevremović, D., Hauschildt, P., Dimitrijević, M. S., Ignjatović, Lj. M., Allard, F.: 2007, "Influence of chemi-ionization and chemi-recombination processes on Hydrogen line shapes in M dwarfs", Astronomy and Astrophysics, **471**, 671-673.
45. La Mura, G., Popović, L. Č., Ciroi, S., Rafanelli, P., Ilić, D.: 2007, "Detailed Analysis of Balmer Line in a SDSS Sample of 90 Broad Line AGN", Astrophysical Journal, **671**, 104-117.

46. Djurašević, G., Vince, I., Atanacković, O.: 2008, "Accretion disk in massive binary RY Scuti", Astronomical Journal, **136,** 767-772.
47. La Mura, G., Di Mille, F., Ciroi, S., Popović, L. Č., Rafanelli, P.: 2009, "Balmer Emission Line Profiles and the Complex Properties of Broad Line Regions in Active Galactic Nuclei", Astrophysical Journal, **693**, 1437-1448.
48. Popović, L. Č., Smirnova, A. A., Kovačević, J., Moiseev, A. V., Afanasiev, V. L.: 2009, "Three-dimensional Spectroscopic Study of the Line-Emitting Regions of Mrk 493", Astronomical Journal, **137**, 3548-3557.
49. Urošević, D., Vukotić, B., Arbutina, B., Ilić, D., Filipović, M., Bojičić, I., Šegan, S., Vidojević, S.: 2009, "The Sigma-D relation for planetary nebulae", Astronomy and Astrophysics, **495**, 537-546.
50. Ignjatović, Lj. M., Mihajlov, A. A., Sakan, N. M., Dimitrijević, M. S., Metropoulos, A.: 2009, "The total and relative contribution of the relevant absorbtion processes to the opacity of DB white dwarf atmospheres in UV and VUV regions", Monthly Notices of the Royal Astronomical Society, **396**, 2201-2210.
51. Djurašević, G., Vince, I., Khruzina, T. S., Rovithis-Livaniou, E.: 2009, "Accretion disk in the massive V448 Cygni system", Monthly Notices of the Royal Astronomical Society, **396**, 1553-1558.
52. Vukotić, B., Urošević, D., Filipović, M. D., Payne, J. L.: 2009, "The Sigma - D Analysis of Recently Detected Radio Planetary Nebulae in the Magellanic Clouds", Astronomy and Astrophysics, **503**, 855-858.
53. Bon, E., Popović, L. Č., Gavrilović, N., La Mura, G., Mediavilla, E.: 2009, "Contribution of a Disk Component to Single Peaked Broad Lines of Active Galactic Nuclei", Monthly Notices of the Royal Astronomical Society, **400**, 924-936.
54. Shapovalova, A. I., Popović, L. Č., Burenkov, A. N., Chavushyan, V. H., Ilić, D., Kovačević, A., Bochkarev, N. G., Leon-Tavares, J.: 2010, "Long-term variability of the optical spectra of NGC 4151: II. Evolution of the broad Hα and Hβ emission-line profiles", Astronomy and Astrophysics, **509**, A106.
55. Cubarsi, R., Alcobe, S., Vidojević, S., Ninković, S.: 2010, "Disk and halo kinematic populations from HIPPARCOS and Geneva-Copenhagen surveys of the solar neighbourhood", Astronomy and Astrophysics, **510**, A102.
56. Shapovalova, A. I., Popović, L. Č., Burenkov,A. N., Chavushyan, A. N., Ilić, D., Kollatschny, W., Kovačević, A., Bochkarev, N. G., Carrasco, L., Leon-Tavares, J., Mercado, A., Valdes, J. R., Vlasuyk, V. V., de la Fuente, E.: 2010, "Spectral optical monitoring of 3C390.3 in 1995-2007: I. Light curves and flux variation of the continuum and broad lines", Astronomy and Astrophysics, **517**, A42.
57. Srećković, V. A., Ignjatović, Lj. M., Mihajlov, A. A., Dimitrijević, M. S.: 2010, "The electrical conductivity of plasmas of DB white dwarf atmospheres", Monthly Notices of the Royal Astronomical Society, **406**, 590-596.
58. Kovačević, J., Popović, L. Č., Dimitrijević, M. S.: 2010, "Analysis of the optical Fe II lines in a sample of AGN spectra", Astrophysical Journal Supplement Series, 189,15-36.

59. Jovanović, P., Popović, L. Č., Stalevski, M., Shapovalova, A.I.: 2010, "Variability of the Hbeta line profiles as an indicator of orbiting bright spots in accretion disks of quasars: a case study of 3C 390.3", Astrophysical Journal, **718**, 168-176.
60. Urošević, D., Vukotić, B., Arbutina, B., Sarevska, B.: 2010, "The orthogonal fitting procedure for determination of the empirical Sigma - D relations for supernova remnants: Application to starburst galaxy M82", Astrophysical Journal, **719**, 950-957.
61. Djurašević, G., Latković, O., Vince, I., Cseki, A.: 2010, "Accretion disk in the eclipsing binary AU Mon", Monthly Notices of the Royal Astronomical Society, **409**, 329-336.
62. Djurašević, G., Yilmaz, M.,Basturk, O., Kilicoglu, T., Latković, O., Caliskan, S.:2010, "Physical parameters of close binaries QX And, RW Com, MR Del and BD +07o 3142", Astronomy and Astrophysics, **525**, A66.
63. Popović, L. Č., Moiseev, A. V., Mediavilla, E., Jovanović, P., Ilić, D., Kovačević, J., Muñoz, J.: 2010, “RXJ 0921+4529: a binary quasar or gravitational lens?”, Astrophysical Journal Letters, **721**, L139-L142.
64. Mihajlov, A. A., Ignjatović, Lj. M., Srećković, V. A., Dimitrijević, M. S.: 2011, "Chemi-ionization in Solar Photosphere: Influence on the Hydrogen Atom excited States Populations", Astrophysical Journal Supplement Series, **193,** 2.
65. Popović, L. Č., Shapovalova, A. I., Ilić, D., Kovačević, A., Kollatschny, W., Burenkov, A. N., Chavushyan, V. H., Bochkarev, N. G., Leon-Tavares, J.: 2011, "Spectral optical monitoring of 3C 390.3 in 1995-2007: II. Variability of the spectral line parameters", Astronomy and Astrophysics, **528**, A130.
66. Popović, L. Č., Kovačević, J.: 2011, "Different spectral properties of a sample of the broad line AGNs: Baldwin effect and EV 1", Astrophysical Journal, **738**, 68.
67. Donnarumma,I., De Rosa, A., Vittorini, V., Miller, H. R., Popović, L. Č., Simić, S., Tavani, M., Eggen, J., Maune, J., Kuulkers, E., Striani, E., Vercellone, S., Pucella, G., Verrecchia, F., Pittori, C., Giommi, P., Pacciani, L., Barbiellini, G., Bulgarelli, A., Cattaneo, P., Chen, A. W., Costa, E., Del Monte, E., Evangelista, Y., Feroci, M., Fuschino, F., Gianotti, F., Giuliani, A., Giusti, M., Lazzarotto, F., Longo, F., Lucarelli, F., Pellizzoni, A., Piano, G., Soffitta, P., Trifoglio, M., Trois, A.: 2011, "The remarkable gamma-ray activity in the gravitationally lensed blazar PKS 1830-211", Astrophysical Journal Letters, **736**, 30.
68. Elabidi, H., Sahal-Bréchot, S., Dimitrijević, M. S., Ben Nessib, N.: 2011, "Quantum Stark broadening data for C IV, N V, O VI, F VII and Ne VIII resonant transitions", Monthly Notices of the Royal Astronomical Society, **417**, 2624-2630.
69. Baes, M., Verstappen, J., De Looze, I., Fritz, J., Saftly, W., Vidal Perez, E., Stalevski, M., Valcke, S.: 2011, "Efficient 3D NLTE dust radiative transfer with SKIRT", Astrophysical Journal Supplement Series, **196,** 22.
70. Stalevski, M., Fritz, J., Baes, M., Nakos, T., Popović, L.Č.: 2012, "Three-dimensional radiative transfer modeling of AGN dusty tori as clumpy two-phase medium", Monthly Notices of the Royal Astronomical Society, **420**, 2756 (accepted 2011).
71. Popović, L. Č., Jovanović, P., Stalevski, M., Antoniu, S., Andrei, A. H., Kovačević, J., Baes, M.: 2012, "Photo-centric variability of quasars caused by var-

iations in their inner structure: Consequences on GAIA measurements", Astronomy and Astrophysics, **538**, A107 (accepted, 2011).
72. Kovačević, A.: 2012, "Determination of Ceres mass based on most gravitationally efficient close encounters", Monthly Notices of the Royal Astronomical Society, **419**, 2725-2736 (accepted 2011).
73. Djurašević, G., Vince, I., Antokhin, I. I., Shatsky, N. I., Cseki, A., Zakirov, M., Eshankulova, M.: 2012, "A study of the active binary system V455 Cygni", Monthly Notices of the Royal Astronomical Society, **420**, 3081 (accepted 2011).
74. Mennickent, R.E., Djurašević, G., Kolaczkowski, Z., Michalska, G.: 2012, "The Double Periodic Variable V 393 Scorpii: evolution stage and possible massive disk", Monthly Notices of the Royal Astronomical Society, **421**, 862 (accepted 2011).
75. Bozzetto, L.M., Filipović, M. D., Crawford, E.J., Haberl, F., Sasaki, M., Urošević, D., Pietsch, W., Payne, J. L., De Horta, A. Y., Stupar, M., Tothill, N., Dickel, J., Chu, Y.-H., Gruendl, R.: 2012, "Multi-frequency study of the Large Magellanic Cloud Supernova Remnant J0529-6653 near Pulsar B0529-66", Monthly Notices of the Royal Astronomical Society, **420**, 2588-2595 (accepted 2011).
76. Arbutina, B., Urošević, D., Andjelić, M., Pavlović, M., Vukotić, B.: 2012, "Modified equipartition calculation for supernova remnants", Astrophysical Journal, **746**, 79 (accepted 2011).

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References

***: *Isaac Newton Institute of Chile in Eastern Europe and Eurasia.*

***: 2003, *Isaac Newton Institute of Chile in Eastern Europe and Eurasia*, in INI - Isaac Newton Institute of Chile in Eastern Europe and Eurasia, Santiago, Chile, 1-714.

***: 2004, *Isaac Newton Institute of Chile in Eastern Europe and Eurasia*, in INI - Isaac Newton Institute of Chile in Eastern Europe and Eurasia, Santiago, Chile, 1-511.

Alcaino, G.: 2003, *Isaac Newton Institute of Chile in Eastern Europe and Eurasia*, Bulletin of the American Astronomical Society, **35**, 109.

Alcaino, G.: 2004, *Isaac Newton Institute of Chile in Eastern Europe and Eurasia*, Bulletin of the American Astronomical Society, **36**, 59.

Alcaino, G.: 2005, *Isaac Newton Institute of Chile in Eastern Europe and Eurasia*, Bulletin of the American Astronomical Society, **37**, 78.

Димитријевић, М. С.: 2002, *Васиона*, бр. 5, 141.

Димитријевић, М. С., Поповић, Л. Ч., Симић, З., Јовановић, П., Миловановић, Н., Бон, Е.: 2005, „Огранак „Југославија“ Међународног астрономског „Исак Њутн“, Зборник радова конференције „Развој астрономије код Срба III”, Београд 25-28. Април 2004, уредник М. С. Димитријевић, Публ. Астрон. Друштва „Руђер Бошковић“, **6**, 255.

Proceedings of the VIII Serbian-Bulgarian Astronomical Conference (VIII SBAC)
Leskovac, Serbia, May 8-12, 2012,
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Publ. Astron. Soc. "Rudjer Bošković" No 12, 2013, 189-204

ACTIVITIES OF PARTICIPANTS OF THE PROJECTS 146001 AND 176002 "INFLUENCE OF COLLISIONAL PROCESSES ON THE ASTROPHYSICAL PLASMA SPECTRA" – 2010-2011

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Abstract. The brief review is given, of activities of participants of the projects 146001 (in the 2010 year) and 176002 (in the 2011 year) "Influence of collisional processes on the astrophysical plasma spectra", within the period from 1st January 2010 up to 31st December 2011. Besides the bibliography of scientific results, other activities of the project participants, such as activities in popularization of science and in literature, editing, organization of scientific conferences, etc. are presented.

The period described here was specific, since in 2010 one project cyclus was completed (project 146001) and started a new one in which the project 176002 was submitted with the same name: "Influence of collision processes on astrophysical plasma spectra", but with a much broader content. In addition, the group of Anatolij Mihajlov was included and their experimental investigations of the influence of solar activity on the characteristics of the earth-ionosphere waveguide.Sonja Vidojević with a new topic of research of solar wind was also included as well as foreign associates.

The new Project is the continuation of long standing research of the influence of atomic collisional processes on the spectra of astrophysical and laboratory plasmas, and contains also two Project tasks where the investigations in two new research fields will start. The topics proposed to the Ministry of Education and Science are:

1. Determination of parameters of Stark broadening and investigations of its influence on spectral lines of white dwarfs and of chemically peculiar A and B type stars. This research field is particularly actualized with the development of satellite born astronomy, which provides the good quality spectra with unreachable before resolution, so that spectral lines of trace elements are becoming more and more astrophysically significant. Particularly is interesting recently discovered

new type of white dwarfs with carbon atmospheres,[1] which spectra contain numerous C II lines broadened by impacts with charged particles. Data on their Stark broadening available in literature are scarce and insufficient, and in order to understand the origin and evolution of this new type of stars the inclusion of accurate spectral line broadening is crucial for this type of white dwarf atmosphere modellisation.

The influence of Stark broadening on other types of white dwarf spectra, as well as on that of A and B type stars, will be investigated as well. For determination of Stark broadening parameters, semiclassical perturbation and modified semiempirical method will be used, and the results will be compared with observed stellar spectra and synthetic ones, modeled with SYNTH2 and PHOENIX code. These results enter within the frame of FP7 project VAMDC 239108 (http://www.vamdc.org/), in STARK-B database (http://stark-b.obspm.fr/), and Serbian Virtual Observatory (http://servo.aob.rs/~darko/).

Except for Astrophysics, obtained results will be of importance and for research of laboratory plasma, plasma technologies, lightning, lasers, laser produced plasmas and inertial fusion.

2. The influence of solar activity on the characteristics of waveguide Earth-ionosphere (Space weather), as well as the influence of electrical discharges in the Earth's atmosphere will be studied experimentally, by permanent measuring of the amplitude and phase of VLF radio-waves which propagate trough the waveguide Earth-ionosphere. Measuring of the amplitude and phase of narrowband transmitters within the range 10-30 κHz, by using AbsPAL (*A*bsolute *P*hase and *A*mplitude *L*ogger) and AWESOME (Atmospheric Weather Electromagnetic System for Observation Modeling and Education) systems. On the base of obtained data will be analyzed daily changes in the ionosphere which are caused by reinforced radiation from the Sun during flares and the electron density profiles during the flares as well as in the period when regular conditions in the D layer of ionosphere are established. Also, it will be studied the perturbation of the electron density in the D layer of ionosphere during night conditions which are caused by falling down high energy electrons from the radiative bands (Lightning-induced electron precitation, LEP event). We plan the continuation of the work within European action COST ES0803 «Developing space weather products and services in Europe", as well as of the bilateral collaboration with the University of Nova Gorica (Slovenia).

3. We will study the influence of inelastic atom-Rydberg atom and radiative ion-atom collision processes on the kinetics of weakly ionized plasma of Sun, white dwarfs and Earth's ionosphere. As the result, the needed rate coefficients of chemi-ionization/recombination and excitation/deexcitation processes in atom-Rydberg atom collisions, as well as the coefficients of the absorption caused by ion-atom collisions in UV and VUV spectral regions will be determined. On the base of these data the influence of atom-atom and ion-atom collision processes to

[1] Dufour, P., Liebert, J., Fontaine, G., Behara, N. : 2007, White dwarf stars with carbon atmospheres, *Nature*, **450**, 522.

the kinetic transport properties of weakly ionized solar, stellar and ionospheric plasmas will be studied.

4. Within the Project frame is the Project task "Solar wind", leaded by Sonja Vidojević. By analysis of observations with different devices on the satellites "Wind" and "STEREO", in collaboration with Paris Observatory (Milan Maksimović) will be investigated the interaction of beams with highly energetic electrons, formed in various violent events on the the Sun, with interplanetary plasma (Solar wind), through which they propagate on lines of force of the solar magnetic field. One will work and on the investigation of relationship between Langmuir oscillations/waves, and the type III solar radio bursts. As the result, one expect to determine reliably a large number of parameters of Langmuir oscillations/waves and to prove the cause and effect relationship with the type III solar radio bursts.

5. The second Project's task is "Investigation of exoplanet's reflectance spectra" in order to search biomarkers in them. This is the beginning of such investigations here, and in collaboration with Siegfried Franck from Potsdam our younger researcher will be trained to synthesize, with the JPL (Jena, Potsdam, Lund) code, the reflectance spectrum of a planet and to investigate observability of the influence of biosphere on it. The spectrum of host-star, which should be subtracted, will be modeled with the PHOENIX code or obtained by observations. Unfortunately, this activity stopped, since Professor Siegfrid Franck passed away.

Besides the scientific investigations, what is the principal objective of the Project, it will be (as in the previous Project's cycle) a basis for wide international collaboration in this research field, as it is the work on FP7 project VAMDC 239108 (Virtual Center for Atomic and Molecular Data http://www.vamdc.org/), which has participants from 9 countries (and the Project's leader, and the author of this text, is a member of the Project Board and leader of the Serbian node - AOB node), and on COST action ES0803 «Developing space weather products and services in Europe" (http://www.costes0803.noa.gr/). Because of needed equipment for the Project (observations from satellites „Wind» and "STEREO", observations of stellar spectra) will be continued and enlarged the collaboration with Paris Observatory and Russia. On the other hand, in order to obtain results of high quality, in the work on Project will participate our coauthors and colleagues from France, Russia, Greece, Spain, Germany, Tunisia, Bulgaria, Belgium (Jovo Vranješ) and Slovenia (Vida Žigman). The Project will be and a basis for scientific training and education of the young, so that we expect that at least three PhD Theses will be defended until the end of this Project, and that some tasks on the Project become themes for Diploma theses of Master studies.

Within the 2010-2011 period, participants of the Project published 7 papers in leading international journals, namely (the number of papewrs is in the brackets): Astronomy and Astrophysics (1), Astrophysical Journal (1), Astrophysical Journal Supplement Series (2), Monthly Notices of the Royal Astronomical Society (2), Journal of Physics A: Mathematical and Theoretical Physics (1).

In international journals European Physical Journal: Applied Physics (1), Journal of Quantitative Spectroscopy and Radiative Transfer (1) Physica Scripta (1) Baltic Astronomy (14) and Acta Astronomica (1), 18 papers are published. Moreover, three papers, not connected with project, are published in the journal from SSC list, and in international journals not in SCI list, and books of international publishers 20 papers are published.

The other results are: Invited lectures on international conferences published in journals and books of international publishers (8), national monographies (2), scientific papers in national journals and books (13), scientific papers in proceedings of international conferences (3), contributions on national conferences (12), abstracts of invited lectures on international conferences (12), abstracts of contributions to international conferences (27), abstracts of invited lectures on national conferences (1), book reviews in national journals (1) and 13 entries for Serbian Encyclopedia. In the considered period Dragana Tankosić defended her PhD Thesis.

In total, associates of the Project published 141 bibliographic item, from which 95 are connected with Project and 46 not.

Associates of the Project have organiyed also four conferences and one summer school, giving and in this way a contribution to the development of scientific collaboration. These meetings are:

1. „DEVELOPMENT OF ASTRONOMY AMONG SERBS VI“, Belgrade, 22 – 26 April 2010, M. S. Dimitrijević Chair of Scientific Committee, M. Dačić member; M. Dačić Chair of Local Organizing Committee, M. S. Dimitrijević member.
2. THE THIRD INTERNATIONAL SCHOOL IN ASTRONOMY: ASTROINFORMATICS – VIRTUAL OBSERVATORY, Belgrade, 29 Jun – 1 July 2010, M. S. Dimitrijević and A. Kovačević Co-Chairs of Scientific Committee, D. Jevremović Co-Vice chair, Z. Simić member, A. Kovačević Chair of Local Organizing Committee, J. Kovačević, M. Dačić, Z. Simić members.
3. I WORKSHOP: SPECTROSCOPY AS A TOOL TO INVESTIGATE ACTIVE GALACTIC NUCLEI AND GRAVITATIONAL LENSES, Бабе (Космај), 7-11. јули 2010, M. S. Dimitrijević, D. Jevremović, A. Kovačević members of Scientific Committee, J. Kovačević Chair of Local Organizing Committee, A. Kovačević member.
4. 8th SERBIAN CONFERENCE ON SPECTRAL LINE SHAPES IN ASTROPHYSICS, Divčibare, 6-10 Jun 2011, D. Jevremović Co-Chair of Scientific Committee, M. S. Dimitrijević, A. A. Mihajlov members, D. Jevremović Co-Chair of Local Organizing Committee, A. Kovačević Secretary, M. S. Dimitrijević, J. Kovačević, M. Dačić, Z. Simić members
5. I WORKSHOP ON ASTROPHYSICAL SPECTROSCOPY, Orašac, 26-30. August 2011. M. S. Dimitrijević co-Chair of the Scientific and Local Organizing Committees, D. Jevremović, Z. Simić, A. Kovačević members,

A. Kovačević Co-Chair of Local Organizing Committee, M. Dačić, J. Kovačević, Z. Simić members.

In addition, associates of the Project contributed and to the organization of the following conferences:

1. 7th BULGARIAN-SERBIAN ASTRONOMICAL CONFERENCE, ASTROINFORMATICS, Chepelare, 1 – 4. June, 2010, M. S. Dimitrijević, D. Jevremović, Z. Simić members of Scientific Committee.
2. IX CONFERENCE NEW TECHNOLOGIES AND STANDARDS: NATIONAL HERITAGE DIGITIZATION, Belgrade, 16-17. June 2010, M. S. Dimitrijević member of the Organizing Committee.
3. 20th International Conference on Spectral Line Shapes, 6-11 June 2010, St. Johns, Newfoundland, Canada, Milan S. Dimitrijević member of Scientific Committee.
4. 12th International Conference on Computer Systems and Technologies, CompSysTech'11, Wien, 16-17 June 2011, International Programme Committee, M. S. Dimitrijević, member.
5. 10th CONFERENCE NEW TECHNOLOGIES AND STANDARDS: NATIONAL HERITAGE DIGITIZATION, Belgrade, 22-23 September 2011, M. S. Dimitrijević member of the Organizing Committee.

During 2010, on the project 146001 seven associates participated, six from Astronomical Observatory and Andjelka Kovačević from Mathematical Faculty (MF). The Project Leader was Zoran Simić and the list of associates is:

1. ***Miodrag Dačić***, (born 1946) with 10 rm (research months)
2. ***Milan S. Dimitrijević***, (born 1947) with 12 rm
3. ***Darko Jevremović***, (born 1968) with 9 rm
4. ***Andjelka Kovačević***, (born 1972, MF) with 8 rm
5. ***Nenad Milovanović***, (born 1972) with 12 rm
6. ***Zoran Simić***, (born 1967) with 12 rm
7. ***Dragana Tankosić***, (born 1968) with 4 rm

During 2011, twenty six researches have been engaged on the new project 176002, sixteen from Serbia and ten from abroad. Among researches from Serbia, seven was from Astronomical Observatory (AO), four from Institute of Physics (IF), three from Mathematical Faculty (MF), one from Mathematical Institute (MI) and one from Instituite for chemical power sources (IHIS). The Project leader was M. S. Dimitrijević and the list of participants is:

1. ***Sonja Vidojević***, (born 1960, IHIS) with 12 rm (research months)
2. ***Miodrag Dačić***, (born 1946, AO) with 0 rm
3. ***Milan S. Dimitrijević***, (born 1947, AO) with 9 rm

4. ***Sanja Životić,*** (born 1984, MF) with 2 rm
5. ***Ljubinko Ignjatović***, (born 1959, IF) with 12 rm
6. ***Darko Jevremović***, (born 1968, AO) with 3 rm
7. ***Andjelka Kovačević***, (born 1972, MF) with 7 rm
8. ***Jelena Kovačević***, (born 1981, AO) with 1 rm
9. ***Dušan Marčeta***, (born 1980, MF) with 4 rm
10. ***Nenad Milovanović***, (born 1972, AO) with 2 rm
11. ***Anatolij Mihajlov***, (born 1941, IF) with 0 rm
12. ***Aleksandra Nina,*** (born 1977, IF) with 5 rm
13. ***Zoran Simić***, (born 1967, AO) with 10 rm
14. ***Vladimir Srećković,*** (born 1972, IF) with 5 rm
15. ***Dragana Tankosić***, (born 1968, AO) with 6 rm
16. ***Brankica Šurlan,*** (born 1974, MI) with 6 rm

Foreign participants of the Project were ***Jovo Vranješ*** (Belgium), ***Milan Maksimović*** (France), ***Tatjana Ryabchikova*** (Russia), ***Magdalena Christova*** (Bulgaria), ***Emanouel Danezis*** (Greece), ***Antonios Antoniou*** (Greece), ***Sylvie Sahal-Bréchot*** (France), ***Nebil Ben Nessib*** (Tunisia), ***Maria Dolores Calzada*** (Spain) and ***Siegfrid Franck*** (Germany).

In 2010, seven participants of the project 146001 realized 67 months of research, ie. 5.6 years. Average age of researchers was 1963.9 or about 46 years. In 2011 the situation is different because we have ten foreigners and two retired with yero months. If we consider only funded researchers, fourteen associates participated with a total of 84 months of research or 7 years. Average age was 1970.6 or about 40.4 years.

An important result of the project is the PhD thesis defended by Dragana Tankosić in 2010. The information concerning the acieved scientific results and extensive international cooperation, provides the bibliography of published works, listed in the Appendix. The new project, which was accepted by the Ministry of Education and Science in the new cycle, which began in 2011, greatly exceeded the old, completed in 2010, both in scope and in number of research assistants, as well as with opportunities for further education of the young. Also, a fruitful and successful international cooperation with a number of colleagues from other countries has been developed and the obtained results are, and will be included in European projects such as FP7 (Virtual Atomic and Molecular Data Center) and COST action.

BIBLIOGRAPHY OF SCIENTIFIC WORKS OF PARTICIPANTS OF THE PROJECTS 146001 AND 176002 WITHIN THE PERIOD 2010-2011

PhD THESES

1. Dragana Tankosić: EXPERIMENTAL INVESTIGATIONS OF THE OPTICAL AND PHYSICAL PROPERTIES OF INTERSTELLAR AND LUNAR DUST, PhD Thesis defended 16.09.2010, on the University of State Alabama, Huntsville, USA.

SCIENTIFIC PAPERS IN LEADING INTERNATIONAL JOURNALS

1. J. Kovačević, L. Č. Popović, M. S. Dimitrijević: 2010, ANALYSIS OF OPTICAL Fe II EMISSION IN A SAMPLE OF ACTIVE GALACTIC NUCLEUS SPECTRA, Astrophysical Journal Supplement Series, **189**, 15-36.
2. V. A. Srećković, Lj. M. Ignjatović, A. A. Mihajlov, M. S. Dimitrijević: 2010, **"**ELECTRICAL CONDUCTIVITY OF PLASMAS OF DB WHITE DWARF ATMOSPHERES" Monthly Notices of the Royal Astronomical Society, **406**, 590-596.
3. A. A. Mihajlov, Lj. M. Ignjatović, V. A. Srećković, M. S. Dimitrijević: 2011, CHEMI-IONIZATION IN SOLAR PHOTOSPHERE: INFLUENCE ON THE HYDROGEN ATOM EXCITED STATES POPULATION, Astrophysical Journal Supplement Series, **193**, 2(1-7).
4. H. Elabidi, S. Sahal-Bréchot, M. S. Dimitrijević, N. Ben Nessib: QUANTUM STARK BROADENING DATA FOR THE C IV, N V, O VI, F VII AND NE VIII RESONANCE DOUBLETS, Monthly Notices of the Royal Astronomical Society **417** (2011), 2624-2630.
5. L. Č. Popović, A. I. Shapovalova, D. Ilić, A. Kovačević, W. Kollatschny, A. N. Burenkov, V. H. Chavushyan, N. G. Bochkarev, J. León-Tavares: SPECTRAL OPTICAL MONITORING OF 3C 390.3 IN 1995-2007. II. VARIABILITY OF THE SPECTRAL LINE PARAMETERS, Astronomy and Astrophysics, **528** (2011), A130.
6. A. A. Mihajlov, N. M. Sakan, V. A. Srećković, Y. Vitel: MODELING OF CONTINUOUS ABSORPTION OF ELECTROMAGNETIC RADIATION IN DENSE PARTIALLY IONIZED PLASMAS, Journal of Physics A: Mathematical and Theoretical Physics, 44 (2011), 095502.
7. L. Č. Popović, J. Kovačević: OPTICAL EMISSION-LINE PROPERTIES OF A SAMPLE OF THE BROAD-LINE ACTIVE GALACTIC NUCLEI: THE BALDWIN EFFECT AND EIGENVECTOR 1, Astrophysical Journal, **738** (2011), 68.

SCIENTIFIC PAPERS IN INTERNATIONAL JOURNALS FROM SCI AND SSCI LISTS

1. R. Qindeel, M. S. Dimitrijević, N. M. Shaikh, N. Bidin, Y. M. Daud: SPECTROSCOPIC ESTIMATION OF ELECTRON TEMPERATURE AND DENSITY OF ZINC PLASMA OPEN AIR INDUCED BY Nd:YAG LASER, European Physical Journal: Applied Physics, **50** (2010), 30701.
2. M. L. Dubernet, V. Boudon, J. L. Culhane, M. S. Dimitrijevic, A. Z. Fazliev, C. Joblin, F. Kupka, G. Leto, P. Le Sidaner, P. A. Loboda, H. E. Mason, N. J. Mason, C. Mendoza, G. Mulas, T. J. Millar, L. A. Nuñez, V. I. Perevalov, N. Piskunov, Y. Ralchenko, G. Rixon, L. S. Rothman, E. Roueff, T. A. Ryabchikova, A. Ryabtsev, S. Sahal-Bréchot, B. Schmitt, S. Schlemmer, J. Tennyson, V. G. Tyuterev, N. A. Walton, V. Wakelam, C. J. Zeippen: VIRTUAL ATOMIC AND MOLECULAR DATA CENTRE, Journal of Quantitative Spectroscopy and Radiative Transfer, **111** (2010), 2151-2159.
3. E. Theodossiou, V. Manimanis, M. S. Dimitrijević: THE INCONVENIENT RELATION BETWEEN RELIGION AND SCIENCE: THE PREVALENCE OF THE HELIOCENTRIC THEORY, Euopean Journal for Science and Theology **6 (3)** (2010), 47-56.
4. B. Zmerli, N. Ben Nessib, M. S. Dimitrijević, S. Sahal-Bréchot: 2010, STARK BROADENING CALCULATIONS OF NEUTRAL COPPER SPECTRAL LINES AND TEMPERATURE DEPENDENCE, Physica Scripta **82,** 055301 (9pp).
5. E. Theodossiou, V. Manimanis, M. S. Dimitrijević: THE CONTRIBUTION OF BIZANTINE PRIESTS IN ASTRONOMY AND COSMOLOGY. I. THE CHURCH FATHERS: THREE BISHOPS ST. BASIL THE GREAT, ST. GREGORY OF NAZIANZUS AND ST. JOHN CHRYSOSTOM, Euopean Journal for Science and Theology **7 (2)** (2011), 33-47.
6. E. Theodossiou, V. Manimanis, M. S. Dimitrijević: THE CONTRIBUTION OF BIZANTINE PRIESTS IN ASTRONOMY AND COSMOLOGY. II. GREAT CHURCH SCHOLARS IN THE EARLY BYZANTINE EMPIRE, Euopean Journal for Science and Theology **7 (4)** (2011), 25-45.
7. S. Sahal-Bréchot, M. S. Dimitrijević, N. Ben Nessib: COMPARISONS AND COMMENTS ON ELECTRON AND ION IMPACT PROFILES OF SPECTRAL LINES, Baltic Astronomy **20,** (2011) 523-530.
8. P. Dufour, N. Ben Nessib, S. Sahal-Bréchot, M. S. Dimitrijević: STARK BROADENING OF CARBON AND OXYGEN LINES IN HOT DQ WHITE DWARF STARS: RECENT RESULTS AND APPLICATIONS, Baltic Astronomy **20,** (2011) 511-515.
9. F. Kupka and the VAMDC (participant M. S. Dimitrijević) collaboration (P.[rincipal] I.[nvestigator] M.-L. Dubernet): VAMDC AS A RESOURCE FOR ATOMIC AND MOLECULAR DATA AND THE NEW RELEASE OF VALD, Baltic Astronomy **20,** (2011) 503-510.

10. M. S. Dimitrijević, A. Kovačević, Z. Simić, S. Sahal-Bréchot: STARK BROADENING AND WHITE DWARFS, Baltic Astronomy **20,** (2011) 495 -502.
11. R. Hamdi, N. Ben Nessib, M. S. Dimitrijević, S. Sahal-Bréchot: AB INITIO DETERMINATION OF ATOMIC STRUCTURE AND STARK BROADENING PARAMETERS: Pb IV AND RECENT RESULTS, Baltic Astronomy **20,** (2011) 552-557.
12. A. A. Mihajov, Lj. M. Ignjatović, V. A. Srećković, M. S. Dimitrijević: THE INFLUENCE OF CHEMI-IONIZATION AND RECOMBINATION PROCESSES ON SPECTRAL LINE SHAPES IN STELLAR ATMOSPHERES, Baltic Astronomy **20,** (2011) 566-571.
13. E. Lyratzi, E. Danezis, L. Č. Popović, A. Antoniou, M. S. Dimitrijević, D. Stathopoulos: THE COMPLEX BROAD ABSORPTION LINE PROFILES IN A SAMPLE OF QSO SPECTRA, Baltic Astronomy **20,** (2011) 448-452.
14. Z. Simić, M. S. Dimitrijević, A. Kovačević, S. Sahal-Bréchot: STARK BROADENING OF In III LINES IN ASTROPHYSICAL AND LABORATORY PLASMA, Baltic Astronomy **20,** (2011) 613-617.
15. M. S. Dimitrijević, A. Kovačević, Z. Simić, S. Sahal-Bréchot: STARK BROADENING OF SEVERAL Ne II, Ne III AND O III SPECTRAL LINES FOR THE STARK-B DATABASES, Baltic Astronomy **20,** (2011) 580-586.
16. M. S. Dimitrijević, A. Kovačević, Z. Simić, S. Sahal-Bréchot: STARK BROADENING OF SEVERAL Ar I SPECTRAL LINES IN THE VISIBLE SPECTRUM, Baltic Astronomy **20,** (2011) 576-579.
17. A. Antoniou, E. Danezis, E. Lyratzi, D. Stathopoulos, M. S. Dimitrijević: A STATISTICAL STUDY OF THE Si IV RESONANCE LINE PARAMETERS IN 19 Be STARS, Baltic Astronomy **20,** (2011) 548-551.
18. A. I. Shapovalova, L. Č. Popović, D. Ilić, A. Kovačević, J. Kovačević, A. N. Burenkov, V. H. Chavushyan: SPECTRAL MONITORING OF AGN: PRELIMINARY RESULTS FOR ARK 564 AND ARP 102B, Baltic Astronomy **20,** (2011) 476-480.
19. S. Šegan, S. Milisavljević, D. Marčeta: A COMBINED METHOD TO COMPUTE THE PROXIMITIES OF ASTEROIDS, Acta Astronomica, **61** (2011) 275-283.
20. A. Nina, V. Čadež, V. Srećković, D. Šulić: THE INFLUENCE OF SOLAR SPECTRAL LINES ON ELECTRON CONCENTRATION IN TERRESTRIAL IONOSPHERE, Baltic Astronomy, **20** (2011), 609–612.
21. A. Mihajlov, N. Sakan, V. Srećković, Y. Vitel: MODELING OF THE CONTINUOUS ABSORPTION OF ELECTROMAGNETIC RADIATION IN DENSE HYDROGEN PLASMA, Baltic Astronomy, **20** (2011),604-609.

INVITED LECTURES ON INTERNATIONAL CONFERENCES PUBLISHED IN BOOKS AND JOURNALS OF INTERNATIONAL PUBLISHERS

1. E. Lyratzi, E. Danezis, E., L. Č. Popović, A. Antoniou, M. S. Dimitrijević, D. Stathopoulos: STUDYING THE COMPLEX BAL PROFILES IN THE BALQSOS SPECTRA, Journal of Physics: Conference Series **257,** (2010) 012035 (1-8).
2. M. S. Dimitrijević, S. Sahal-Bréchot, A. Kovačević, D. Jevremović, L. Č. Popović: EUROPEAN VIRTUAL ATOMIC DATA CENTRE - VAMDC, Journal of Physics: Conference Series **257,** (2010) 012032 (1-8).
3. K. Tsvetkova, M. Tsvetkov, M. S. Dimitrijević, V. Protić-Benišek, V. Benišek, D. Jevremović: WIDE-FIELD PLATE ARCHIVES IN ROZHEN AND BELGRADE OBSERVATORIES, Memorie della Societa Astronomica Italiana Supplementi **15,** (2010) 192-203.
4. M. Christova, M. S. Dimitrijević: STARK BROADENING OF SPECTRAL LINES OF INERT GASES, Memorie della Societa Astronomica Italiana Supplementi **15,** (2010) 126-137.
5. M. S. Dimitrijević: ASTRONOMICAL SPECTRA AND COLLISIONS WITH CHARGED PARTICLES, Memorie della Societa Astronomica Italiana Supplementi **15,** (2010) 32-43.
6. E. Danezis, E. Lyratzi, A. Antoniou, L. Č. Popović, M. S. Dimitrijević: STUDYING THE COMPLEX SPECTRAL LINE PROFILES IN THE SPECTRA OF HOT EMISSION STARS AND QUASARS, Memorie della Societa Astronomica Italiana Supplementi **15,** (2010) 13-31.
7. M. S. Dimitrijević, S. Sahal-Bréchot, A. Kovačević, D. Jevremović, L. Č. Popović: 2011, NEW CHALENGES OF ASTROINFORMATICS – STARK-B DATABASE AND SERBIAN VIRTUAL OBSERVATORY ' – SerVO, AND RELATIONS TO VIRTUAL ATOMIC AND MOLECULAR DATA CENTER – VAMDC, INFLUENCE OF COLLISIONS WITH CHARGED PARTICLES ON ASTRONOMICAL SPECTRA, in Computer Systems and Technologies, Proceedings of the 12th International Conference CompSysTech'11, eds. B. Rachev, A. SmrikarovAngelopoulos, ACM (Association for Computing Machinery) ICPS (International Conference Proceedings Series), ACM Press, New York **578**, 23-31.
8. Rixon, G., Dubernet, M. L., Piskunov, N., Walton, N., Mason, N., Le Sidaner, P., Schlemmer, S., Tennyson, J., Akram, A., Benson, K., Bureau, J., Doronin, M., Endres, C., Heiter, U., Hill, C., Kupka, F., Nenadović, L., Marquart, T., Mulas, G., Ralchenko, Y., Shih, A., Smith, K., Schmitt, B., Witherick, D., Boudon, V., Culhane, J. L., Dimitrijević, M. S., Fazliev, A. Z., Joblin, C., Leto, G., Loboda, P. A., Mason, H. E., Mendoza, C., Millar, T. J., Nunez, L. A., Perevalov, V. I.,

Rothman, L. S., Roueff, E., Ryabchikova, T. A., Ryabtsev, A., Sahal-Bréchot, S., Tyuterev, V. G., Wakelam, V., Zeippen, C. J.: 2011, VAMDC - THE VIRTUAL ATOMIC AND MOLECULAR DATA CENTRE - A NEW WAY TO DISSEMINATE ATOMIC AND MOLECULAR DATA - VAMDC LEVEL 1 RELEASE, 7th International Conference on Atomic and Molecular Data and their Applications - ICAMDATA - 2010, Vilnius, Lithuania 21-24 September 2010, eds. A. Bernotas, R. Karazija, Z. Rudzikas, American Institute of Physics Conference Proceedings **1344**, 107-115.

PAPERS IN INTERNATIONAL JOURNALS WHICH ARE NOT ON SCI LIST AND IN BOOKS OF INTERNATIONAL PUBLISHERS

1. A. Antoniou, E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, D. Stathopoulos: 2010, A NEW APPROACH OF THE GR MODEL, in "Advances in Hellenic Astronomy during the IYA09", K. Tsinganos, D. Hatzidimitriou, and T. Matsakos, eds., Astronomical Societz of the Pacific (ASP) Conference Series, **424**, 187-188.
2. E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, A. Antoniou: 2010, INVESTIGATING DACS/SACS PHENOMENA IN HOT EMISSION STARS AND QUASARS, in "Advances in Hellenic Astronomy during the IYA09", K. Tsinganos, D. Hatzidimitriou, and T. Matsakos, eds., Astronomical Societz of the Pacific (ASP) Conference Series, **424**, 305-307.
3. E. Lyratzi, E. Danezis, L. Č. Popović, M. S. Dimitrijević, A. Antoniou: 2010, WAYS OF CREATION OF DACS AND SACS IN THE SPECTRA OF PG 0946+301AND PG 1254+047, in "Advances in Hellenic Astronomy during the IYA09", K. Tsinganos, D. Hatzidimitriou, and T. Matsakos, eds., Astronomical Societz of the Pacific (ASP) Conference Series, **424**, 308-310.
4. N. Larbi-Terzi, S. Sahal-Bréchot, N. Ben Nessib, M. S. Dimitrijević: 2010, VAMDC FP7 PROJECT AND STARK-B DATABASE: C II STARK BROADENING PARAMETERS FOR WHITE DWARF ATMOSPHERES RESEARCH, in 17th European White Dwarf Workdhop, eds. M. K. Werner, T. Rauch, American Institute of Physics Conference Proceedings **1273**, 428-431.
5. V. A. Srećković, Lj. M. Ignjatović, A. A. Mihajlov, M. S. Dimitrijević: 2010, ELECTRICAL CONDUCTIVITY OF PLASMA IN DB WHITE DWARF ATMOSPHERES, in 17th European White Dwarf Workdhop, eds. M. K. Werner, T. Rauch, American Institute of Physics Conference Proceedings **1273**, 428-431.
6. M. Christova, M. S. Dimitrijević, A. Kovačević: SIMILARITIES IN CALCULATED STARK BROADENING PARAMETERS OF ARGON SPECTRAL LINES, Journal of Physics: ConferenceSeries **207,** (2010) 012024 (1-6).

7. M. Christova, M. S. Dimitrijević, Z. Simić, S. Sahal-Bréchot: STARK BROADENING PARAMETERS OF Ne I 837.8 nm SPECTRAL LINE, Journal of Physics: ConferenceSeries **207,** (2010) 012025 (1-4).
8. J. Kovačević, L. Č. Popović, M. S. Dimitrijević: THE OPTICAL FE II EMISSION LINES IN ACTIVE GALACTIC NUCLEI, Memorie della Societa Astronomica Italiana Supplementi **15,** (2010) 176-181.
9. E. Lyratzi, E. Danezis, L. Č. Popović, M. S. Dimitrijević, A. Antoniou, D. Stathopoulos: KINEMATIC PROPERTIES OF THE BROAD ABSORPTION LINE REGIONS IN THE SPECTRA OF QUASARS, Memorie della Societa Astronomica Italiana Supplementi **15,** (2010) 161-165.
10. J. Muñoz, C. Yubero, M. S. Dimitrijević, M. D. Calzada: VAN DER WAALS BROADENING IN ATMOSPHERIC PRESSURE SURFACE WAVE DISCHARGES SUSTAINED IN RARE GASES, Memorie della Societa Astronomica Italiana Supplementi **15,** (2010) 157-160.
11. B. Zmerli, N. Ben Nessib, M. S. Dimitrijević, S. Sahal-Bréchot: ON THE STARK BROADENING OF CU I SPECTRAL LINES, Memorie della Societa Astronomica Italiana Supplementi **15,** (2010) 152-156.
12. R. Hamdi, N. Ben Nessib, M. S. Dimitrijević, S. Sahal-Bréchot: AB INITIO CALCULATIONS OF CA V STARK BROADENING PARAMETERS, Memorie della Societa Astronomica Italiana Supplementi **15,** (2010) 148-151.
13. Z. Simić, M. S. Dimitrijević, A. Kovačević: ON THE STARK BROADENING IN HOT STARS, Memorie della Societa Astronomica Italiana Supplementi **15,** (2010) 143-147.
14. A. Antoniou, E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, E. Theodossiou: STUDYING THE LOCATION OF SACS AND DACS REGIONS IN THE ENVIRONMENT OF HOT EMISSION STARS, Memorie della Societa Astronomica Italiana Supplementi **15,** (2010) 138-142.
15. N. A. Walton, M. L. Dubernet, N. J. Mason, N. Piskunov, G. T. Rixon and VAMDC Consortium: 2011, VAMDC: The Virtual Atomic and Molecular Data Center, in " ASTRONOMICAL DATA ANALYSIS SOFTWARE AND SYSTEMS XX", I. N. Evans, A. Accomazzi, D. J. Mink, A. H. Rots, eds., Astronomical Society of the Pacific (ASP) Conference Series, **442**, 89-92.
16. M. S. Dimitrijević: 2011, PROBLEMS OF CALENDAR REFORM AND EASTER DATE DETERMINATION AND A PROPOSITION TO THE SERBIAN ORTHODOX CHURCH, MADE BY DJORDJE STANOJEVIĆ, Transdisciplinary Studies **1** (2011), 147-156.
17. E. Th. Theodossiou, V. N. Manimanis, P. Z. Mantarakis M. S. Dimitrijević: 2011, ASTRONOMY AND CONSTELLATIONS IN ILIAD AND ODISSEY, Journal of Astronomical History and Heritage **14(1)** (2011), 22-30.

18. E. Theodossiou, P. Mantarakis, M. S. Dimitrijević, V. N. Manimanis, E. Danezis: FROM THE INFINITY (APEIRON) OF ANAXIMANDER IN ANCIENT GREECE TO THE THEORY OF INFINITE UNIVERSES IN MODERN COSMOLOGY, Astronomical and Astrophysical Transactions **27** (2010/2011), 172-176.
19. E. Th. Theodossiou, V. N. Manimanis, M. S. Dimitrijević, P. Z. Mantarakis: 2011, SIRIUS IN ANCIENT GREEK AND ROMAN LITERATURE: FROM THE ORPHIC ARGONAUTICS TO THE ASTRONOMICAL TABLES OF GEORGIOS CHRYSOCOCCA, Journal of Astronomical History and Heritage **14(3)** (2011), 180-189.
20. B. Šurlan, J. Kubát: LINE PROFILES OF OB STAR WINDS USING A MONTE CARLO METHOD, Proceedings of the International Astronomical Union, IAU Symposium, **272** (2011) 214-215.

NATIONAL MONOGRAPHIES

1. Мр Јелена Ковачевић, АКТИВНА ГАЛАКТИЧКА ЈЕЗГРА И ЊИХОВИ ЕМИСИОНИ РЕГИОНИ, Academia, **235**, Задужбина Андрејевић, Београд, 2010.
2. Др Зоран Симић, ШТАРКОВО ШИРЕЊЕ СПЕКТРАЛНИХ ЛИНИЈА У ХЕМИЈСКИ НЕОБИЧНИМ ЗВЕЗДАМА, Dissertatio, **245**, Задужбина Андрејевић, Београд, 2010.

SCIENTIFIC WORKS IN NATIONAL JOURNALS AND BOOKS

1. E. Danezis**,** E**.** Theodossiou**,** M. S. Dimitrijević**,** A. Dacanalis**,** Ch. Katsavrias: THE COSMOLOGY OF DEMOCRITUS, Bulgarian Astronomical Journal 13 (2010), 140-152.
2. J. Kovačević: SPECTRAL PROPERTIES OF AGN WITH VERY WEAK [O III] LINES, Serbian Astronomical Journal, **182** (2011), 17-24.
3. E. Theodossiou**,** A. Dacanalis**,** M. S. Dimitrijević**,** P. Mantarakis: GAIA, HELIOS, SELENE AND OURANOS: THE THREE PRINCIPAL CELESTIAL BODIES AND THE SKY IN THE ANCIENT GREEK COSMOGONY, Bulgarian Astronomical Journal, **16** (2011), No. 2, 1-19.
4. E. Theodossiou, V. N. Manimanis, M. S. Dimitrijević: SIX CALENDAR SYSTEMS IN THE EUROPEAN HISTORY FROM 18TH TO 20TH CENTURY, Bulgarian Astronomical Journal**, 16** (2011), No. 6, 1-20.
5. Еманоил Данезис, Ефстратиос Т. Теодосиу, Милан С. Димитријевић, Арис Даканалис: 2010, КОЗМОЛОГИЈЕ АЛКМАНА, ЛЕУКИПА И ДЕМОКРИТА И НЕКЕ СЛИЧНОСТИ СА МОДЕРНИМ НАУЧНИМ КОНЦЕПТИМА, Античка култура, европско и српско наслеђе, Друштво за античке студије Србије, Институт за теолошка истраживања, Београд, 162-173.

6. M. S. Dimitrijević, ELECTRONIC EDITIONS FROM ASTRONOMICAL INSTITUTIONS OF BELGRADE, Pregled NCD, 17, 2011, 17-24.
7. E. Danezis, E. Th. Theodossiou, M. S. Dimitrijević, A. Dacanalis: 2010, COSMOLOGIES OF ALCMAN, LEUCIPPUS AND DEMOCRITUS AND SOME SIMILARITIES WITH MODERN SCIENTIFIC CONCEPTS, Зборник Матице српске за класичне студије, бр. 12, Нови Сад 2010, 281-297.
8. E. Theodossiou, V. Manimanis, M. C. Димитријевић: 2011, НЕПОДЕСАН ОДНОС ИЗМЕЂУ РЕЛИГИЈЕ И НАУКЕ: ПРЕВЛАДАВАЊЕ ХЕЛИОЦЕНТРИЧНЕ ТЕОРИЈЕ, Антика и савремени свет: Религија и култура, Друштво за античке студије Србије, Институт за теолошка истраживања, Београд, 374-386.
9. E. Theodossiou, V. Manimanis, M. C. Димитријевић: 2011, КОЗМОЛОГИЈА ГНОСТИКА, Антика и савремени свет: Религија и култура , Друштво за античке студије Србије, Институт за теолошка истраживања, Београд, 366-373.
10. E. Theodossiou, V. Manimanis, M. S. Dimitrijević: 2011, THE COSMOLOGICAL THEORIES OF PRE-SOCRATIC GREEK PHILOSOPHERS AND THEIR PHILOSOPHICAL VIEWS FOR THE ENVIRONMENT, Facta Universitatis, Series: Philosophy, Sociology, Psychology and History, **10**, 89-99
11. E. Theodossiou, V. Manimanis, M. S. Dimitrijević, M. Katsiotis: THE PYRAMIDS OF GREECE – ANCIENT MERIDIAN OBSERVATORIES?, Bulgarian Astronomical Journal , 16, 2011, 130-143.
12. Евстратије Теодосију, Василије Н. Маниманис, Милан С. Димитријевић: 2010-2011, „ТЕОРИЈА СВЕГА“ БЕНЏАМИНА ЛЕЗБИОСА, Phlogiston, 18, 2010-2011, 7-16.
13. Efstratios Theodossiou, Vassilios N. Manimanis, Milan S. Dimitrijević: 2010-2011, THE THEORY OF PANTAHEKINETON OF BENJAMIN LESBIOS, Phlogiston, 18, 20010-2011, 17-32.

CONTRIBUTED PAPERS IN PROCEEDINGS OF INTERNATIONAL CONFERENCES

1. V. Srećković, Lj. M. Ignjatović, A. A. Mihajlov, M. S. Dimitrijević: 2010, ELECTRICAL CONDUCTIVITY OF PLASMAS IN DB WHITE DWARF ATMOSPHERES, Publ. Astron. Obs. Belgrade **89**, 383.
2. N. Larbi-Terzi, S. Sahal-Bréchot, N. Ben Nessib, M. S. Dimitrijević: 2010, C II STARK BROADENING PARAMETERS FOR WHITE DWARF ATMOSPHERES RESEARCH, Publ. Astron. Obs. Belgrade **89**, 375.
3. M. S. Dimitrijević, VAMDC Consortium (Dubernet, P. I. M- L.) A. Kovačević, D. Jevremović, L. Č. Popović, S. Sahal-Bréchot: EUROPEAN VIRTUAL ATOMIC DATA CENTRE - VAMDC, XIXth Symposium of Physics of Switching Arc, Invited Lectures and

Contributed Papers**,** Nove Mesto na Morave, 5-9 September 2011, Brno University of Technology, Faculty of Electrical Engineering and Communication, 201,1 153-156.

CONTRIBUTED PAPERS IN PROCEEDINGS OF NATIONAL CONFERENCES

1. Евстратије Теодосију, Василије Н. Маниманис, Милан С. Димитријевић: 2011, ДОПРИНОС ВИЗАНТИЈЕ ПРИРОДНИМ НАУКАМА; ВИЗАНТИЈСКИ АСТРОНОМИ И НАУЧНИЦИ, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 693-706.
2. Евстратије Теодосију, Василије Н. Маниманис, Милан С. Димитријевић: 2011, ШЕСТ КАЛЕНДАРСКИХ СИСТЕМА У ЕВРОПСКОЈ ИСТОРИЈИ ОД 18. ДО 20. ВЕКА, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 745-769.
3. Милан С. Димитријевић: 2011, ФИЛАТЕЛИЈА И АСТРОНОМИЈА, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 845-865.
4. Еди Бон, Милан С. Димитријевић, Игор Стојић, Весна Мијатовић: 2011, МОТИВИ АСТРОНОМСКИХ ПОЈАВА У ХРИШЋАНСКОЈ УМЕТНОСТИ, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 931-939.
5. Милан С. Димитријевић: 2011, НЕБЕСКИ ЗНАЦИ И КОСМИЧКА ТРАГАЊА У ПОЕЗИЈИ ДРАГАНА ДРАГОЈЛОВИЋА, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 1061-1068.
6. Милан С. Димитријевић: 2011, ЛИРСКО-ПОЕТСКО И ДОКУМЕНТАРИСТИЧКО ВИЂЕЊЕ АСТРОНОМИЈЕ У „БЛАГОДАРНИКУ“ МИЛАНА С. КОСОВИЋА, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 1069-1082.
7. Милан С. Димитријевић: 2011, „С ГЕОМ НА РЕДУТУ“ ПОД ЗВЕЗДАМА, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 1093-1124.

8. Милан С. Димитријевић: 2011, КОСМИЧКЕ ИНСПИРАЦИЈЕ СТРАТОСА ТЕОДОСИЈУА, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 1125-1132.
9. Милан С. Димитријевић: 2011, ПЕСНИЧКИ ДЕКОНСТРУИСАНА ЛИРСКО-СОНЕТНА КОСМОГОНИЈА У ИЗВРНУТОМ ОГЛЕДАЛУ; Поетски дар Петковићевом уздарју, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 1185-1189.
10. Анђелка Ковачевић, Милан С. Димитријевић, Лука Ч. Поповић: 2011, ДРУГА ЛЕТЊА ШКОЛА ИЗ АСТРОНОМИЈЕ, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 1257-1284.
11. Анђелка Ковачевић, Милан С. Димитријевић, Лука Ч. Поповић: 2011, VII СРПСКА КОНФЕРЕНЦИЈА О ОБЛИЦИМА СПЕКТРАЛНИХ ЛИНИЈА У АСТРОФИЗИЦИ, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 1285-1308.
12. Милан С. Димитријевић: 2011, АКТИВНОСТИ САРАДНИКА ПРОЈЕКТА 146001 „УТИЦАЈ СУДАРНИХ ПРОЦЕСА НА СПЕКТРЕ АСТРОФИЗИЧКЕ ПЛАЗМЕ“ – 2008-2009, Зборник радова конференције “Развој астрономије код Срба VI”, Београд, 22-26. април 2010, уредник М. С. Димитријевић, Публ. Астр. друш. “Руђер Бошковић” св. 10, 289-341.

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ON THE STARK BROADENING OF B IV SPECTRAL LINES

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Abstract. The preliminary results for Stark broadening parameters of B IV lines from 8 spectral series have been calculated using Sahal-Bréchot theory based on the semi-classical perturbation formalism.

1. INTRODUCTION

A major interest consists in the understanding of the evolution of the Universe, of the birth, growing, evolution and death of stars, which eject their material into the interstellar medium at the end of their life. The light trace elements lithium, beryllium, and boron (LiBeB) are at the centre of astrophysical puzzles involving sites as diverse as the primordial fireball, interstellar (IS) or even intergalactic space, and stellar surfaces and interiors (Venn et al., 2002). The origins of the light element trio are connected, by varying degrees, to the big bang nucleosynthesis, cosmic-ray spallation, and stellar evolution. Abundance determinations of Li, Be, and B in a variety of stars provide data on the above astrophysical processes that can both produce and destroy these rare elements. The light elements are sensitive probes of stellar models due to the fact that the stable isotopes of all three consist of nuclei with small binding energies that are destroyed easily by (p, a) reactions at modest temperatures (Cunha and Smith, 1999). The origin and evolution of boron are of special interest because it is hardly produced by the standard big bang nucleosynthesis (BBN), and cannot be produced by nuclear fusion in stellar interiors (Tan, Shi and Zhao, 2010). The light isotopes ^{10}B and ^{11}B are believed to be primarily formed via spallation of carbon and oxygen nuclei (Proffitt et al.,

1999). Traditional models for this process (Meneguzzi, Audouze and Reeves, 1971), where cosmic ray protons and alpha-particles collide with pre-existing CNO nuclei in the interstellar medium, predicted that beryllium and boron would scale quadratically with the overall metal abundance and that the ratio $^{11}B/^{10}B \approx 2.5$. However, boron and beryllium abundances actually scale linearly with the total metal abundance, and it has long been known that the meteoritic ratio of $^{11}B/^{10}B \approx 4$ (Proffitt et al., 1999, Meneguzzi, Audouze and Reeves, 1971, Duncan, Lambert and Lemke, 1992, Duncan et al., 1997, Shima, 1963). These papers are concerned primarily with boron's role in testing models of stellar interiors and evolution. This role arises because boron nuclei are destroyed by warm protons, and thus even quite shallow mixing of the atmosphere with the interior reduces the surface abundance by bringing boron-depleted material to the surface. Lithium and beryllium are similarly affected. Thus, a determination that the surface abundance of a light element is less than the star's initial abundance is an observational constraint for testing models of stellar interiors (Venn et al., 2002).

Boron alone is observable in hot stars. A principal goal of most of studies of hot stars was to establish the present-day boron abundance in order to improve the understanding of the Galactic chemical evolution of boron (Venn et al., 2002). In Tan, Shi and Zhao (2010) has been reported that, the abundances of the nine stars which are not depleted in Be or B show that, no matter what the strength of collisions with neutral hydrogen may be, both Be and B increase with O quasilinearly in the logarithmic plane, which confirms the conclusions that Be and B are mainly produced by the primary process in the early Galaxy. Boron in hot stars, like lithium in cool stars, is shown to be a tracer of some of the various processes affecting a star's surface composition that are not included in the standard models of stellar evolution. If the initial boron abundances of local hot stars are similar from star to star and association to association, then the large spread in boron abundances shows that boron abundances are a clue to unravelling the nonstandard processes that affect young hot stars.

The cosmic abundances of ^{11}B is of major importance for the model of Galactic chemical evolution (GCE) (Ritchey et al., 2011), where the authors conclude that a major portion of the cosmic abundances of ^{11}B can be attributed to neutrino nucleosynthesis. Thus, it is necessary to accurately describe the stellar evolution, and the formation of elements, which are closely connected. To make progress in these developments chemical abundances are crucial parameters to be determined. This needs an accurate interpretation of the detailed line spectra of the stellar objects.

2. STARK BROADENING OF BORON LINES

Pressure broadening of spectral lines arises when an atom, ion, or molecule which emits or absorbs light in a gas or plasma, is perturbed by its interactions with the other particles of the medium. Interpretation of this phenomenon is currently used for modelling of the medium and for spectroscopic diagnostics, since the broadening of the lines depends on the temperature and density of the

medium. The physical conditions in the Universe are very various, and collisional broadening with charged particles (Stark broadening) appears to be important in many domains. For example, at temperatures around 10^4 K and densities 10^{13} - 10^{15} cm^{-3}, Stark broadening is efficient for modelling and analysing spectra of moderately hot (A), hot (B) and very hot (O) types of stars Sahal-Bréchot, 2010). In white dwarfs, especially, Stark broadening is the dominant collisional line broadening process. The theory of Stark broadening is well applied, especially for accurate spectroscopic diagnostics and modelling. This requires the knowledge of numerous profiles, especially for trace elements, as boron in this case, which are used as useful probes for modern spectroscopic diagnostics. Interpretation of the spectra of white dwarfs, which are very faint, allows understanding the evolution of these very old stars, which are close to death.

The primary results for Stark broadening parameters of BIV lines from 8 spectral series have been calculated using Sahal-Bréchot theory based on the semi-classical perturbation formalism. (Sahal-Bréchot, 1969ab). Within the Sahal-Bréchot theory the full width at half intensity maximum (W) and the shift (d) of an isolated line originating from the transition between the initial level i and the final level f is expressed as:

$$W = n_e \int_0^\infty v f(v) dv \left[\sum_{i' \neq i} \sigma_{ii'}(v) + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_{el} \right] \tag{1}$$

$$d = \int_0^\infty v f(v) dv \int_{R_3}^{R_d} 2\pi\rho d\rho \sin 2\varphi_p \tag{2}$$

where i' and f' are perturbing levels, n_e and v are the electron density and the velocity of perturbers respectively, and $f(v)$ is the Maxwellian distribution of electron velocities.

The inelastic cross sections $\sigma_{ii'}(v)$ (respectively $\sigma_{ff'}(v)$) can be expressed by an integration of the transition probability $P_{ii'}$ over the impact parameter ρ:

$$\sum_{i' \neq i} \sigma_{ii'}(v) = \frac{1}{2} \pi R_1^2 + \int_{R_1}^{R_d} 2\pi\rho d\rho \sum_{i' \neq i} P_{ii'}(\rho, v) \tag{3}$$

The elastic collision contribution to the width is given by:

$$\sigma_{el} = 2\pi R_2^2 + \int_{R_2}^{R_d} 8\pi\rho d\rho \sin^2 \delta \tag{4}$$

$$\delta = \left(\varphi_p^2 + \varphi_q^2 \right)^{1/2} \tag{5}$$

The phase shifts φ_p and φ_q are due to the polarization and quadrupole potential respectively. The cut-offs parameters R_1, R_2, R_3, the Debye cut-off R_d and the symmetrization procedure are described in Sahal-Bréchot (1969ab). The collisons of emitters with electrons, protons and ionized helium have been examined, and the contribution of different perturbers in the total Stark broadening parameters have been discussed.

3. RESULTS AND DISCUSSION

Stark broadening width and shift for spectral lines of 8 series are presented in Table 1. The temperature dependence of Stark width and shift for the $1s^{21}S - 1s2p\ ^1P^\circ$ transition at electron density 1.10^{18} cm^{-3} have been presented in Table 1., Fig. 1 and Fig. 2, respectively. The both parameters dramatically change at lower temperature values up to 10 000 K then they vary slowly, the width decreases while the shift increases. The electron contribution in total width decreases from almost 100% to 60%, the proton one increases to 13 %, and the ionized helium one increases too, up to 26 % within the temperature interval of interest. We observe the same tendency for the Stark shift. The contribution of electron perturbers decrease from 97 % to 11 %, the role of collisions with protons increase from 1 % to 27 %, and the ionized helium perturbers broad the line from 2 % to 72 % in all temperature interval. The values of Stark shift due to collisions with different perturbers are negative in the considered case. The principal quantum dependence of the electron impact width within the series is illustrated in Fig. 3. The examined conditions of interest are 100 000 K and 1.10^{14} cm^{-3} electron density. The calculated data are fitted with polynomial function of 4-th order; the fit-curve is added in the figure. The polynomial function permits the interpolation and extrapolation to obtain electron impact width for other lines within the series where there is a lack of the data to perform the calculations. The analytical function is given below:

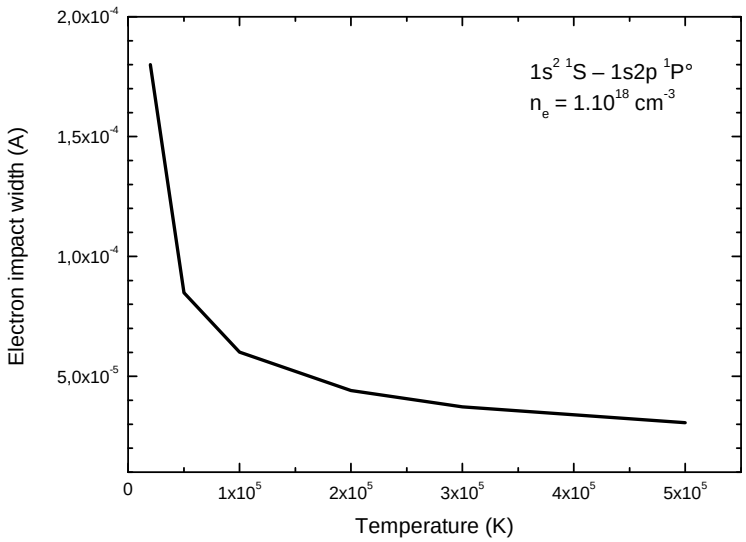

Figure 1: Temperature dependence of the electron impact width for $1s^{21}S - 1s2p\ ^1P^\circ$ transition at electron density 1.10^{18} cm^{-3}.

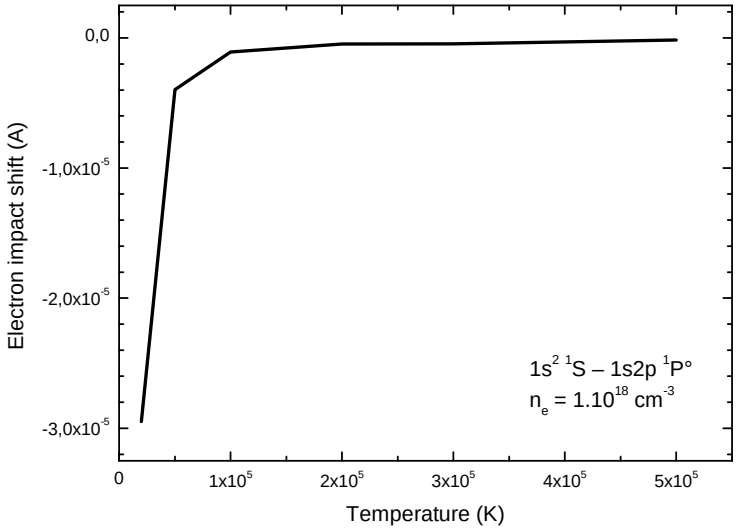

Figure 2: Temperature dependence of the electron impact shift for $1s^2\,^1S - 1s2p\,^1P^\circ$ transition at electron density 1.10^{18} cm^{-3}.

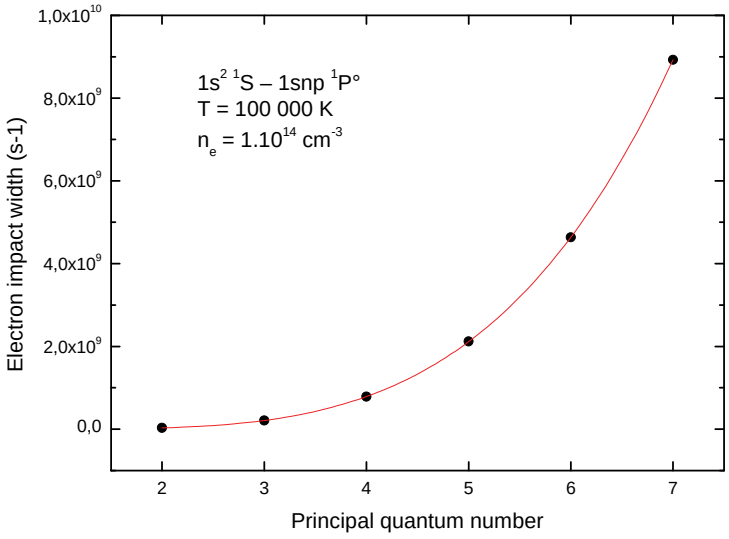

Figure 3: Principal quantum dependence of the electron impact widthfor transitions within $1s^2\,^1S - 1snp\,^1P^\circ$ series at electron density 1.10^{14} cm^{-3} and 100 000 K

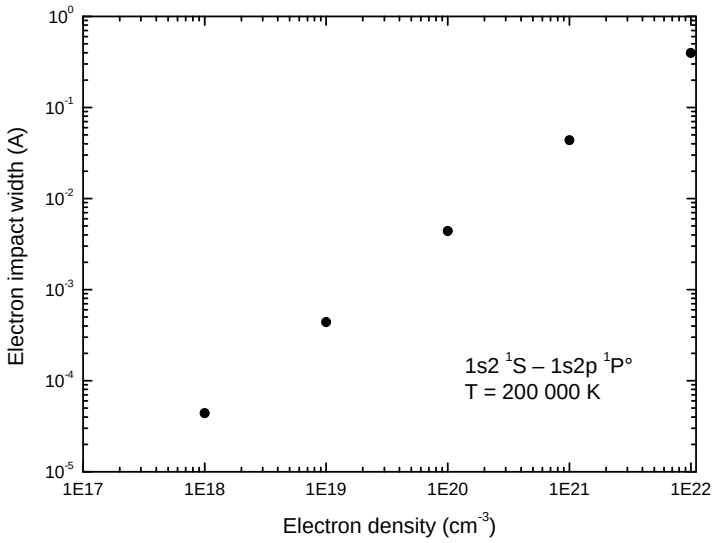

Figure 4: Electron density dependence of the electron impact widthof $1s^{21}S$ – 1s2p $^1P^\circ$ transition at 200 000 K.

$$W(n) = a_4 n^4 + a_3 n^3 + a_2 n^2 + a_1 n + a_0 \quad (6)$$

Where $W(n)$ is the full width at half-maximum in rad.s, a_0 = 3.36x10^7, a_1 = -2.00x10^7, a_2 = 2.96x10^6, a_3 = -5.77x10^6, a_4 = 4.53x10^6. The fitt curve is added in the figure.

The electron density dependence of the electron impact width for $1s^{21}S$ – 1s2p $^1P^\circ$ transition at 200 000 K have been obtained (see Fig.4). For the electron density values above 1.10^{21} cm^{-3} the small deviation from linear function has been observed.

The second studied spectral series in this paper is 1s2s ^1S – 1snp $^1P^\circ$. We have obtained the similar temperature dependence (see Fig.1) of the electron impact width for the lowest transition within the spectral series, 1s2s ^1S – 1s2p $^1P^\circ$. The variation of Stark width within the studied temperature range has been shown in Fig. 5.

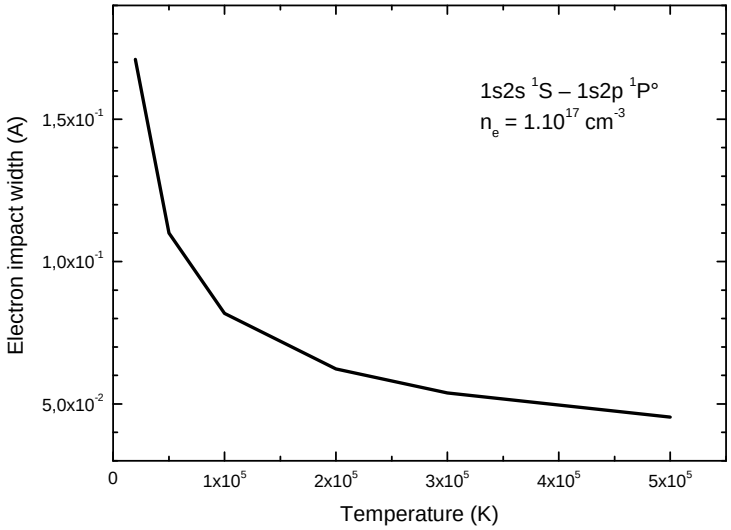

Figure 5: Temperature dependence of the electron impact width for 1s2s^{1}S – 1s2p ^{1}P$^\circ$ transition at electron density 1.10^{17} cm^{-3}.

The electron contribution in total width decreases from 99 % to 57 %, the proton one increases up to 12 %, and the ionized helium one increases to 30 % in the whole temperature interval. All shift values are negative. The impact electron Stark shift decreases from 61 % to 16 %, the role of collisions with protons increases from 13 % to 22 %, and the ionized helium shift varies from 26 % to 61 %.

4. CONCLUSION

The results for Stark broadening parameters of boron lines could be applicable for the adequate interpretation of the observed spectra to determine reliable chemical boron abundance which is of major importance for the model of Galactic chemical evolution, interstellar and intergalactic space, and stellar interiors and surfaces as white dwarfs.

Table 1: Stark broadening parameters for B IV lines for a perturper density 10^{14} cm^{-3} and temperatures from 20 000 to 500 000 K. The width (FWHM) W and shift d values from different perturbers are given in (Å). The ratio of the included parameter C versus the corresponding Stark width estimates the maximal pertuber density for which the line may be treated as isolated. W_e - electron-impact width, d_e - electron-impact shift, W_p - proton-impact width, d_p - proton-impact shift, W_{He+} - singly charged helium-impact width, d_{He+} - singly charged helium-impact shift.

Transition	T(K)	W_e(Å)	d_e(Å)	W_p(Å)	d_p(Å)	W_{He+}(Å)	d_{He+}(Å)
B IV 1s2-2	20000	0.180E-07	-0.130E-08	0.687E-10	-0.478E-10	0.524E-10	-0.956E-10
60.3 A	50000	0.860E-08	-0.118E-09	0.211E-09	-0.113E-09	0.204E-09	-0.236E-09
C= 0.81E+14	100000	0.601E-08	-0.697E-10	0.365E-09	-0.191E-09	0.470E-09	-0.429E-09
	200000	0.441E-08	-0.434E-10	0.524E-09	-0.269E-09	0.823E-09	-0.663E-09
	300000	0.372E-08	-0.447E-10	0.582E-09	-0.317E-09	0.106E-08	-0.805E-09
	500000	0.306E-08	-0.162E-10	0.658E-09	-0.361E-09	0.131E-08	-0.971E-09
B IV 1s2-3p	20000	0.584E-07	-0.434E-08	0.282E-08	-0.387E-08	0.496E-08	-0.956E-08
52.7 A	50000	0.403E-07	-0.349E-08	0.537E-08	-0.551E-08	0.118E-07	-0.148E-07
C= 0.39E+13	100000	0.314E-07	-0.316E-08	0.701E-08	-0.665E-08	0.174E-07	-0.179E-07
	200000	0.249E-07	-0.268E-08	0.867E-08	-0.783E-08	0.223E-07	-0.212E-07
	300000	0.218E-07	-0.234E-08	0.976E-08	-0.847E-08	0.250E-07	-0.235E-07
	500000	0.186E-07	-0.196E-08	0.110E-07	-0.947E-08	0.290E-07	-0.260E-07
B IV 1s2-4p	20000	0.182E-06	-0.182E-07	0.195E-07	-0.205E-07	0.432E-07	-0.550E-07
50.4 A	50000	0.133E-06	-0.166E-07	0.272E-07	-0.261E-07	0.691E-07	-0.704E-07
C= 0.14E+13	100000	0.106E-06	-0.144E-07	0.344E-07	-0.302E-07	0.879E-07	-0.832E-07
	200000	0.854E-07	-0.115E-07	0.408E-07	-0.354E-07	0.108E-06	-0.974E-07
	300000	0.753E-07	-0.101E-07	0.455E-07	-0.377E-07	0.120E-06	-0.106E-06
	500000	0.642E-07	-0.816E-08	0.518E-07	-0.403E-07	0.130E-06	-0.114E-06
B IV 1s2-5p	20000	0.453E-06	-0.582E-07	0.660E-07	-0.651E-07	0.167E-06	-0.175E-06
49.5 A	50000	0.340E-06	-0.504E-07	0.898E-07	-0.804E-07	0.232E-06	-0.220E-06
C= 0.69E+12	100000	0.275E-06	-0.414E-07	0.101E-06	-0.918E-07	0.277E-06	-0.254E-06
	200000	0.222E-06	-0.330E-07	0.124E-06	-0.101E-06	0.327E-06	-0.283E-06
	300000	0.196E-06	-0.279E-07	0.131E-06	-0.117E-06	0.362E-06	-0.305E-06
	500000	0.166E-06	-0.222E-07	0.146E-06	-0.117E-06	0.407E-06	-0.340E-06
B IV 1s2-6p	20000	0.915E-06	-0.143E-06	0.170E-06	-0.159E-06	0.434E-06	-0.430E-06
48.9 A	50000	0.714E-06	-0.118E-06	0.215E-06	-0.190E-06	0.583E-06	-0.529E-06
C= 0.40E+12	100000	0.589E-06	-0.948E-07	0.249E-06	-0.216E-06	0.668E-06	-0.592E-06
	200000	0.479E-06	-0.736E-07	0.299E-06	-0.245E-06	0.804E-06	-0.700E-06
	300000	0.422E-06	-0.617E-07	0.304E-06	-0.252E-06	0.870E-06	-0.739E-06
	500000	0.359E-06	-0.481E-07	0.342E-06	-0.278E-06	0.960E-06	-0.846E-06
B IV 1s2-7p	20000	0.169E-05	-0.306E-06	0.365E-06	-0.339E-06	0.976E-06	-0.940E-06
48.6 A	50000	0.135E-05	-0.238E-06	0.464E-06	-0.398E-06	0.123E-05	-0.113E-05
C= 0.24E+12	100000	0.112E-05	-0.190E-06	0.535E-06	-0.443E-06	0.147E-05	-0.129E-05
	200000	0.917E-06	-0.143E-06	0.578E-06	-0.521E-06	0.175E-05	-0.143E-05
	300000	0.810E-06	-0.119E-06	0.664E-06	-0.527E-06	0.169E-05	-0.156E-05
	500000	0.688E-06	-0.892E-07	0.776E-06	-0.549E-06	0.182E-05	-0.164E-05

Table 1. Continued

Transition	T(K)	W_e(Å)	d_e(Å)	W_p(Å)	d_p(Å)	W_{He^+}(Å)	d_{He^+}(Å)
B IV 2s-2p	20000	0.168E-03	-0.669E-05	0.702E-06	-0.215E-05	0.642E-06	-0.444E-05
4492.1 A	50000	0.110E-03	-0.577E-05	0.274E-05	-0.417E-05	0.401E-05	-0.959E-05
C= 0.45E+18	100000	0.818E-04	-0.702E-05	0.481E-05	-0.578E-05	0.942E-05	-0.142E-04
	200000	0.623E-04	-0.687E-05	0.712E-05	-0.712E-05	0.168E-04	-0.191E-04
	300000	0.538E-04	-0.673E-05	0.820E-05	-0.787E-05	0.203E-04	-0.213E-04
	500000	0.454E-04	-0.644E-05	0.964E-05	-0.891E-05	0.245E-04	-0.243E-04
B IV 2s-3p	20000	0.336E-05	-0.207E-06	0.150E-06	-0.206E-06	0.266E-06	-0.509E-06
380.9 A	50000	0.233E-05	-0.200E-06	0.286E-06	-0.293E-06	0.627E-06	-0.785E-06
C= 0.20E+15	100000	0.181E-05	-0.189E-06	0.371E-06	-0.353E-06	0.924E-06	-0.947E-06
	200000	0.143E-05	-0.164E-06	0.461E-06	-0.419E-06	0.118E-05	-0.113E-05
	300000	0.126E-05	-0.146E-06	0.518E-06	-0.451E-06	0.134E-05	-0.126E-05
	500000	0.107E-05	-0.125E-06	0.596E-06	-0.506E-06	0.155E-05	-0.139E-05
B IV 2s-4p	20000	0.612E-05	-0.583E-06	0.636E-06	-0.669E-06	0.141E-05	-0.180E-05
288.1 A	50000	0.445E-05	-0.552E-06	0.888E-06	-0.852E-06	0.226E-05	-0.230E-05
C= 0.47E+14	100000	0.355E-05	-0.484E-06	0.112E-05	-0.986E-06	0.287E-05	-0.272E-05
	200000	0.286E-05	-0.390E-06	0.133E-05	-0.116E-05	0.353E-05	-0.318E-05
	300000	0.252E-05	-0.344E-06	0.149E-05	-0.123E-05	0.393E-05	-0.346E-05
	500000	0.215E-05	-0.279E-06	0.170E-05	-0.132E-05	0.426E-05	-0.372E-05
B IV 2s-5p	20000	0.125E-04	-0.158E-05	0.181E-05	-0.178E-05	0.459E-05	-0.479E-05
258.9 A	50000	0.942E-05	-0.139E-05	0.246E-05	-0.220E-05	0.637E-05	-0.604E-05
C= 0.19E+14	100000	0.762E-05	-0.115E-05	0.278E-05	-0.252E-05	0.759E-05	-0.696E-05
	200000	0.615E-05	-0.915E-06	0.339E-05	-0.278E-05	0.895E-05	-0.776E-05
	300000	0.541E-05	-0.775E-06	0.358E-05	-0.322E-05	0.993E-05	-0.835E-05
	500000	0.461E-05	-0.620E-06	0.400E-05	-0.322E-05	0.111E-04	-0.931E-05
B IV 2s-6p	20000	0.231E-04	-0.359E-05	0.428E-05	-0.399E-05	0.109E-04	-0.108E-04
245.3 A	50000	0.180E-04	-0.297E-05	0.540E-05	-0.476E-05	0.147E-04	-0.133E-04
C= 0.99E+13	100000	0.149E-04	-0.239E-05	0.625E-05	-0.542E-05	0.168E-04	-0.149E-04
	200000	0.121E-04	-0.186E-05	0.750E-05	-0.616E-05	0.202E-04	-0.176E-04
	300000	0.107E-04	-0.156E-05	0.764E-05	-0.633E-05	0.219E-04	-0.186E-04
	500000	0.906E-05	-0.122E-05	0.861E-05	-0.698E-05	0.241E-04	-0.213E-04
B IV 2s-7p	20000	0.404E-04	-0.730E-05	0.874E-05	-0.810E-05	0.233E-04	-0.225E-04
237.8 A	50000	0.323E-04	-0.570E-05	0.111E-04	-0.950E-05	0.295E-04	-0.270E-04
C= 0.58E+13	100000	0.269E-04	-0.456E-05	0.128E-04	-0.106E-04	0.351E-04	-0.308E-04
	200000	0.220E-04	-0.342E-05	0.138E-04	-0.125E-04	0.418E-04	-0.341E-04
	300000	0.194E-04	-0.285E-05	0.159E-04	-0.126E-04	0.404E-04	-0.373E-04
	500000	0.165E-04	-0.214E-05	0.185E-04	-0.131E-04	0.435E-04	-0.393E-04
B IV 3s-3p	20000	0.853E-02	-0.604E-03	0.321E-03	-0.455E-03	0.635E-03	-0.113E-02
15513.5 A	50000	0.591E-02	-0.658E-03	0.600E-03	-0.627E-03	0.142E-02	-0.169E-02
C= 0.33E+18	100000	0.462E-02	-0.614E-03	0.776E-03	-0.746E-03	0.197E-02	-0.202E-02
	200000	0.367E-02	-0.553E-03	0.970E-03	-0.877E-03	0.248E-02	-0.241E-02
	300000	0.324E-02	-0.515E-03	0.111E-02	-0.939E-03	0.284E-02	-0.263E-02
	500000	0.277E-02	-0.444E-03	0.120E-02	-0.103E-02	0.327E-02	-0.295E-02

Table 1. Continued

Transition	T(K)	W_e(Å)	d_e(Å)	W_p(Å)	d_p(Å)	W_{He+}(Å)	d_{He+}(Å)
B IV 3s-4p	20000	0.104E-03	-0.983E-05	0.950E-05	-0.100E-04	0.213E-04	-0.270E-04
1098.9 A	50000	0.749E-04	-0.967E-05	0.133E-04	-0.128E-04	0.338E-04	-0.345E-04
C= 0.68E+15	100000	0.597E-04	-0.854E-05	0.165E-04	-0.147E-04	0.427E-04	-0.409E-04
	200000	0.481E-04	-0.709E-05	0.203E-04	-0.172E-04	0.537E-04	-0.470E-04
	300000	0.424E-04	-0.637E-05	0.223E-04	-0.180E-04	0.597E-04	-0.511E-04
	500000	0.363E-04	-0.525E-05	0.250E-04	-0.194E-04	0.644E-04	-0.560E-04
B IV 3s-5p	20000	0.117E-03	-0.146E-04	0.160E-04	-0.158E-04	0.406E-04	-0.423E-04
767.8 A	50000	0.877E-04	-0.130E-04	0.218E-04	-0.195E-04	0.560E-04	-0.534E-04
C= 0.17E+15	100000	0.709E-04	-0.108E-04	0.247E-04	-0.224E-04	0.671E-04	-0.617E-04
	200000	0.572E-04	-0.874E-05	0.300E-04	-0.247E-04	0.786E-04	-0.690E-04
	300000	0.504E-04	-0.749E-05	0.321E-04	-0.283E-04	0.879E-04	-0.732E-04
	500000	0.429E-04	-0.603E-05	0.354E-04	-0.285E-04	0.991E-04	-0.825E-04
B IV 3s-6p	20000	0.172E-03	-0.264E-04	0.310E-04	-0.289E-04	0.789E-04	-0.784E-04
659.7 A	50000	0.134E-03	-0.221E-04	0.391E-04	-0.345E-04	0.106E-03	-0.962E-04
C= 0.72E+14	100000	0.110E-03	-0.178E-04	0.453E-04	-0.393E-04	0.121E-03	-0.108E-03
	200000	0.897E-04	-0.140E-04	0.542E-04	-0.447E-04	0.146E-03	-0.127E-03
	300000	0.791E-04	-0.118E-04	0.550E-04	-0.458E-04	0.158E-03	-0.135E-03
	500000	0.673E-04	-0.923E-05	0.620E-04	-0.503E-04	0.176E-03	-0.154E-03
B IV 3s-7p	20000	0.268E-03	-0.481E-04	0.571E-04	-0.530E-04	0.153E-03	-0.147E-03
608.0 A	50000	0.214E-03	-0.378E-04	0.725E-04	-0.622E-04	0.193E-03	-0.177E-03
C= 0.38E+14	100000	0.178E-03	-0.303E-04	0.836E-04	-0.693E-04	0.230E-03	-0.201E-03
	200000	0.146E-03	-0.228E-04	0.904E-04	-0.814E-04	0.274E-03	-0.223E-03
	300000	0.129E-03	-0.191E-04	0.104E-03	-0.824E-04	0.265E-03	-0.244E-03
	500000	0.109E-03	-0.144E-04	0.121E-03	-0.858E-04	0.284E-03	-0.257E-03
B IV 4s-4p	20000	0.165	-0.186E-01	0.130E-01	-0.138E-01	0.308E-01	-0.372E-01
37147.1 A	50000	0.121	-0.178E-01	0.180E-01	-0.175E-01	0.467E-01	-0.472E-01
C= 0.77E+18	100000	0.969E-01	-0.160E-01	0.228E-01	-0.201E-01	0.594E-01	-0.560E-01
	200000	0.784E-01	-0.138E-01	0.263E-01	-0.228E-01	0.710E-01	-0.650E-01
	300000	0.693E-01	-0.122E-01	0.289E-01	-0.249E-01	0.768E-01	-0.682E-01
	500000	0.591E-01	-0.101E-01	0.299E-01	-0.268E-01	0.892E-01	-0.751E-01
B IV 4s-5p	20000	0.132E-02	-0.172E-03	0.161E-03	-0.158E-03	0.405E-03	-0.423E-03
2385.2 A	50000	0.990E-03	-0.154E-03	0.216E-03	-0.193E-03	0.556E-03	-0.532E-03
C= 0.16E+16	100000	0.801E-03	-0.130E-03	0.260E-03	-0.226E-03	0.691E-03	-0.621E-03
	200000	0.649E-03	-0.108E-03	0.284E-03	-0.243E-03	0.796E-03	-0.693E-03
	300000	0.572E-03	-0.925E-04	0.331E-03	-0.283E-03	0.824E-03	-0.730E-03
	500000	0.487E-03	-0.750E-04	0.339E-03	-0.286E-03	0.102E-02	-0.831E-03
B IV 4s-6p	20000	0.107E-02	-0.166E-03	0.178E-03	-0.167E-03	0.458E-03	-0.455E-03
1580.5 A	50000	0.830E-03	-0.139E-03	0.227E-03	-0.200E-03	0.614E-03	-0.557E-03
C= 0.41E+15	100000	0.684E-03	-0.114E-03	0.261E-03	-0.229E-03	0.702E-03	-0.633E-03
	200000	0.557E-03	-0.904E-04	0.317E-03	-0.263E-03	0.851E-03	-0.734E-03
	300000	0.492E-03	-0.765E-04	0.312E-03	-0.269E-03	0.942E-03	-0.783E-03
	500000	0.418E-03	-0.603E-04	0.357E-03	-0.292E-03	0.102E-02	-0.888E-03

Table 1. Continued

Transition	T(K)	W_e(Å)	d_e(Å)	W_p(Å)	d_p(Å)	W_{He^+}(Å)	d_{He^+}(Å)
B IV 4s-7p	20000	0.130E-02	-0.235E-03	0.266E-03	-0.248E-03	0.714E-03	-0.688E-03
1313.1 A	50000	0.104E-02	-0.185E-03	0.339E-03	-0.290E-03	0.906E-03	-0.825E-03
C= 0.18E+15	100000	0.866E-03	-0.149E-03	0.390E-03	-0.324E-03	0.108E-02	-0.941E-03
	200000	0.708E-03	-0.113E-03	0.423E-03	-0.382E-03	0.128E-02	-0.104E-02
	300000	0.625E-03	-0.951E-04	0.480E-03	-0.388E-03	0.123E-02	-0.114E-02
	500000	0.532E-03	-0.721E-04	0.565E-03	-0.405E-03	0.132E-02	-0.121E-02
B IV 5s-5p	20000	1.58	-0.251	0.175	-0.172	0.445	-0.462
72971.4 A	50000	1.22	-0.216	0.233	-0.211	0.605	-0.580
C= 0.15E+19	100000	0.998	-0.187	0.273	-0.236	0.711	-0.660
	200000	0.815	-0.151	0.323	-0.279	0.862	-0.772
	300000	0.720	-0.129	0.356	-0.293	0.953	-0.832
	500000	0.613	-0.107	0.379	-0.334	1.05	-0.875
B IV 5s-6p	20000	0.951E-02	-0.163E-02	0.143E-02	-0.137E-02	0.371E-02	-0.368E-02
4401.9 A	50000	0.748E-02	-0.135E-02	0.181E-02	-0.164E-02	0.489E-02	-0.451E-02
C= 0.32E+16	100000	0.620E-02	-0.112E-02	0.211E-02	-0.186E-02	0.562E-02	-0.513E-02
	200000	0.507E-02	-0.884E-03	0.254E-02	-0.208E-02	0.696E-02	-0.592E-02
	300000	0.448E-02	-0.750E-03	0.251E-02	-0.226E-02	0.754E-02	-0.627E-02
	500000	0.382E-02	-0.600E-03	0.277E-02	-0.242E-02	0.830E-02	-0.700E-02
B IV 5s-7p	20000	0.645E-02	-0.126E-02	0.124E-02	-0.116E-02	0.334E-02	-0.319E-02
2809.1 A	50000	0.518E-02	-0.956E-03	0.155E-02	-0.136E-02	0.425E-02	-0.384E-02
C= 0.80E+15	100000	0.433E-02	-0.779E-03	0.181E-02	-0.151E-02	0.503E-02	-0.432E-02
	200000	0.355E-02	-0.594E-03	0.193E-02	-0.178E-02	0.589E-02	-0.475E-02
	300000	0.314E-02	-0.498E-03	0.220E-02	-0.182E-02	0.567E-02	-0.536E-02
	500000	0.267E-02	-0.384E-03	0.259E-02	-0.186E-02	0.589E-02	-0.562E-02
B IV 6s-6p	20000	9.71	-2.14	1.35	-1.28	3.51	-3.47
126390. A	50000	7.79	-1.63	1.72	-1.54	4.67	-4.21
C= 0.26E+19	100000	6.54	-1.34	2.06	-1.76	5.68	-4.91
	200000	5.39	-1.02	2.31	-1.95	6.50	-5.36
	300000	4.77	-0.869	2.55	-2.22	6.89	-5.79
	500000	4.06	-0.702	2.59	-2.49	7.71	-6.54
B IV 6s-7p	20000	0.499E-01	-0.111E-01	0.911E-02	-0.823E-02	0.236E-01	-0.225E-01
7314.1 A	50000	0.405E-01	-0.830E-02	0.112E-01	-0.965E-02	0.298E-01	-0.269E-01
C= 0.55E+16	100000	0.341E-01	-0.669E-02	0.123E-01	-0.106E-01	0.347E-01	-0.307E-01
	200000	0.281E-01	-0.500E-02	0.143E-01	-0.132E-01	0.402E-01	-0.341E-01
	300000	0.248E-01	-0.422E-02	0.157E-01	-0.128E-01	0.423E-01	-0.390E-01
	500000	0.211E-01	-0.330E-02	0.181E-01	-0.135E-01	0.405E-01	-0.428E-01
B IV 7s-7p	20000	45.7	-11.6	7.56	-6.94	20.0	-19.0
201126. A	50000	37.6	-8.59	9.29	-8.41	25.0	-22.8
C= 0.41E+19	100000	32.0	-6.80	9.92	-9.69	30.1	-25.6
	200000	26.5	-5.09	12.7	-10.9	34.0	-29.0
	300000	23.5	-4.30	12.6	-11.1	37.5	-32.8
	500000	20.0	-3.35	13.4	-11.7	41.3	-36.9

Table 1. Continued

Transition	T(K)	W_e(Å)	d_e(Å)	W_p(Å)	d_p(Å)	W_{He+}(Å)	d_{He+}(Å)
B IV 2p-3s	20000	0.366E-05	0.219E-06	0.703E-07	0.139E-06	0.343E-06	0.533E-06
427.7 A	50000	0.233E-05	0.272E-06	0.167E-06	0.211E-06	0.343E-06	0.533E-06
C= 0.12E+16	100000	0.179E-05	0.256E-06	0.239E-06	0.254E-06	0.602E-06	0.676E-06
	200000	0.141E-05	0.239E-06	0.309E-06	0.303E-06	0.795E-06	0.813E-06
	300000	0.124E-05	0.233E-06	0.345E-06	0.327E-06	0.923E-06	0.905E-06
	500000	0.105E-05	0.201E-06	0.398E-06	0.360E-06	0.108E-05	0.101E-05
B IV 2p-4s	20000	0.521E-05	0.680E-06	0.275E-06	0.370E-06	0.565E-06	0.918E-06
310.5 A	50000	0.374E-05	0.611E-06	0.457E-06	0.475E-06	0.114E-05	0.128E-05
C= 0.26E+15	100000	0.297E-05	0.573E-06	0.583E-06	0.564E-06	0.152E-05	0.153E-05
	200000	0.239E-05	0.523E-06	0.700E-06	0.652E-06	0.188E-05	0.180E-05
	300000	0.211E-05	0.465E-06	0.761E-06	0.712E-06	0.210E-05	0.196E-05
	500000	0.180E-05	0.390E-06	0.870E-06	0.765E-06	0.237E-05	0.211E-05
B IV 2p-5s	20000	0.912E-05	0.176E-05	0.835E-06	0.905E-06	0.206E-05	0.243E-05
275.7 A	50000	0.717E-05	0.152E-05	0.116E-05	0.114E-05	0.301E-05	0.308E-05
C= 0.10E+15	100000	0.594E-05	0.136E-05	0.143E-05	0.130E-05	0.390E-05	0.364E-05
	200000	0.488E-05	0.113E-05	0.174E-05	0.151E-05	0.454E-05	0.410E-05
	300000	0.432E-05	0.979E-06	0.188E-05	0.162E-05	0.519E-05	0.451E-05
	500000	0.367E-05	0.827E-06	0.214E-05	0.178E-05	0.533E-05	0.495E-05
B IV 2p-6s	20000	0.164E-04	0.409E-05	0.194E-05	0.199E-05	0.502E-05	0.534E-05
260.0 A	50000	0.134E-04	0.335E-05	0.257E-05	0.243E-05	0.687E-05	0.678E-05
C= 0.53E+14	100000	0.114E-04	0.287E-05	0.320E-05	0.276E-05	0.844E-05	0.764E-05
	200000	0.948E-05	0.224E-05	0.346E-05	0.319E-05	0.957E-05	0.867E-05
	300000	0.839E-05	0.194E-05	0.409E-05	0.342E-05	0.103E-04	0.949E-05
	500000	0.713E-05	0.161E-05	0.397E-05	0.375E-05	0.122E-04	0.103E-04
B IV 2p-7s	20000	0.281E-04	0.823E-05	0.400E-05	0.399E-05	0.105E-04	0.108E-04
251.4 A	50000	0.237E-04	0.664E-05	0.540E-05	0.473E-05	0.143E-04	0.134E-04
C= 0.31E+14	100000	0.205E-04	0.531E-05	0.615E-05	0.535E-05	0.168E-04	0.148E-04
	200000	0.171E-04	0.408E-05	0.725E-05	0.612E-05	0.188E-04	0.174E-04
	300000	0.152E-04	0.356E-05	0.762E-05	0.627E-05	0.216E-04	0.183E-04
	500000	0.129E-04	0.285E-05	0.814E-05	0.693E-05	0.209E-04	0.208E-04
B IV 3p-4s	20000	0.117E-03	0.130E-04	0.645E-05	0.776E-05	0.134E-04	0.198E-04
1221.5 A	50000	0.846E-04	0.126E-04	0.961E-05	0.982E-05	0.248E-04	0.265E-04
C= 0.21E+16	100000	0.675E-04	0.117E-04	0.122E-04	0.116E-04	0.320E-04	0.317E-04
	200000	0.545E-04	0.104E-04	0.150E-04	0.134E-04	0.388E-04	0.366E-04
	300000	0.482E-04	0.916E-05	0.156E-04	0.144E-04	0.448E-04	0.402E-04
	500000	0.411E-04	0.769E-05	0.186E-04	0.155E-04	0.495E-04	0.428E-04
B IV 3p-5s	20000	0.965E-04	0.176E-04	0.793E-05	0.850E-05	0.197E-04	0.228E-04
816.9 A	50000	0.747E-04	0.150E-04	0.109E-04	0.108E-04	0.285E-04	0.291E-04
C= 0.91E+15	100000	0.616E-04	0.133E-04	0.133E-04	0.123E-04	0.355E-04	0.338E-04
	200000	0.506E-04	0.109E-04	0.161E-04	0.137E-04	0.424E-04	0.390E-04
	300000	0.448E-04	0.947E-05	0.175E-04	0.149E-04	0.474E-04	0.410E-04
	500000	0.381E-04	0.800E-05	0.198E-04	0.165E-04	0.508E-04	0.471E-04

Table 1. Continued

Transition	T(K)	W_e(Å)	d_e(Å)	W_p(Å)	d_p(Å)	W_{He^+}(Å)	d_{He^+}(Å)
B IV 3p-6s	20000	0.127E-03	0.312E-04	0.141E-04	0.144E-04	0.363E-04	0.386E-04
692.8 A	50000	0.103E-03	0.248E-04	0.186E-04	0.177E-04	0.504E-04	0.490E-04
C= 0.38E+15	100000	0.877E-04	0.215E-04	0.228E-04	0.200E-04	0.607E-04	0.556E-04
	200000	0.728E-04	0.168E-04	0.251E-04	0.231E-04	0.690E-04	0.631E-04
	300000	0.645E-04	0.143E-04	0.292E-04	0.245E-04	0.744E-04	0.692E-04
	500000	0.548E-04	0.120E-04	0.287E-04	0.270E-04	0.896E-04	0.734E-04
B IV 3p-7s	20000	0.188E-03	0.546E-04	0.258E-04	0.257E-04	0.677E-04	0.692E-04
634.8 A	50000	0.158E-03	0.437E-04	0.345E-04	0.302E-04	0.922E-04	0.853E-04
C= 0.20E+15	100000	0.136E-03	0.348E-04	0.393E-04	0.342E-04	0.107E-03	0.949E-04
	200000	0.114E-03	0.268E-04	0.465E-04	0.392E-04	0.120E-03	0.112E-03
	300000	0.101E-03	0.233E-04	0.482E-04	0.400E-04	0.138E-03	0.117E-03
	500000	0.858E-04	0.186E-04	0.519E-04	0.446E-04	0.137E-03	0.135E-03
B IV 4p-5s	20000	0.129E-02	0.209E-03	0.110E-03	0.114E-03	0.275E-03	0.305E-03
2641.1 A	50000	0.992E-03	0.183E-03	0.151E-03	0.144E-03	0.390E-03	0.389E-03
C= 0.39E+16	100000	0.816E-03	0.165E-03	0.177E-03	0.167E-03	0.495E-03	0.450E-03
	200000	0.669E-03	0.136E-03	0.217E-03	0.188E-03	0.581E-03	0.529E-03
	300000	0.592E-03	0.118E-03	0.239E-03	0.204E-03	0.644E-03	0.564E-03
	500000	0.505E-03	0.986E-04	0.262E-03	0.215E-03	0.729E-03	0.600E-03
B IV 4p-6s	20000	0.852E-03	0.201E-03	0.910E-04	0.911E-04	0.233E-03	0.246E-03
1672.5 A	50000	0.685E-03	0.159E-03	0.122E-03	0.112E-03	0.319E-03	0.309E-03
C= 0.16E+16	100000	0.579E-03	0.137E-03	0.142E-03	0.126E-03	0.371E-03	0.354E-03
	200000	0.480E-03	0.106E-03	0.167E-03	0.147E-03	0.461E-03	0.409E-03
	300000	0.426E-03	0.913E-04	0.185E-03	0.155E-03	0.494E-03	0.441E-03
	500000	0.362E-03	0.759E-04	0.199E-03	0.178E-03	0.536E-03	0.464E-03
B IV 4p-7s	20000	0.947E-03	0.270E-03	0.127E-03	0.122E-03	0.330E-03	0.331E-03
1370.5 A	50000	0.789E-03	0.214E-03	0.161E-03	0.146E-03	0.440E-03	0.407E-03
C= 0.93E+15	100000	0.680E-03	0.170E-03	0.186E-03	0.166E-03	0.513E-03	0.456E-03
	200000	0.568E-03	0.131E-03	0.220E-03	0.189E-03	0.601E-03	0.538E-03
	300000	0.504E-03	0.113E-03	0.225E-03	0.195E-03	0.659E-03	0.566E-03
	500000	0.428E-03	0.908E-04	0.246E-03	0.212E-03	0.685E-03	0.650E-03

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References

Cunha, K., Smith, V. V.: 1999, *ApJ,* **512,** 1006.
Duncan, D. K., Lambert, D. L., Lemke, M.: 1992, *ApJ,* **401,** 584.
Duncan,D. K., Primas, F., Rebull, L. M., Bosegaard, A. M., Deliyannis, C. P., Hobbs, L. M., King, J. R.,
Ritchey, A. M., Federman, S. R., Sheffer, Y., Lambert, D. L.: 2011, *ApJ,* **728,** 70.
Ryan, S. G.: 1997, *ApJ,* **488,** 338.
Sahal-Bréchot, S.: 1969a, *Astron. Astrophys.,* **1,** 91.
Sahal-Bréchot, S.: 1969b, *Astron. Astrophys.,* **2,** 322.
Sahal-Bréchot, S.: 2010, *J. of Phys.: Conf. Ser.,* **257,** 012028.
Shima, M.: 1963, *Geochim. Cosmochim. Acta,* **27,** 991.
Venn, K. A., Brooks, A. M., Lambert, D. L., Lemke, M., Langer, N., Lennon, D. J., Keenan, F. P.: 2002, *ApJ,* **565,** 571.

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IMAGE PROCESSING SUGGESTIONS FOR ASTRONOMICAL MULTIEXPOSURE WIDE FIELD PLATES [1]

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Abstract: In the article is proposed how to assess the quality of archival plates with chains. Certainly, CCD astronomy replacing classical photo astronomy recently makes senseless use of multiexposure wide-field plates (MEWFP) approaches. On the other hand, the world heritage of archive MEWFP, with 4-6 expositions estimated at over 10,000, encourages the development of specific methods for computer processing of MEWFP. Thus, our method is useful to evaluate the structural quality of archival MEWFP (whether it is exacerbated by overlapping of star copies on the plates).

1. INTRODUCTION

The method for locating non-stationary (variable and/or quickly moving) stellar objects by capturing images of star chains is known in astronomy as multiexposure method. The method consists of repeated photo exposures (on the same photo plate) of the observed celestial quadrant. Photo exposures, usually 4 to 6 in number, are equal over time (e.g. ~ 5 ÷ 10 min each) and relative (mechanical) movements of the photo plate toward the instrument (telescope) are uniform from exposure to exposure in selected fixed direction. The exception is the first shift, which is ~ 2 times larger than the other to indicate the beginning of the chains (Aniol et a., 1990, Winterberg et al., 1995).

The idea for this report comes from the difficulty of comprehensive computer processing of plates with star chains (Dimov et al., 2012). The configuration of the chains in a plate is usually static, i.e. direction of the chains and the distances

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between their components (copies of the star over time) were selected from astronomers mainly on the principle of operational ease of use with the given telescope. Thus, in the inherited, during the years, archive plates we meet too many instances of (partially or completely) overlapping star chains, which hinders comprehensive identification of all chains in the plate for the accurate localization of flare star phenomena looked for.

In comparison to the original MEWFP method, the proposed method seems a little late in time, in view of the incoming CCD technology to replace the classical photography in astronomy. There are no technological limits to playing MEWFP method in CCD technology[2]. But this is proved unnecessary because the sequence of CCD images can directly (and more efficiently) be processed by the so-called image differencing approaches[3] (Sonka, Hlavac and Boyle, 1998).

On the other hand, the world heritage of archival astronomical plates with 4-6 expositions could be estimated at least over 10 000, according to the data in (Tsvetkova, 2012), which stimulates the development of specific methods for computer processing (Aniol et al., 1990, Winterberg et al., 1995, Dimov et al., 2012). Method proposed here can be used to assess the quality of existing archival images with MEWFP chains, in particular – to their structural quality determined by proximity to the optimum structure of the chains (as direction and distance between components). Evaluation is obtained a posteriori, i.e. concerns quality of an (already) conducted MEWFP experiment with star chains. It may serve to substantial improvements in computer processing of MEWFP images, e.g. Dimov et al. (2012), for an (external, independent) evaluation of the error in variable chains demand, i.e. variations caused by variable stars rather than random overlap in MEWFP experiment.

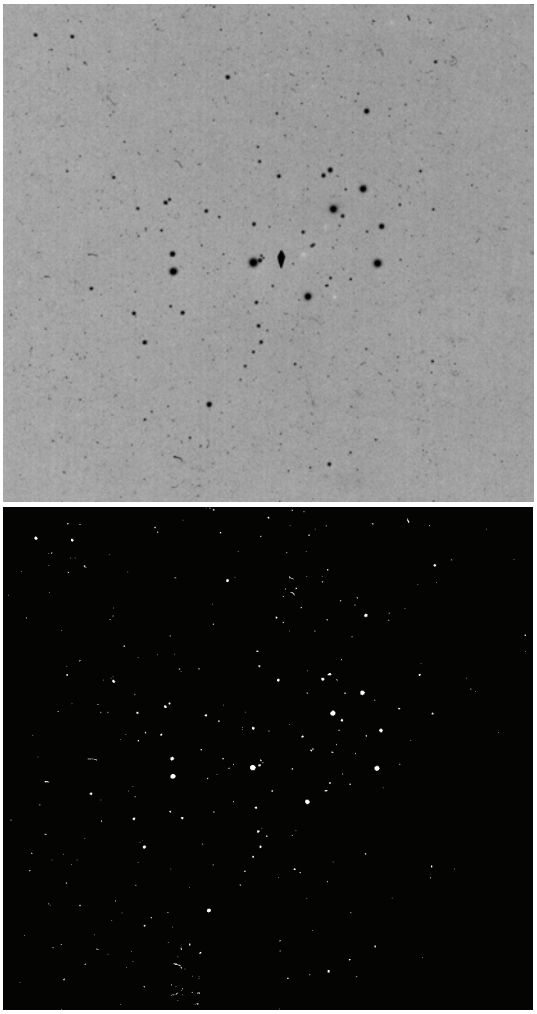
2. PROPOSED METHOD DESCRIPTION

2.1. Preliminary observations

We assume that the input image is pre-processed to an adequately binarized image, i.e. stars are presented by "white" spots against the "black" sky. This type of astro images are considered as "positives", unlike the original negative images obtained by scanning astronomical plates.

For the purposes of this experiment we will use a preview to astronomical image of the Pleiades region, see Fig. 1a, and its corresponding positive – in Fig. 1b.

[2] http://en.wikipedia.org/wiki/Charge-coupled_device
[3] http://en.wikipedia.org/wiki/Blink_comparator



(a)

(b)

Figure 1: Image cluster "Pleiades": a) an original preview-negative 1682x1580 pix; a (diamond like) artifact is observed in the image center caused by photo plate storage in the time; b) the working positive (after binarization of the original), where the artifact is cleaned interactively.

We will mainly consider the case of linear chains (Aniol et al., 1990, Winterberg et al., 1995, Dimov et al., 2012), see also Fig. 2. Without loss of generality (and for definiteness of illustrations), we will consider the most common case:

$$d_{1,2} = 2d, \quad d_{2,3} = d_{3,4} = d_{4,5} = d_{5,6} = d\,, \; d > 0\,, \qquad (1)$$

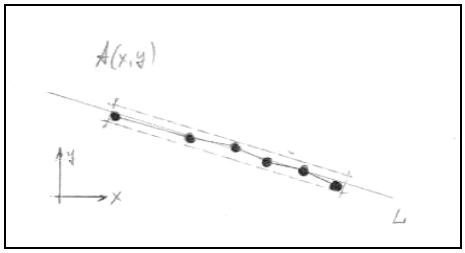
where $d_{i,i+1}, i = 1,...,(n-1)$ are the distances between the consecutive chain components and the length n (in number of components) is $n = 6$. Cases of "non-

linear" chains described in Dimov et al. (2012), see Fig. 2b, will be considered in discussions later on.

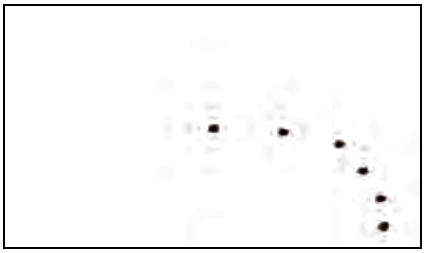
We substantially use analogies with the concepts, *cumulative image* and *reduced cumulative image*, introduced in [3] for the identification of chains in astro images. Here we interpret these concepts for generating images with chains from a single image of a given sky quadrant.

2.2. Idea of the method

***Step* S1:** Let us choose an arbitrary star in the input working image. Since there black areas indicate the absence of significant stars, we can give the following trivial interpretation – black areas mark the possible vectors of displacement of the plate (to receive any chain with $n = 2$, but only for the selected star), so the shift up of this star (in the new exposure of the plate) does not cover any other star.



(a)



(b)

Figure 2: Chain schemes with $n = 6$ components (i.e., n exposures of the plate): a) a linear scheme of chain with illustration of the chain average direction L; b) a non-linear scheme, for details, see [3].

For definiteness, and without loss of generality, we consider that the Cartesian coordinates' origin of the image is moved to the center of the chosen star, i.e. that the star coordinates are (0,0).

***Step* S2:** Let us choose another star with coordinates (x_2, y_2) of its center, get a copy of the input image and impose it upon the previous one, but translated so that the selected second star to coincide with the first one (from step S1). Thus, each pixel (x, y) of the input image is shift τ_2 translated to position $(\tilde{x}, \tilde{y})$, and the second star is also provided with coordinates (0,0) after translation:

$$(\tilde{x}, \tilde{y}) = (x, y) - \tau_2,$$
$$\tau_2 = (x_2, y_2) - (x_{\text{size}} / 2, y_{\text{size}} / 2), \quad 0 \le x < x_{\text{size}}, \quad 0 \le y < y_{\text{size}} \tag{2}$$

where x_{size} and y_{size} define the size of the input working image in pixels.

Now, if we add disjunctively the both images, primary and shifted ones then the resultant black areas will mark the possible positions of the second component

of any chain of length $n = 2$ (but only for the first star and for the second star), do not cover any other star.

***Step* S3:** Repeat the previous step S2 for all other stars in the image. Then, the black areas in resultant (disjunctive) image will mark the option for vector displacements of the plate (i.e., the formation of all chains with length $n = 2$ components), so that no chain can fall on another chain, and more precisely, any particular chain component does not cover any components of other chains.

For formal completeness, we determine starting with a blank (i.e. entirely black) image whose coordinate system is at its center, i.e. that at the current step S3 we brought all the stars found in the input image in the blank image center, like the first star (at S1) and the second one (at S2). The resultant image will be called *disjunctive accumulated image* (DAI).

DAI has the same properties as the accumulated image that had been already described, although for other purposes in Dimov et al. (2012). By analogy with Dimov et al. (2012), we also restrict a substantial square of size a, $a = \min\{x_{\text{size}}, y_{\text{size}}\}/2$, in the central part of DAI, and we call it "*reduced* DAI" (RDI). Obviously, the area outside RDI contains incomplete information about chains overlap, because the area of the original input image, which is also used in the assessment, is uncertain therein and is formally declared by us to empty (all black). An example of DAI is illustrated in Fig. 3, and the respective and only significant RDI – in Fig. 4b. Note that zooming of images in detached figures varies for better illustration, where matching size can be traced by means of squared hints in the figures, see Fig. 3 and Fig. 4.

2.3. Formal description of the method

***Step* S4:** Let us scale the received RDI by a factor 3/2 and limit the result to the initial RDI size towards the coordinate origin. For the resultant, scaled and centered image to mark it as SDI(3), we can write formally:

$$\text{SDI(3)} \Leftarrow \text{RDI}: \left\{ I(\tilde{x}, \tilde{y}) = I(x, y),\ (\tilde{x}, \tilde{y}) = \frac{3}{2}(x, y),\ \ (\tilde{x}, \tilde{y}) \in \text{SDI(3)},\ (x, y) \in \text{RDI} \right\}, \quad (3)$$

where $I(\tilde{x}, \tilde{y})$ and $I(x, y)$ are the intensity values of the pixels in the SDI(3) and RDI. Let us summarize (disjunctively, pixel by pixel) the two images and indicate the result as RDI(3):

$$\text{RDI(3)} = \text{SCDI(3)} \cup \text{RDI} . \quad (4)$$

It can be shown that the black areas in the resultant image RDI(3) represent a mask for possible displacement of the plate, i.e. for optimal selection of a structure of no overlapping chains with length $n = 3$ components. Indeed, if we choose a point (pixel) in the black area of RDI(3), then it is guaranteed with a corresponding (affine, projective) point in the black area of RDI.

Repeat the previous step iteratively, i.e. scaling (3) and disjunction (4) until the desired length n of chains, for example, until $n = 6$.

If we formally write for the first step S1:

$$\mathrm{RDI}(2) = \mathrm{RDI}\,, \tag{5}$$

then we can summarize the description (3) and (4) by the following recursive formulae:

$$\mathrm{RDI}(i) = \mathrm{SDI}(i) \cup \mathrm{RDI}(i-1), \;\; i = 3, \ldots, n; \tag{5a}$$

where

$$\mathrm{SDI}(i) \Leftarrow \mathrm{RDI}(i-1) : \left\{ I(\tilde{x}, \tilde{y}) = I(x, y)\,, (\tilde{x}, \tilde{y}) = \frac{i}{i-1}(x, y), \;\; (\tilde{x}, \tilde{y}) \in \mathrm{SDI}(i), (x, y) \in \mathrm{RDI}(i-1) \right\}$$

. (5b)

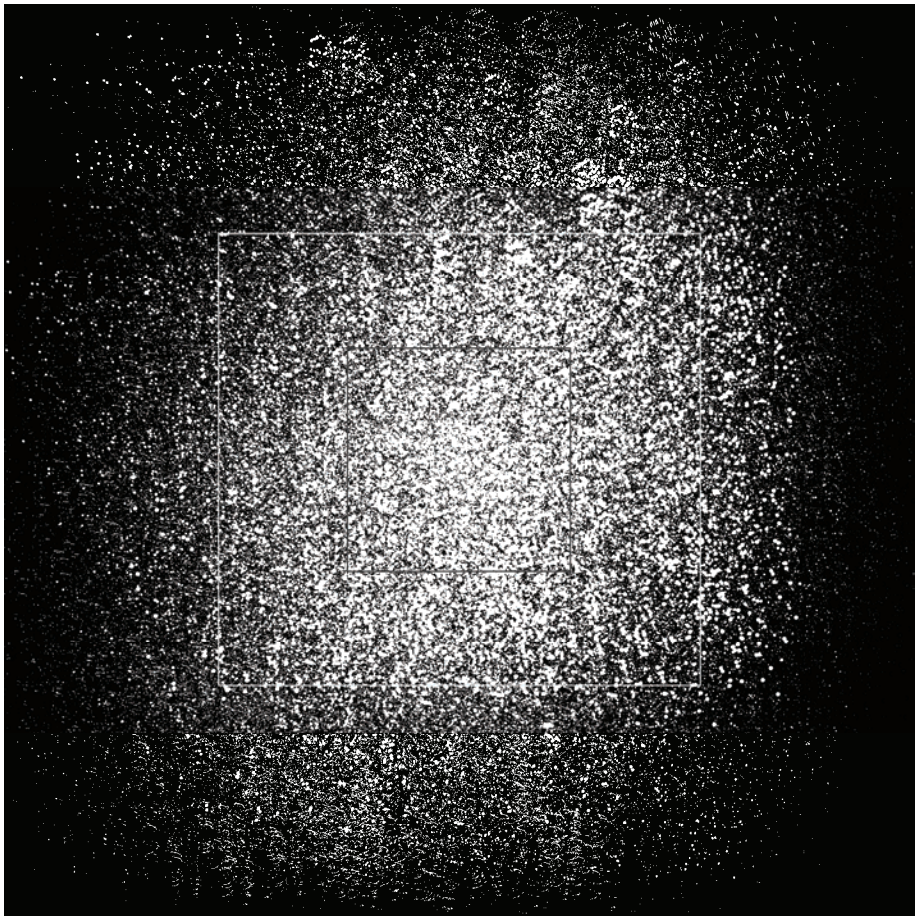


Figure 3: Full accumulated disjunctive image DAI, derived from the binarized input image (Fig. 1b). The position and size of both, the input image and the reduced disjunctive image RDI, are pointed by extra square hints.

The final image RDI(n) of the sequence RDI(i), $i = 2, \ldots, n$, shows the optimal choice of the last, n-th component of the chains of the desired length of n components. Indeed, if we choose a point in the black area of RDI(6), it follows that it is guaranteed with a series of corresponding (affine) points from black areas of each one of the images RDI(5), RDI(4), RDI(3) and RDI(2), and that these points can be used to structure the chains of type (1), which first component is the beginning (0,0), i.e. the common center of these RDI images.

Now, we can specify the intuitively used concept of "*optimal choice of linear chains structure*" by the following:

Statement: Each chain structure choice by the above method is optimal in the sense that the centers of all the components of the chains generated for the stars found in the input image will fall only in the free (black) areas and not on other components and/or stars. Something else, if the mask RDI(i) be empty for some i, $2 \le i \le n$, then the task of optimal chains with the number of components $\ge i$, has no solution.

Proof: ♦ Since working images here are black and white only, we can consider white areas (i.e., star spots) as sets of logical (Boolean) units, and black areas as sets logical (Boolean) zeros. Thus, for a set A of image pixels, we will denote by $\overline{A}$, $\overline{A} \subset A$, the subset of black pixels only.

Let us choose a point C_n (a vector $\overrightarrow{C_n}$) from the black field of RDI(n), i.e., $C_n \in \overline{\mathrm{RDI}(n)} \neq \varnothing$.

Then from definition (5a,b) applied to RDI(n): $\mathrm{RDI}(n) = \left(\frac{n}{n-1} * \mathrm{RDI}(n-1) \right) \cup \mathrm{RDI}(n-1)$, and from de Morgan's laws for the Boolean intensities of each pixel, it follows that $C_n \in \left(\frac{n}{n-1} * \overline{\mathrm{RDI}(n-1)} \right) \cap C_n \in \overline{\mathrm{RDI}(n-1)}$, where the two-place operation $a*A$ denotes scaling a given point (vector) set A by a coefficient a towards the initial point (vector) C_0, $\left| \overrightarrow{C_0} \right| \equiv 0$. Consequently: $\exists! C_{n-1}$, $C_{n-1} \in \overline{\mathrm{RDI}(n-1)}$, where $\overrightarrow{C_{n-1}} = \left(\frac{n-1}{n} \right) \overrightarrow{C_n}$, for the chosen $C_n \in \overline{\mathrm{RDI}(n)}$.

In this way, recursively it follows that for each point $C_i \in \overline{\mathrm{RDI}(i)}$, $i = n,\ldots,3$, it exists an unique point $C_{i-1} \in \overline{\mathrm{RDI}(i-1)}$ such that $\overrightarrow{C_{i-1}} = \frac{i-1}{i} \overrightarrow{C_i}$. Hence, the vectors $\overrightarrow{C_i}$, $i = 2,\ldots,n$, are collinear, and the points C_i, $i = 1,\ldots,n$ are situated on an unique line.

Finally, for the $\overrightarrow{C_2}$ component of the chains, we have $C_2 \in \overline{\mathrm{RDI}(2)}$, wherefrom according to (5) it follows that $\left|\overrightarrow{C_1}\right| \equiv 0$, which ends the proof. ♦

Fig. 4(b÷f) show the masks RDI(*i*) for optimal selection of the plate displacement, for each length *i* of the chains, respectively *i* = 2,3,4,5,6. Fig. 4a refers to the formal chain of length *i*=1 component, i.e. it coincides with the input binarized image (cf. Fig. 1b).

2.4. Enhanced interpretation of the method

In such a way, each pixel in the black area of RDI(6), if non-empty, is a solution to our task.

- In case one gives some requirements for physical dimensions of the chains, as in celestial degrees (or minutes, or seconds) or in pixels, then we can sort pixels of free (black) areas according to their distances to the RDI center and look for an optimum on this sorting.
- Since stars on astro images are not ideal (mathematical) points but real spots (of significant intensity measurement), see Fig. 1(a,b), it is actually a good idea in the free (black) areas to look not as for isolated pixels but for circular areas with a diameter of more than average amount over all stellar spots in the image. For example, in the present working image of the Pleiades (Fig. 2b) the average diameter of the star spots is ~3.9 pixels, while the maximum diameter is ~17.3 pixels.
- So far, we discussed the simplest (and most used) chain structure – linear structure, in which the distances between the components of the chains are given by (1) (see also Aniol et al., 1990, Winterberg et al., 1995).

Obviously, for generality of results, we may consider arbitrary structure of chains such as Fig. 2b, i.e. when, instead of (1), we ask an arbitrary chain structure through respective vector displacements of components towards the starting component (the original star) (Dimov et al., 2012):

$$\overrightarrow{C_i} = (x_i, y_i) - (x_1, y_1), \;\; i = 1,...,n, \qquad (6)$$

where (x_i, y_i) are the vectors (i.e. centers) of components of a given chain towards the beginning (first component) $\overrightarrow{C_1} = (0,0)$ of the chain. Furthermore to this general case, it is sufficient to add rotation of SDI(*i*) at angle φ_i at step S4, after scaling (5b), as follows:

$$\mathrm{rSDI}(i) \Leftarrow \mathrm{SDI}(i) : \left\{ I(\tilde{x},\tilde{y}) = I(x,y),\ (\tilde{x},\tilde{y}) = (x,y) \begin{Vmatrix} \cos\varphi_i & -\sin\varphi_i \\ \sin\varphi_i & \cos\varphi_i \end{Vmatrix},\ (\tilde{x},\tilde{y}) \in \mathrm{rSDI}(i), (x,y) \in \mathrm{SDI}(i) \right\}$$

$$\mathrm{SDI}(i) := \mathrm{rSDI}(i)\ , \tag{6a}$$

where $\varphi_i = \angle(C_{i-1}, C_i),\ i = 3,...,n$, see also Fig. 2b, where n=6.

By the way, the linear case (1) can be represented by (6) and (6a), like:

$$d_{1,2} = \left|\overrightarrow{C_1} - \overrightarrow{C_2}\right| = 2d\ ,\quad d_{i,i+1} = \left|\overrightarrow{C_i} - \overrightarrow{C_{i+1}}\right| = d,\quad i = 2,...,(n-1), \tag{7}$$

and $\varphi_i \equiv 0,\ i = 3,...,n$, n=6.

2.5. The Algorithm Proposed

Input data:

- Astro image (a negative, an original or preview) N, $0 \le N(x,y) < L_{\max}$, $(x,y) \in [x_{\text{size}} \times y_{\text{size}}]$, where $[x_{\text{size}} \times y_{\text{size}}]$ is the domain of N, x_{size} and y_{size} are in pixels, and $L_{\max} - 1$ is the possible maximum of image intensity values ($L_{\max}$ is natural number usually written in the image file format).
- Number n of the components of wanted chains, usually $3 \le n \le 6$.

NB.: For overall processing speed use as simple preview as possible, while the stars of interest (or of given magnitude) are still visible on the preview. Over this limit, the preview precision used does not affect essentially the method performance.

Expected result:

♦ Slope α (in radians) of the chain direction towards the abscissa in the image N, and

♦ Basic distance d for the components, according to (1) or (7).

We describe the algorithm in two main steps: pre (A1) and core (A2):

A1) ***Preprocessing:*** Evaluation of the centroides (mass centers of the star spots) in the image. For this purpose:

♠ Invert the input image (see Fig. 1) from negative N to positive P by the formulae:

$$\forall (x,y)\big((x,y) \in [x_{\text{size}} \times y_{\text{size}}]\big):\ P(x,y) = L_{\max} - N(x,y) - 1, \tag{8}$$

where $[x_{\text{size}} \times y_{\text{size}}]$ is the domain either for N or for P.

♠ Binarize the received positive P to get input working image B (see Fig. 1b), by the formulae:

$$\forall (x, y)(0 \le x < x_{\text{size}},\ 0 \le y < y_{\text{size}}):\ \ B(x, y) = \begin{cases} L_{\max} - 1, & \text{if } P(x, y) < t(x, y) \\ 0 \quad\quad , & \text{if } P(x, y) \ge t(x, y) \end{cases}, \qquad (9)$$

where $t(x, y)(0 \le x < x_{\text{size}}, 0 \le y < y_{\text{size}})$ is binarizing (threshold) surface in the general case of locally adaptive binarization, see for example (Dimov and Dimov, 2010). In relatively "clean" images: $t(x, y) = t_0 = \text{cte}$, t_0 a threshold for global binarization, $0 \le t_0 < L_{\max}$.

♠ Find the center of mass (centroide) of each star spot. In our case, for simplicity of demonstrations, we work directly with binarized image *B*. For larger precision, binarized image *B* can be used as a mask for positive input *P* in assessing the centroides.

NB.: Finding centroides can be also conducted through sophisticated computer software for registration of astronomical images, e.g., the program SExtractor (Bertin and Arnouts, 1996), and then computer to generate the working image *B* using stars data (declination, right ascension and magnitude) registered in the corresponding to B area of used sky catalog. This approach, however, is very resource intensive and unnecessarily precise for the intended purpose here.

A2) ***Basic processing:*** As described in paragraph 2.2 and 2.3:

♥ Generate initial RDI, pursuant to paragraph 2.2 (see also Fig. 4b). Announce RDI(2) = RDI.

♥ Generate cyclically all RDI(*i*), *i* =3,…*n*, according to (5a) and (5b) in paragraph 2.3.

♥ Look for position of the optimal chain in the black areas of the RDI(*n*), i.e. in $\overline{\text{RDI}(n)}$.

Here, various heuristics are possible, such as:

- Find the solution $(x_{\text{opti}}, y_{\text{opti}})$, $(x_{\text{opti}}, y_{\text{opti}}) \in \overline{\text{RDI}(n)}$, as the minimum $D_{\min}$ of distances $D = \sqrt{x^2 + y^2}$ from all points $(x, y) \in \overline{\text{RDI}(n)}$ to the image center, either
- The same, but with the following premise: look for $(x_{\text{opti}}, y_{\text{opti}})$, not as an isolated pixel, but as the center of isolated circle of diameter ϕ, $\phi > 0$. An upper limit for ϕ can be determined at step A1, for example, as the average (or maximal) diameter of star spots in the working image *B*;
- Other heuristics.

♥ Calculate the expected result:

$$\alpha = \text{tg}(y_{\text{opti}} / x_{\text{opti}}), \quad d = \sqrt{x_{\text{opti}}^2 + y_{\text{opti}}^2} \Big/ n \qquad (10)$$

End of algorithm.

NB.: The existence of a solution for working binarized image *B*, i.e. $\exists((x,y)\in \mathrm{RDI}(n))(I(x,y)=0)$ or what is the same: $\left|\overline{\mathrm{RDI}(n)}\right|>0$, obviously leads to the existence of a solution for the original image *N* too.

3. EXPERIMENTS AND DISCUSSION

3.1. Experiments

A standard Windows-7/Vista/XP application is performed to test the proposed method for the estimation how good was the choice of the plate movements. The application is C/C++ written in a Borland C Builder 5.0 environment. The experimental computer is an IBM compatible PC: Intel Core 2 Quad CPU 2.8 GHz, MM 4,0 GB. The input images should be preliminary converted to Windows BMP/JPG format (1 bpp).

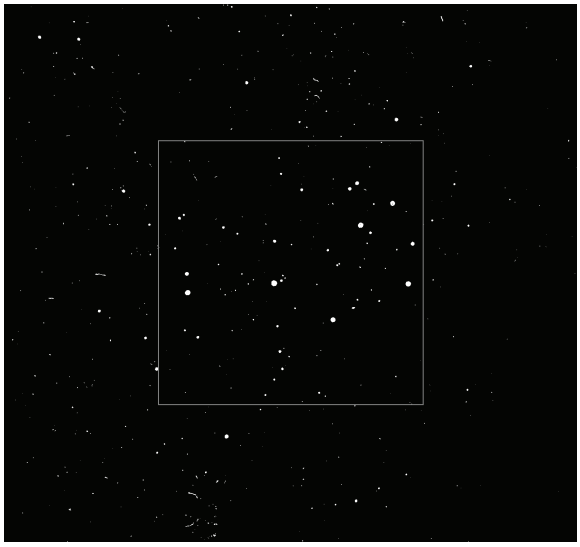
A preview image of the Pleiades region has been used for experiments, whose dimensions are $(x_{\mathrm{size}}, y_{\mathrm{size}}) = (1682, 1580)$, see also Fig. 1. The length *n* of the chains is chosen: $n = 6$.

The result of the proposed algorithm performance on the image (cf. Fig. 4f) is as follows: $(x_{\mathrm{opti}}, y_{\mathrm{opti}}) = (331, 372)$, where the RDI(6) domain is a square of size 780.

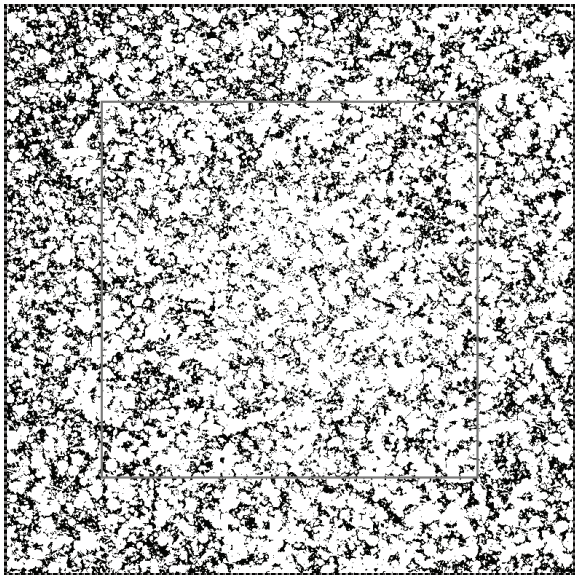
Consequently $(\tilde{x}_{\mathrm{opti}}, \tilde{y}_{\mathrm{opti}}) = (\text{-}59,\text{-}18)$, according to (2), wherefrom to (10), we have:

$$D_{\min} = 61.2\,,\ d = 10.2\,,\ \alpha = -163.0^{\circ}\,, \tag{11}$$

hence for the optimal structure of the chains (in central coordinates, and restrictively to pixel precision) we obtain:
$(0,0), (\text{-}20,\text{-}6), (\text{-}29,\text{-}9), (\text{-}39,\text{-}12), (\text{-}49,\text{-}15), (\text{-}59,\text{-}18)$.



(a)



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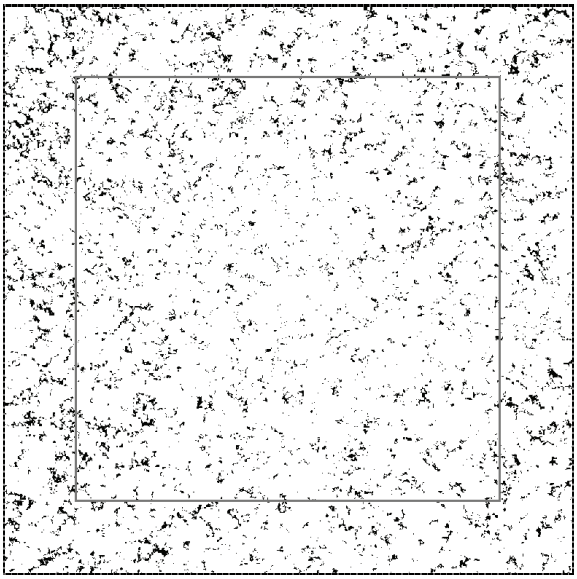

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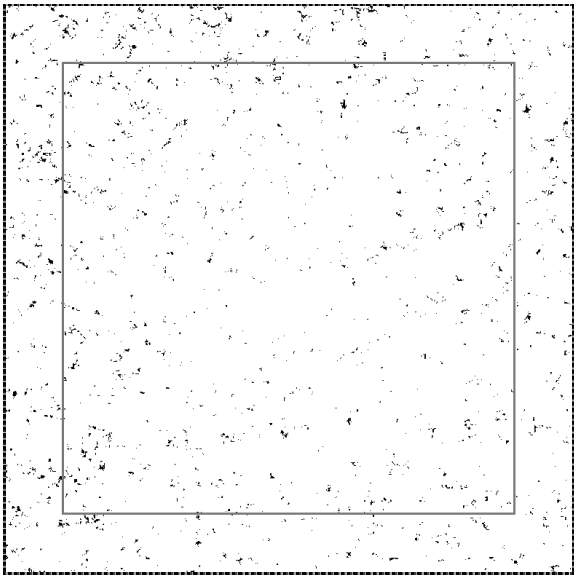


(d)

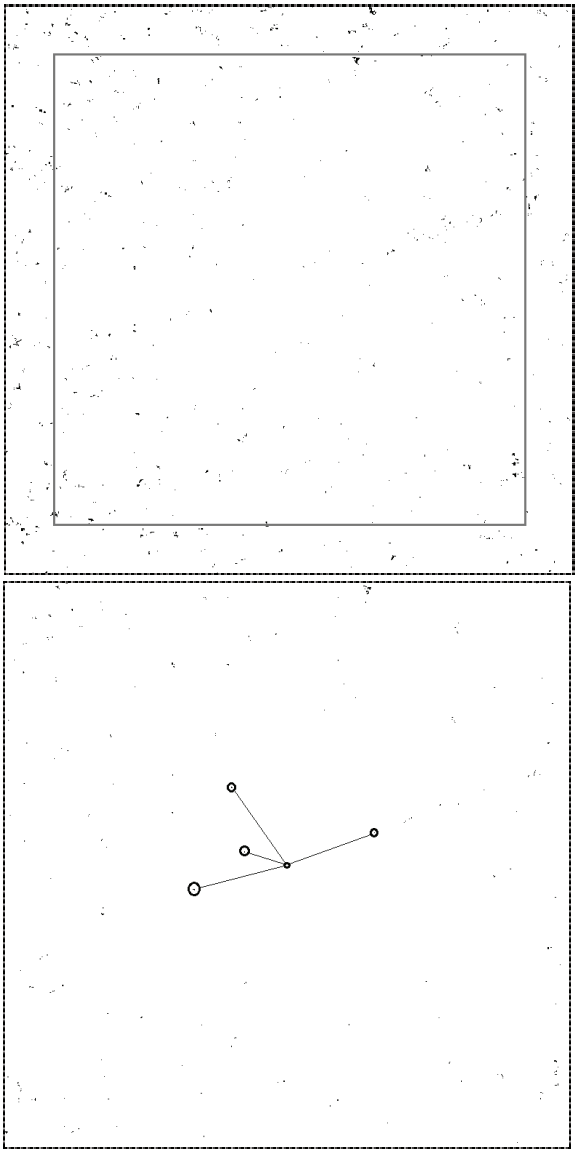


Figure 4: A sequence of reduced accumulated images RDI (*n*): a) *n* = 1 (formally), b) *n* = 2 (RDI), c) *n*=3, d) *n*=4, e) *n*=5, and f) *n*=6. Black areas of each RDI mark the current (*n*-th) component for selecting non-overlapping chains. Also, the position and size of next RDI is graphically illustrated by respective artifact-rectangle herein.

The sequence of reduced accumulated images, RDI(*i*), *i* = 1, ... 6, associated with the proposed method and algorithm, is illustrated in Fig. 4(a÷f). Black areas in RDI(*i*), i.e. relevant $\overline{\mathrm{RDI}(i)}$, mark the position of *i*-th component for selecting

of non-overlapping chains. An artificial square hint on each RDI(*i*) marks the position and size of the next RDI(*i*+1), *i*=1,…5, for better understanding of illustrations. For similar reasons, the sequence beginning is prefaced by the work image *B* (see also Fig. 1b), which plays a formal role as RDI(1). On RDI(6), i.e. last RDI, the first few (closest to the center) opportunities for chains' choice are illustrated, including the above announced optimal solution. The corresponding precise values of these solutions are given in Table 1.

Table 1: Choice of (linear) chains parameters for the image of Fig. 1a.

No.	$(x_{\text{opti}}, y_{\text{opti}})$	$(\tilde{x}_{\text{opti}}, \tilde{y}_{\text{opti}})$	$D_{\min}$	d [pix]	α [degrees]	$\varnothing$ [pix]	Overlaps %
1	(331, 372)	(-59, -18)	61.7	10.3	-163.0	1.5	4.9
2	(510, 345)	(120, -45)	128.2	21.4	-20.6	1.0	-
3	(313, 282)	(-77, -108)	132.6	22.1	-125.5	2.5	-
4	(261, 423)	(-129, 33)	133.2	22.2	165.7	2.5	-
*	(413, 388)	(23, -2)	24.0	4.0	-3.2	-	29.0

Each row of Table 1 corresponds to possible choice of the (linear) chains parameters for the image *B*, i.e., for the input image *N* too. The table rows are sorted in ascending order of $D_{\min}$. Thus, row 1 represents the optimal choice for chains parameters, and the corresponding image of chains artificially generated for this choice is illustrated in Fig. 5a. The last column of the Table assesses the overlap area among the chains as a percentage of the maximum possible area A_{ovr} of overlap, $A_{\text{ovr}} = (n-1)S$, n = 6, and S the total area of stellar spots localized in the input image.

It is clear from Table 1 that if seeking a minimum length of the chains, and the diameter of the circle of guaranteed non-overlapping is, for example, ϕ = 2, then instead of the obvious choice (row 1), we should prefer row 3 of the Table.

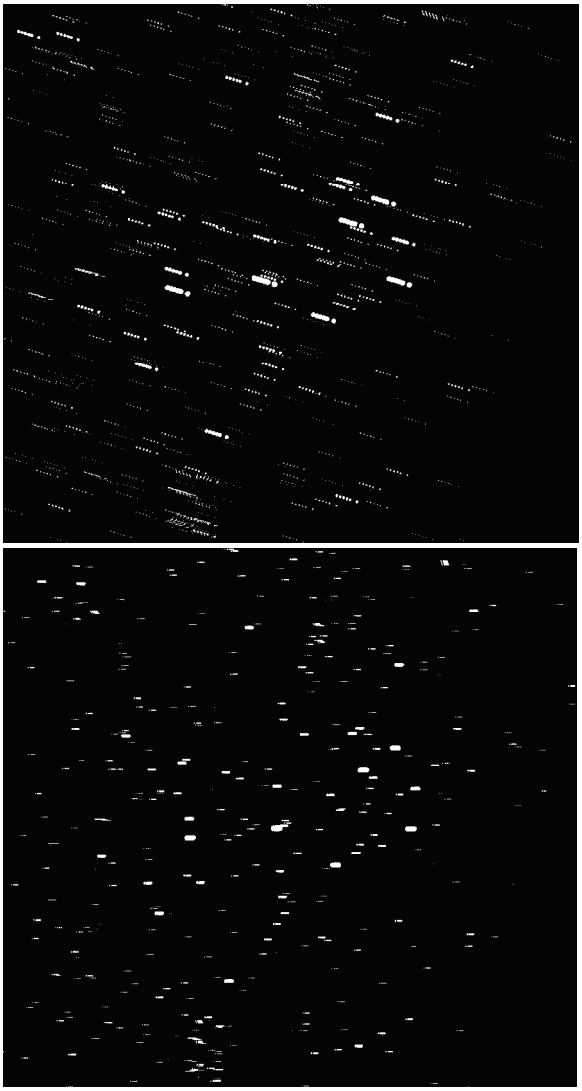


Figure 5: Astro image with chains (of 6 components' length): a) the optimal astro image (with a slope of chains α = 163.0°, d = 61 [pix]), generated from the working image of Fig. 1b; and b) generated (from Fig. 1b) a virtual copy of the original image ROZ050_000046 with chains' parameters: α = -3.2°, d = 24.

The last row marked with (*) in Table 1 refers to an image (see Fig. 5b) generated toward the choice that was (ever) made for an archival "Pleiades' chains" image, reviewed in (Dimov et al., 2012). The quantitative evaluation (29%) of overlap here is about 5 times larger than the estimated overlap for the optimal choice (row 1 of Table 1), which can be traced also by visual comparison of Fig. 5(a,b).

3.2. Discussion

The experiment illustrated in Fig. 5, shows the optimal choice of chains (α = 163.0°, d=61 [pix]) following the method proposed here (Fig. 5a), compared to a random choice (Fig. 5b), which parameters α = -3.2° and d=24, are evaluated for the original “Pleiades chains” image, namely ROZ050_000046.bmp (Dimov et al., 2012). Both images (Fig. 5a and Fig. 5b) were obtained through the binarized input image B (Fig. 1b) by generating the appropriate software chains to simulate as close as possible experimental conditions in the two cases under comparison.

In fact, the differences in the both experiments are essential – the first one is incomplete (no actual image of chains were produced, we have only the input image of Fig. 1), while the second is represented only by an image with chains, and no initial image (like in Fig. 1). We should consider differences in experiment dates, hence varying degrees of aging of the plates, as well as differences in the type of plates, duration of exposure, type of telescopes used, etc.

Further, and beyond the illustrated comparison, we can see that the chains’ overlap in the original image "Pleiades’ chains" of Dimov et al. (2012), even above the optimum here defined is not as big as this occurs in its recovery (Fig. 5b) from the input image (Fig. 1). Taking note that the average diameter of the star spots in the input image is about two times larger than the one in the original image with chains from Dimov et al. (2012), explains this discrepancy.

The complexity of the proposed algorithm can be considered linear over the volume of the input image. The measured duration of the experiment is ~1.04 [sec], for the test image volume V = 2.6MB, in a BMP format. So, at the main step A1 of the algorithm proposed, we evaluate an experimental time constant τ, $\tau \sim$ 0.4 [sec/MB], which can be applied to estimate the processing time t for an arbitrary input image, $t \approx V\tau$ [sec].

Interest is the ability to manage the situation of "no solution" at some step i of the proposed algorithm, i.e. when reaching $\overline{|\mathrm{RDI}(i)|} = 0$, $i \le n$. This will summarize two approaches: 1) by manipulating the size of the stellar spots in primary image $B \equiv$ RDI(1), and 2) by redefining the proposed method – from black-and-white (B/W) images to gray (halftone) ones.

1) If reducing the star spots’ diameters ϕ in the image $B \equiv$ RDI(1) (see Fig. 4a), for example, by a specific operation such as "morphologic erosion" (Sonka, Hlavac and Boyle, 1998) but remaining unchanged the smallest spots, such as $\phi \le$ 2, then the resultant RDI(6) (see Fig. 4f) will obviously contain larger black areas, i.e. more opportunities for optimal selection of chains. Conversely, if an operation like "morphologic dilation" (Sonka, Hlavac and Boyle, 1998), increases the diameter of the spots, even these few options for optimal choice (see also Table 1) will disappear from RDI(6), i.e. problem will become unsolvable at n = 6. We already commented this effect in Fig. 5(a,b), where the differences in the

diameters of stellar spots are due to differences (most likely in duration of exposure at) in both experiment compared.

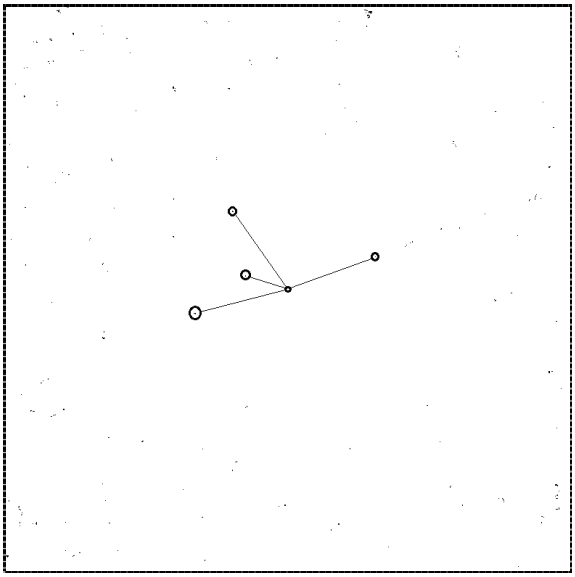
2) The proposed method was justified here for B/W images. Thus, if at the current step i of the algorithm, the black areas of RDI(i), $i \le n$, we can choose a circle ϕ, $\phi > \phi_{\max}$, where $\phi_{\max}$ is the diameter of the largest star spot in the initial image B, then the method ensures complete lack of overlap between the chains. This is a very strong condition. To avoid early reaching of "no decision" the key condition is weakened to $\phi > \phi_{\text{avrg}}$, where ϕ_{avrg} is the average diameter of the star spots in B. We still weaken to $\phi > 0$, which allows for larger values of n, at the expense of minor overlaps on the periphery of the chains. This brings the idea of an extension defined on the halftone images instead of B/W ones. To do this:

- Define a new initial image B_E, $B_E = B \cap P$, P the original input image, and B is its binarization used as mask to pass only essential (above the binarization threshold) intensities of star spots in P;

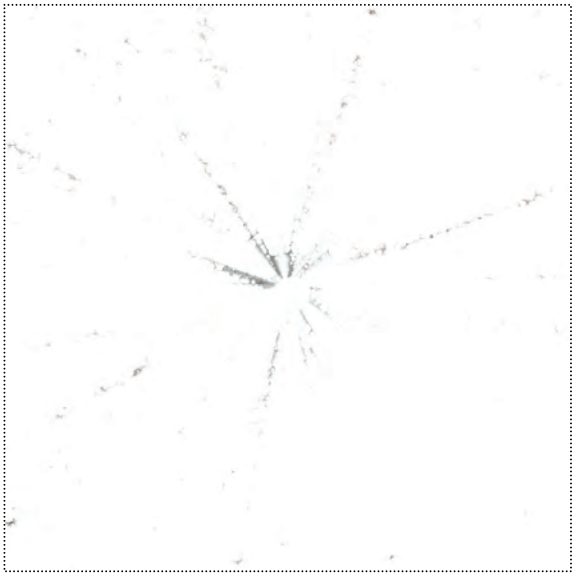
- Instead of disjunction in (4) and (5a) use an “extended disjunction", i.e. like the conventional summation but restricted above by the intensity $L_{\max}$, $L_{\max}=256$ for P and B_E images, $B_E \equiv \text{RDI}_E(1)$, as well as for the subsequent $\text{RDI}_E(i)$ and $\text{SDI}_E(i)$, $i=2,\ldots,n$;

- Look for the optimal solution $(x_{\text{opti}}, y_{\text{opti}})$ like a point (pixel) in $\text{RDI}_E(n)$, where the intensity of $\text{RDI}_E(n)$ reaches (a local) minimum.

Fig. 6(a,b) illustrates the comparison of final results obtained by the basic B/W method and by its halftone extension both applied to the same example, cf. Fig. 4f.



(a)



(b)

Figure 6: Comparison between of the proposed B/W method and its halftone extension: a) resultant B/W RDI(6) copied from Fig. 4f; and b) corresponding halftone result $RDI_E(6)$. Obviously, the ability to define an optimal choice for the halftone expansion is significantly more flexible.

4. CONCLUSION

The method presented here, algorithm and program are developed for evaluation of optimal design parameters (slope and reference distances) of the chains in the astronomical MEWFP method.

The proposed method is described for linear chains structure and is generalized for synthesis of arbitrary (non-linear) chains structure. Various modifications of the basic B/W method are discussed including its halftone expansion, leading to an optimal compromise in no-decision cases by the basic method.

The primary purpose of this development is for a posteriori evaluation of the structural quality of (images of) astronomical archives of MEWFP type. Evaluating whether (and how much) the quality is exacerbated by overlapping stellar copies, allows improvements in demand for really variable stellar objects in archival (available, known) MEWFP. And this is considered important because of the large number of known and/or available MEWFP in astronomical observatories archives around the world.

References

Aniol, R., Duerbeck, H. W., Seitter, W. C., Tsvetkov, M. K.: 1990, "An automatic search for flare stars in southern stellar aggregates of different ages", In Flare Stars in Star Clusters, Associations and Solar Vicinity, eds. L.V. Mirzoyan, B.R. Pettersen and M.K. Tsvetkov, IAU Symp. 137, Kluwer Acad. Publish., Dordrecht-Boston-London, 85-94.

Bertin, E., Arnouts, S.: 1996, "SExtractor: Software for source extraction", *Astron. Astrophys. Suppl. Series*, **117**, 393-404.

Dimov, D., Dimov, A.: 2010, "Data Driven Approach to Binarization of Astronomical Images", In: Proceedings of CompSysTech'10, June 17-18, 2010, Sofia, Bulgaria, Mini-Symposium on Astroinformatics, ACM International Conf. Proceeding Series, **471**, ACM PRESS, New York, 478-484.

Dimov, D., Tsvetkova, K., Tsvetkov, M., Kolev, A., Kounchev, O.: 2012, "Hough Transform Approach to Flare Stars Identification in Multi-Exposure Plates Images', *Serdica J. Computing*, **6**, 121–148.

Sonka M., Hlavac, V., Boyle, R.: 1998, Image Processing, Analysis, and Machine Vision, 2-d edition, Brooks/Cole Publishing Co., CA.

Tsvetkova, K. P.: 2012, "Astroinformatics for the flare stars in stellar clusters and associations", Proceedings of the VII Bulgarian-Serbian Astronomical Conference (VII BSAC), Chepelare, Bulgaria, June 1-4, 2010, Eds. M. K. Tsvetkov, M. S. Dimitrijević, K. Tsvetkova, O. Kounchev, Ž. Mijajlović, Publ. Astron. Soc. "Rudjer Bošković", **11**, 127-139.

Winterberg, J., Nolte, M., Seitter, W. C., Duerbeck, H. W., Tsvetkov, M. K., Tsvetkova, K. P.: 1995, "Flares and Flashes", Proc. IAU Coll. 151, eds. J. Greiner, H.W. Duerbeck and R.E. Gershberg, Springer Verlag, Berlin, 119.

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THE MANIFESTATIONS OF THE NON-SYMMETRIC ION–ATOM ABSORPTION PROCESSES IN THE SOLAR ATMOSPHERES IN UV AND VUV REGION

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Abstract. In this work we draw attention to the radiative processes in strongly non-symmetric ion-atom collisions as factors of influence on the opacity of the solar atmosphere in UV and VUV region. For several ion-atom systems, $He + H^+$ and $H + A^+$, where A is the atom of one of the metal (Mg, Si, Al etc), some characteristics have been determined, such as molecular potential curves and dipole matrix elements. Here the non-symmetric radiative processes are considered under the conditions characterizing the non-LTE standard model of the solar atmosphere. In this work the calculations of the corresponding spectral absorption coefficients have been performed. It is shown that the examined processes generate rather wide and firm molecular absorption stripes in the UV and VUV regions, whose intensity is comparable and sometimes even larger than the intensity of known one's generated in the $H + H^+$ radiative collision processes. Due to all these reasons the processes have to be consistently included in standard models of the solar atmosphere.

1. INTRODUCTION

The important influence of some ion-atom radiative collision processes on the optical characteristics of the stellar atmospheres was already established. Here we have in mind the symmetric radiative processes of the photo absorption/emission and radiative charge exchange which can be presented by

$$\varepsilon_\lambda + A_2^+ \leftrightarrow A + A^+ \qquad (1)$$

$$\varepsilon_\lambda + A^+ + A \leftrightarrow A + A^+ \qquad (2)$$

where A = H(1s) or He($1s^2$), A^+ and A_2^+ are the corresponding positive, single charged atomic and molecular ions in the ground electronic states, and ε_λ is the photon energy. Previously, it was shown in Mihajlov et al. (1993, 2007) that these processes can influence to the opacity of Solar atmospheres. Nevertheless, the mentioned papers have leaved opened the questions of the significance of the non-symmetric radiative processes.

The main objective of this paper is to draw attention to the possible significance of the non-symmetric radiative processes as factors which influence to the opacity of stellar atmosphere in UV and VUV region. Here we will consider the processes of absorption charge exchange and photo-dissociation of the type

$$\varepsilon_\lambda + AB^+ \leftrightarrow A^+ + B \qquad (3)$$

$$\varepsilon_\lambda + A + B^+ \leftrightarrow A^+ + B \qquad (4)$$

$$\varepsilon_\lambda + A + B^+ \leftrightarrow (AB^+)^* \qquad (5)$$

where B is the ground state atom with the ionization potential I_B which is less than the ionization potential I_A of the atom A, and AB^+ - the corresponding molecular ion in one of the electronic states which are asymptotically correlated with the state of the system $A + B^+$. One can see that the processes of charge exchange and photo-dissociation i.e. (3) and (4) represent the analogues of the processes (1) and (2), while the process (5) has not it's symmetric analog.

In this paper the strongly non-symmetric radiative processes are investigated under the conditions characterizing the model of the solar atmosphere presented in Vernazza et al. (1981). All needed data for the calculations of the spectral absorption coefficients are provided in tabular form only in chosen models. In accordance with this model is possible that atom A = He($1s^2$) and B = H(1s), and A = H(1s) and B = Mg, Si and Al.

We should point out that for the molecular ions HeH^+ and $(HeH^+)^*$ the corresponding potential curves and the dipole matrix elements, as the functions of the internuclear distances, are taken from Green et al. (1974a,b), while for all other considered molecular ions the mentioned quantities are calculated within this manuscript and in Srećković et al. (2011).

The spectral absorption coefficients calculated here, as the function of the local temperature T, wavelength λ, and the particle densities are determined in the region 40 nm $\leq \lambda \leq$ 230 nm.

2. RESULTS AND DISCUSSION

The strongly non-symmetric processes (3)-(5) are schematically shown in Fig. 1, where: bf-, ff-, and fb denote the bound-free, free-free and free-bound radiative transitions; $\Delta I = I_A - I_B$; $E = E_{imp}$ and E'_{imp} are the impact energies of the corresponding ion-atom systems; $U_{in}(R)$ and $U_{fin}(R)$ - are the adiabatic potential curves of the initial and final molecular electronic states; v , v' , J, and J' - the quantum numbers of the corresponding bound ro-vibration and free states.

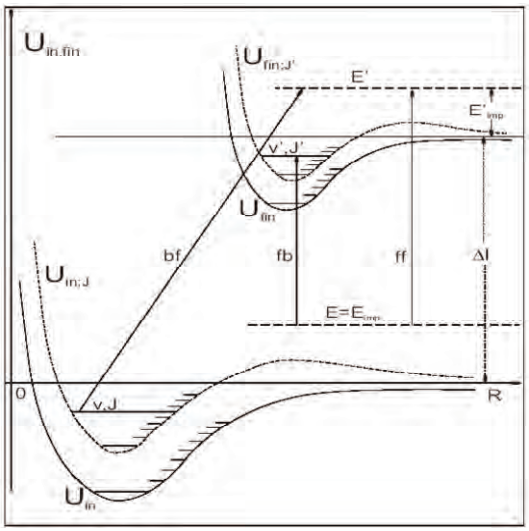

Figure 1: Schematic presentation of the non-symmetric processes (3)-(5) caused by the bf-, ff-, and fb- radiative transitions.

The contribution of the considered non-symmetric ion-atom absorption processes (3) - (5) to the opacity of the solar atmosphere is described here by the spectral absorption coefficient $\kappa_{ia;nsim}(\lambda; T)$. The behavior of $\kappa_{ia;nsim}(\lambda; T)$ for several values of λ is illustrated by Fig.2, where h is the distance of considered layer from the referent one (h=0) in accordance with Vernazza et al. (1981).

The behavior of the quantity $G = \kappa_{ia;nsim}(\lambda; T)/ \kappa_{ia;tot}(\lambda; T)$, where $\kappa_{ia;tot}(\lambda; T)$ characterize the total contribution of all ion-atom absorption processes, i.e. (1) - (5), is shown in Fig.3. Then, in Fig.4 is presented the behavior of the quantities $F_{sim} = \kappa_{ia;sim}(\lambda; T)/ \kappa_{ea}(\lambda; T)$ and $F_{tot} = \kappa_{ia;tot}(\lambda; T)/\kappa_{ea}(\lambda; T)$, dash and full lines respectively. Here $\kappa_{ia;sim}(\lambda; T)$ characterizes the contribution of the symmetric ion-atom absorption processes (1) and (2), and $\kappa_{ea}(\lambda; T)$ - the contribution of the concurrent electron-atom processes i.e. H^- continuum, which were treated until recently as the absolutely dominant.

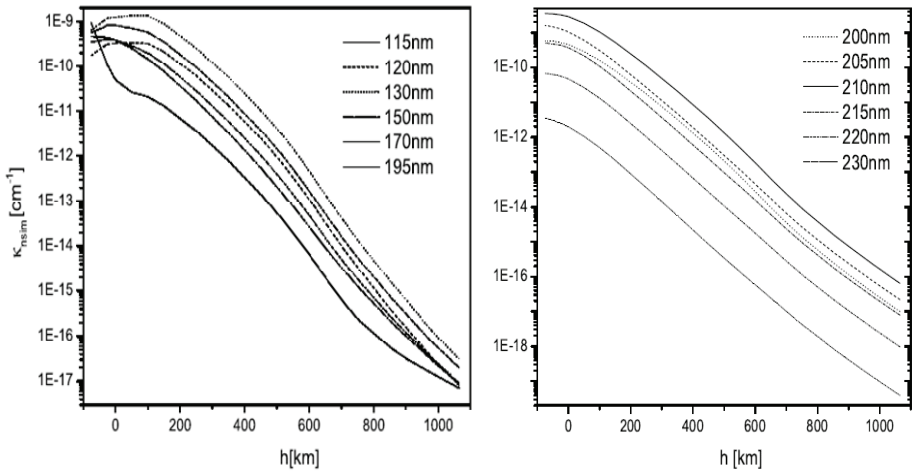

Figure 2: Spectral absorption coefficients $\kappa_{ia;nsim}(\lambda; T)$ as the function of h for the Solar atmosphere for 115 nm $\leq \lambda \leq$ 230 nm.

On the basis of the above mentioned it follows that the non-symmetric absorption processes (3)-(5) should be *ab initio* included in the relevant models.

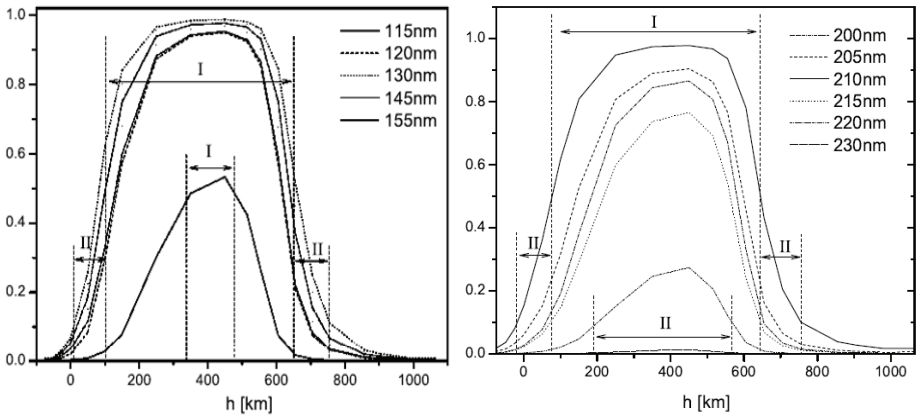

Figure 3: The behavior of the quantity $G= \kappa_{ia;nsim}(\lambda; T)/ \kappa_{ia;tot}(\lambda; T)$ as the function of h for the Solar atmosphere for 115 nm $\leq \lambda \leq$ 230 nm.

Even only the results presented in figures 3 and 4 show that the neglecting of the contribution of the non-symmetric processes (3) - (5) to the opacity of the solar atmosphere, in respect to the contribution of symmetric processes (1) and (2) would caused noticeable errors.

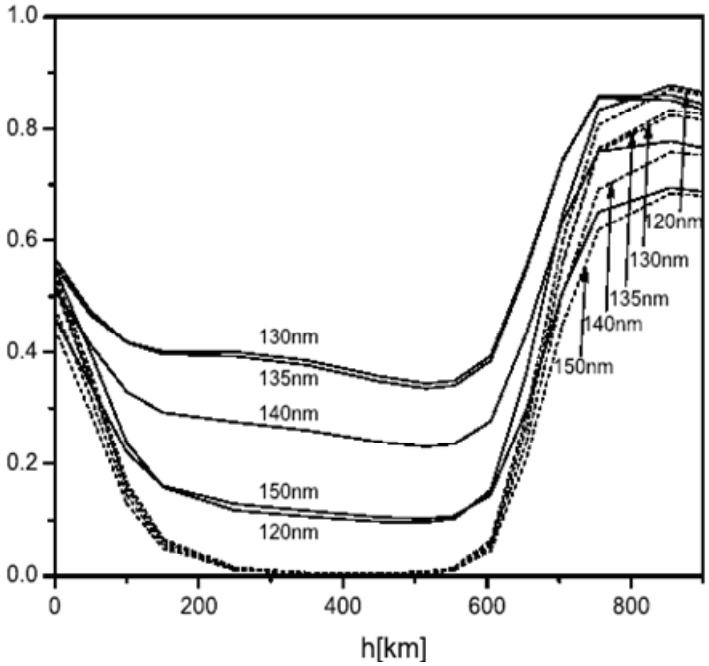

Figure 4: The behavior of the quantities F_{sim} (dash lines) and F_{tot} (full lines) as the function of h for the Solar atmosphere for 115 nm $\leq \lambda \leq$ 230 nm.

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References

Green, T., Browne, J., Michels, H., Madsen, M.: 1974a, *J. Chem. Phys*., **61**, 5198.
Green, T. A., Michels, H. H., Browne, J. C., Madsen, M. M.: 1974b, *J. Chem. Phys*., **61**, 5186.
Mihajlov, A. , Dimitrijević, M. S., Ignjatović , Lj.: 1993, A&A, 276, 187.
Mihajlov, A., Ignjatović, Lj. , Sakan, N., Dimitrijević, M. S.: 2007, *A&A*, **437**, 1023.
Srećković, V. et al.: 2011, JENAM Saint-Petersburg, Russia, Contrib. Papers p. 84.
Vernazza, J., Avrett, E., Loser, R.: 1981, *ApJS*, **45**, 635.

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BEOGRAD 1985

RADOVAN DANIĆ – POPULARIZATOR ASTRONOMIJE (II) PREDAVANJA I KURSEVI

A. Tomić, M. S. Dimitrijević

Profesor Danić bio je oduševljeni i izvanredan popularizator astronomije. Astronomijom se počeo baviti u izuzetno reškim okolnostima, u ratnom zarobljeništvu 1943–44. godine, gde mu je učitelj bio naš poznati astronom Pero Đurković (17), (1). Upravo iz tog vremena vuku koren neke bitne odlike Danićevog pristupa astronomiji, kao npr. ozbiljan i svestran pristup, traženje lepog i verovatno sam koncept za kasnije popularisanje astronomije. (Danić je već bio profesor na univerzitetu, a Đurković priznati stručnjak.) Otuda potiče i duboko doživotno prijateljstvo sa Perom Đurkovićem i njihova saradnja, kasnije nastavljena u okviru rada društva.

Danić je praktično odmah po oslobođenju nastojao da nabavi astronomski durbin i tu želju je konačno realizovao krajem 1951. godine (3). U to vreme javlja se inicijativa za osnivanjem (obnavljanjem) astronomskog društva, koju Danić sa oduševljenjem prihvata i stavlja svoj teleskop Društvu na raspolaganje (2). Danić posmatra nebo (4), drži popularna predavanja na Vojno-medicinskoj akademiji, Kolarčevom narodnom univerzitetu, radničkim univerzitetima u Beogradu, Sarajevu, Novom Sadu, Rumi, Sremskoj Mitrovici i drugim mestima, kao i godišnjim skupštinama Društva (5) – (13). Kao takav, on je prava ličnost za predsednika Društva i tu dužnost uspešno obavlja neprekidno 15 godina, da bi bio proglašen i za doživotnog počasnog predsednika (14).

Tačan broj predavanja koje je održao profesor Danić teško je utvrditi. Međutim, treba napraviti podelu na tematska predavanja i na kurseve, koje je držao nakon otvaranja Narodne opservatorije. Za mnoga predavanja unapred je spremao tekstove, koje je kasnije modifikovao. U njegovoj zaostavštini ostalo je nekoliko debelih fascikli rukopisa (5) i one su, zajedno sa arhivskim materijalom u Društvu (15, 16) bile osnova za analizu.

Aktuelni fenomeni bili su Daniću istovremeno povod za održavanje predavanja i zahvalna tema, koju je veoma umešno iskorištavao. Tematska predavanja su stoga najčešće o pomračenjima, velikim planetama, godišnjim dobima, izgledu neba, prividnom i stvarnom kretanju planeta i Meseca, ali i njegove omiljene teme – o arhitekturi Vasione, zašto proučavamo nebo, odnosu medicine i astronomije... U prilogu I dat je spisak sačuvanih kompletnih rukopisa tematskih predavanja, kao i štampanih predavanja. Njih je bilo znatno više, jer su neka više puta ponavljana i dopunjavana. Prvo predavanje iz astronomije R. Danić je održao 12. februara 1952. godine (u svojoj 59 godini) (5, 6) osoblju Vojno-medicinske akademije na temu "O pomračenjima Sunca i Meseca". Kao ilustraciju njegovog pristupa citirajmo sačuvanu njegovu napomenu pre predavanja u međuzvezdanoj materiji 1954. godine članovima Društva (5):

> "Pre no što počnem izlaganje o današnjoj temi neka mi je dozvoljena sledeća napomena. Sve što ću izneti nije proizvod nekakvog mog originalnog rada iz ove teške oblasti, iz prostog razloga što ni moje kompetencije, ni moje ambicije ne mogu dotle stizati. Izlaganje treba, naprotiv, shvatiti kao jedan zbirni referat iz literature o ovom pitanju, u kome sam se trudio da što vernije iznesem sve što sam mogao bar donekle da razumem. Prema tome, predavanje ima zadatak obaveštavanja naših članova, koji možda nisu bili u mogućnosti da prelistaju po časopisima i monografijama."

Prema sačuvanom obaveštenju sa oglasne table opservatorije iz juna 1966. godine u leto te godine održani su sledeći kursevi:

1) Osnovi opšte astronomije, za početnike, nastavnik R. Danić,
   3 x nedeljno po 1 h,
2) Astronomska praksa, za spoljne saradnike, nastavnik R. Danić,
   2 x nedeljno po 1 h,
3) Astrofotografija, za članove fotografske sekcije, nastavnik A. Kubičela,
   1 x nedeljno po 2 h,
4) Istorija astronomije, nastavnik N. Janković,
   1 x nedeljno po 2 h,
5) Praktične vežbe, rukovodioci R. Danić i N. Janković,
   3 x nedeljno po 2 h.

Prema dnevniku opservatorije, Danić je od 1966. do 1973. godine održao 14 kurseva (poslednji sa A. Tomićem), sa ukupno 192 predavanja. Danićev kurs je zavisio od prosečnog uzrasta i nivoa predznanja slušalaca, pa je zato bio

PRILOG I

SAČUVANI RUKOPISI TEMATSKIH PREDAVANJA

1. O pomračenjima Sunca i Meseca (Vojno-medicinska akademija; 12. II 1952.)
2. Orjentacija u prostoru pomoću neba (planinarima, 1953. g.)
3. Najznačajniji događaji u astronomiji prethodne godine (skupština Društva, februar 1954)
4. Izgled i lepote zvezdanog neba (Kolarčev narodni univerzitet, 1954.)
5. Merkurov prolaz ispred Sunca (skupština Društva, februar 1954.)
6. Zašto proučavamo nebeo (Kolarčev narodni univerzitet, 2. I 1955. i ponovljeno 1958. g.)+
7. Novo u astronomiji (Skupština Društva 1956. g.)
8. Evolucija nebeskih tela (1956, april)
9. U beskrajnim dubinama Vasione (Kolarčev narodni univerzitet, 1956.)+
10. Zvezdano nebo (Kolarčev narodni univerzitet, 5. I 1959.)
11. Međuzvezdana materija (skupština Društva, 1959)
12. Astronomske konsekvence opšte teorije relativnosti (skupština Društva, 1959. g.)
13. Arhitektura Vasione (Novi Sad), 1960.+
14. Pomračenje Meseca od 24. VI 1964. i opšte o pomračenjima (1964. g.)
15. "Mariner IV" – fantastičan podvig američke astronautike (1965. g.)+
16. O značaju teorije relativnosti za astronomiju (1968. g., jun)
17. O planeti Mars (1970. g.)+
18. Astronomija i medicina (Kolarčev narodni univerzitet, 29. I 1971)+

Napomena: Naslovi označeni sa "+" su i štampani – videti bibliografiju uz prvi deo članka.

PRILOG II

DANIĆEV KURS OPŠTE ASTRONOMIJE – SPISAK TEMA (15, 16)

Uvod i podela stronomije. Astronomski instrumenti. Kretanje nebeskih tela – Njutnov i Keplerovi zakoni. Vreme i časovnici. Kalendar i zvezde. Zvezdano nebo. Sjaj, boja i rastojanja nebeskih tela. Zvezdani sistemi i širenje vasione. Tačke, pravci i krugovi na nebeskoj sferi. Koordinatni sistemi (često u dva predavanja). Refrakcija, aberacija, precesija, nutacija. Sunce i Sunčev sistem. Unutrašnje planete. Mesec i Zemlja. Pomračenja Meseca i Sunca. Spoljašnje planete. Komete, meteori i zodijačna svetlost.

Broj održanih časova po godinama (15, 16):

1966	1967	1968	1969	1970	1971	1972	1973	ukupno
36	22	8	19	24	26	33	24	192

PRILOG III

PREGLED SADRŽAJA DANIĆEVIH KURSEVA (5)

1. **Popularna stronomija**
   Sunčev sistem: Sunce (1), Planete (7), Pomračenja (19), Mars (27), Male planete (28), Jupiter (29), Saturn (31), Uran (32), Neptun (32), Pluton (33), Komete (34), Meteori (38), Zodijakalna svetlost (40).
   Dodatak: Planete – poreklo imena (4 str.), Razdelnice Saturnovnih prstena (2 str.).
   Zvezdani sistem: Zvezde (9 str.).
   Spektralna analiza u astronomiji (13 str.).

2. **Kretanja nebeskih tela** (osnovi opšte astronomije u elementarnoj obradi)
   Uvod (1), Keplerovi zakoni (16), Putanje (25), Elementi planetnih putanja (25), Njutnov zakon opšte gravitacije (27), Nebeska mehanika (36), Problem dva tela (40), Problem tri tela (41), Perturbacije (44), Završne napomene (49)(uk. 52 str.).
   Dodatak (14 strana): Opisivanje planetnih putanja, Izračunavanje udaljenosti planete od Sunca. Izračunavanje sideričnе i sinodične revolucije i srednje udaljenosti planete od Sunca. Geocentrično kretanje planeta.
   Dodatak 2: Vreme u astronomiji (16 str.), Pretvaranje vremenskih u lučne jedinice (4 str.).

3. **Stelarna astronomija i astrofizika**
   (I) Uvod: Uvod (1), Udaljenosti zvezda (6), Kretanje zvezda (14), Zvezdani spektri (14), Klasifikacija zvezdanih spektara (33), Sjaj zvezda (42), Rassel-ov dijagram (53).
   (II) Građa zvezda: Građa zvezda (57), Građa atoma (58), Zvezdana atmosfera (68), Unutrašnjost zvezda (78), Zvezdane populacije (104), Zvezdane asocijacije (105) (uk. 107 str.).
   (III) Zvezdani sistemi: Zvezdana jata: Određivanje udaljenosti jata. Loptasta ili globularna jata (uk. 10 str.).
   Zvezdani sistemi: Mlečni put. Vangalaktički sistemi (uk. 21 str.).
   Međuzvezdana materija: Međuzvezdana materija. Difuzne magline. Međuzvezdana prašina. Međugalaktička materija (uk. 10 str.).
   Antimaterija (uk. 5 str.).

4. **Odabrana poglavlja iz astronomije**
   1. Gravitacija (18 str.) 2. Značaj teorije relativnosti za astronomiju (16 + 8 str. prevod) 3. Poremećaji u kretanju planeta (6 str.) 4. Kvazari (16 str.).

promenljivog obima iako istog programa. Broj predavanja iz tih razloga je varirao od 6 do 17. U prilogu 2 dat je spisak tema Danićevih predavanja na kursu opšte astronomije. Za ovaj kurs, Danić je ostavio napisan priručnik. On se sastoji iz nekoliko celina koje su pisane odvojeno i hronološki ovim redom:

1963–64. Sunčev sistem, (45 strana) i uvod u zvezdane sisteme (9 str.); zajednički nad-naslov: popularna astronomija,

1965. Kretanje nebeskih tela (59 str.), sa dodatkom – opisivanje planetskih kretanja. Zajednički nad-naslov: osnovi opšte astronomije u elementarnoj obradi,

1966-67. 6. kurs za spoljne saradnike: Stelarna astrnomija i astrofizika (209 str.) sa podnaslovom: u elementarnoj obradi,

1968. 7. kurs za spoljne saradnike: Odabrana poglavlja iz astronomije (58 str.) sve na formatu A5.

Pregled sadržaja sva tri kursa dat je u prilogu III. Poslednja dva kursa nominalno nisu držana, već su inkorporirani u predavanja kursa opšte astronomije u različitom obimu, zavisno od nivoa znanja slušalaca. To se očigledno vidi iz opisa tema datih u dnevniku opservatorije (15, 16).

Danić je učio astronomiju u zarobljeništvu po "Lehrbuch der Astronomie" Elis i Bengta Stroemgrena, iz 1933. god. (Springer Verlag, Berlin) (18). Knjigu je posle rata preveo i predao V. V. Miškoviću da se štampa (17). Rukopis nije štampan, a u Danićevoj ostavštini nema kopije prevoda. Uticaj ovog dela na Danića je očigledan i po tome što on prihvata navedenu u knjizi podelu materije na oblasti i koristi u svojim kursevima. Obradio je i sfernu trigonometriju i održavao predavanja po potrebi.

Poslednje predavanje Danić je održao 1. novembra 1973. godine (16), dakle gotovo 22 godine nakon prvog predavanja, sa temom kao kod prvog predavanja: Pomračenje Sunca. Prof. dr. Radovan Danić je bio izvanredan predavač, koji se najviše zadržavao na najvažnijim stvarima, uvek ukazivao na praktičnu stranu problema i gotovo uvek "začinjavao" predavanja anegdotama. Zato je i bio veoma omiljen predavač kod svih uzrasta slušalaca.

IZVORI:

(1) M. Jeličić, Vasiona, XXVII, 2, 33. (1979)
(2) Vasiona, I, 1, 29. (1953)
(3) A. Tomić, Vasiona, XXXII, 2, 31. (1984)
(4) Observationes (posmatračke beleške, rukopisna zaostavština R. Danića) 26. VI 1947 – 4. VI 1964.
(5) Rukopisna ostavština Radovana Danića, Astronomsko društvo "R. Bošković"
(6) Arhivska knjiga br. 21: I redovna godišnja skupština (Astronomsko društvo "Ruđer Bošković")
(7) Arhivska knjiga br. 22: II redovna godišnja skupština
(8) Arhivska knjiga br. 23: III redovna godišnja skupština
(9) Arhivska knjiga br. 24: IV redovna godišnja skupština
(10) Arhivska knjiga br. 25: V redovna godišnja skupština 10. II 1957.
(11) Arhivska knjiga br. 26: VI redovna godišnja skupština 2. III 1958.
(12) Arhivska knjiga br. 27: VII redovna godišnja skupština 1. III 1959.
(13) Arhivska knjiga br. 28: VIII redovna godišnja skupština 20. III 1960.
(14) Arhivska knjiga br. 31: IX redovna godišnja skupština 24. II 1963.
(15) Evidencija o izvršenim predavanjima i posetama Narodnoj opservatoriji 4. VI 1965 – 27. XII 1970.
(16) Dnevnik Nardone opservatorije, arh. knjiga br. 80, 1. I 1971 – 31. XII 1976.
(17) P. Đurković, Vasiona, XXVII, 2, 37 (1979)
(18) Kompletna knjiga se čuva u biblioteci Društva, u "raskomadanom" stanju u kakvom je izneta iz logora Hamelburg.

RADOVAN DANIĆ – A POPULARIZER OF ASTRONOMY (II): LECTURES AND COURSES

Prof. Danić has been the director of the Public Observatory of the Astonomical Society "R. Bošković" for 11 years. During that time he has been poying particular attention to lectures and courses for the assistents of the Observatory. Alone, he gave 192 lectures on varios courses at the Observatory. For all lectures he used to prepare the texts in advance, and, by consulting Observatory archives, we have traced which lectures have been given at the Observatory, and which have taken place elsewhere (or never took place). We give an assesment of Prof. Danić as an exquisite popularizer of astronomy who, has clearly expressed his position in written form, as notes accompanying his lectures.

Proc. IV Serbian-Bulgarian Astronomical Conference,
Belgrade 21–24 April 2004,
eds. M. S. Dimitrijević, V. Golev, L. Č. Popović, M. Tsvetkov,
Publ. Astron. Soc. "Rudjer Bošković" No 5, 2005, 51 - 58 *Invited lecture*

FULLERENES AND ASTRONOMY

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Abstract. The astrophysically motivated investigations of the chemistry of carbon stars resulted with the discovery of the C_{60} molecule, first and the most interesting representative of fullerenes molecules. Here is presented a review of astronomical researches connected with fullerenes as for example the search for interstellar and circumstellar ones or presence of such molecules in meteorites brechias of impact craters on Earth and impact traces on spacecrafts. Also, their connection with the problem of the diffuse interstellar and circumstellar absorption lines is discussed. Particular attention is payed to the search for polyynes in interstellar space which resulted in the formulation of investigation of chemistry of carbon stars and in discovery of fullerenes.

1. INTRODUCTION

Possibilities which provides the new C_{60} molecule and variety of the possible new compounds with this molecule as the basis, will result possibly in the birth of a new chemistry. The basic impulse, resulting with the discovery of this new molecule, came from astrophysics, from the attempt to explain the origin of unexplained bands and lines in emission and absorption spectra from interstellar space. It was first of all the intensive absorption band at 217 nm. It was supposed that its origin is connected with small graphite particles (Hufman, 1977). Also a group of interstellar diffuse absorption lines in the visible part of the spectrum, was an unexplainable puzzle for more than 70 years (Hufman, 1977; Herbig, 1975; Krätschmaher et al, 1990a). There were as well several intensive emission bands, with polycyclic aromatic hydrocarbons as carriers (Léger et al, 1984; Allamandola et al, 1985).

We will present shortly here, the development of investigations related to the astrophysical spectra, motivating researches resulting in the discovery of fullerenes.

2. INTERSTELLAR MOLECULES

The development of interstellar spectroscopy was particularly stimulated by the question of the origin of life on Earth. Chemists and biologists belived that a lot of complex organic molecules in the warm sea of the young Earth is needed for that. In 1923., russian scientist A. I. Oparin, supposed that the spontaneous creation of the first primitive single-celled organisms two billion years ago, was the result of the accumulation of biologically important molecules in microscopic coloidal droplets. But

which is the origin of such complex organic molecules? Charles Townes, who in the 1964 obtained the Nobel Prize for the invention of the maser, discovered with coworkes (Cheung et al, 1968) in 1968 the ammonia molecule (NH_3) in space. The ammonia molecules in interstellar space, coming from a dense cloud lying in the direction of the galactic center, were discovered with the help of the microwave radiation with a wavelength of 1.25 cm, observed by the Hat Creek radio telescope. It was the first polyatomic molecule (a molecule with more than two atoms) found in the interstellar space, and it was only the beginning. During the next three years approximately twenty molecules have been identified in the interstellar space, water, formaldehyde, hydrogen cyanide, and acetylene among them. The astrochemistry was born, and it was the beginning of the identification of more and more complex organic molecules in space.

It was assumed that the majority of the observed molecules originate in a series of reactions between molecular ions and molecules, combined with reactions on the surfaces of interstellar dust particles (Turner, 1989).

3. CARBON ATOM CHAINES - POLYYNES IN INTERSTELLAR SPACE

The new breakthrough in the investigation of the interstellar polyatomic molecules was when Barry Turner, an astronomer at the National Radio Astronomy Observatory at Green Bank in West Virginia detected microwave signals identified as due to cyanoacetylene HC_3N. The fact that interstellar clouds where such complex organic molecules have been found, are in the same time the places of the condensation of new stars with planetary systems, was in favour of the hypothesis that complex organic molecules, needed for the creation of life, were present in the warm sea of the young Earth, and that they are maybee of cosmic origin. The question was if even more complex molecules are present in interstellar space. Namely the last identified complex molecule belonged to the carbon chain molecules of the general form HC_nN (where n is equal to or larger than three), named cyanopolyynes (see e. g. Bell et al, 1982; Čelebonović, 1992). But in order to answer on this question one needs the good knowledge of their microwave spectra, and exotic cosmic conditions held the promise of the presence of molecules which are not present on Earth and which have not been synthesized in laboratories.

In 1975, Harry Kroto, a young chemistry lecturer at the University of Sussex, who was an expert in microwave spectroscopy, was very interested by the problem of organic molecules in space. Together with his colleague David Walton, he decided to investigate the existence of cyanobutadiyne (HC_5N) in interstellar clouds. An undergraduate student Antony Alexander, was engaged to synthesize cyanobutadiyne under Kroto and Walton's supervision, in order to measure its microwave spectrum and search for similar signals in space. Alexander synthesized cyanobutadiyne and measured its microwave spectrum between 26.5 and 40.0 gigahertz (Alexander et al, 1976). Than, Kroto asked his colleague Takeshi Oka from Ontario in Canada, and Oka with Lorne Avery, Norman Broten and John MacLeod, with the help of Kroto's data discovered HC_5N in Sagittarius B2 using the 43-metre diameter radio telescope

at Algonquin Park in Ontario (Avery et al, 1976).

Does in interstellar space exists and more complexe molecule cyanohexatriyne HC_7N? Kroto and Walton engaged a new graduate student Colin Kirby to synthesize this molecule. It was not an easy task but after a lot of difficulties it was done (Kirby et al, 1980) and the result enabled to identify and this molecule in space (Kroto et al, 1978). How far one can continue in this manner? It was obvious that an attempt to synthesize further members of the series will be an extremely difficult task. But Oka suggested to estimate the microwave spectrum of HC_9N molecule by extrapolation on the basis of the properties of preceeding members of the series. This attempt was successful and this molecule (Broten et al, 1978) and soon $HC_{11}N$ (Bell et al, 1982) as well, joined to the list of molecules identified in space.

4. CHEMISTRY OF THE CARBON STARS AND DISCOVERY OF FULLERENES

It was of little probability that chains of carbon atoms originate in ion - molecule reactions as it is with simpler molecules. Polyynes and small carbon clusters have been found not only in interstellar clouds (C_3) but as well in the shell around carbon star IRC+10^o216 (Turner, 1989). Kroto (1981) assumed that the source of carbon chain molecules and clusters are carbon rich red giant stars, which by radiation pressure pour in interstellar space dust containing carbon grains, mostly in the form of amorphous graphite. Kroto (1982) supposed that carbon chains may be synthesized in reactions between carbon clusters made by the vaporization of graphite from carbon grains, and simpler molecules. Together with Robert Curl and Richard Smalley, Kroto formulated a project on the simulation of carbon star chemistry and included also students Jim Heath and Sean O'Brien. The result of this project was the synthesis of C_{60} (Kroto et al, 1985) which led to the Nobel prize for Chemistry for Kroto, Curl and Smalley in 1996. They showed that by laser vaporization of graphite, carbon clusters C_n with n from 1 up to 190 are formed, with C_{60} as dominant one (Kroto et al, 1987). Due to the similarity of the structure of C_{60} and domes constructed by the architect Buckminster Fuller, such clusters obtained the name buckminsterfullerenes or simply fullerenes.

It is interesting that Andrew Kaldor from an oil company in New Jersey obtained molecules C_{60} and C_{70} during plasma graphite formation, still in 1984, but has not remarked and identified them on the spectrogram (Cheush, 1999).

Krätschmer et al. (1990)demonstrated that in sooth obtained by electric arc with graphite electrodes with helium as the working gas, are present C_{60} and C_{70}. The fullerenes are a new cristal allotropic modification of the carbon, besides graphite and diamond.

We have also hiperfullerenes with onion type structure where e.g. a C_{60} molecule is within C_{240}. This one within C_{540} and this one within C_{960}. Such multishell fullerenes or buckyonions suggested by Kroto and McKay (1988) are firstly synthetized in laboratory by Ugarte (1992, 1993)

In the spherically symmetrical vacuum hole within a C_{60} molecule, one can put different atoms and ions. For example Weiss et al. (1988), obtained with an arc

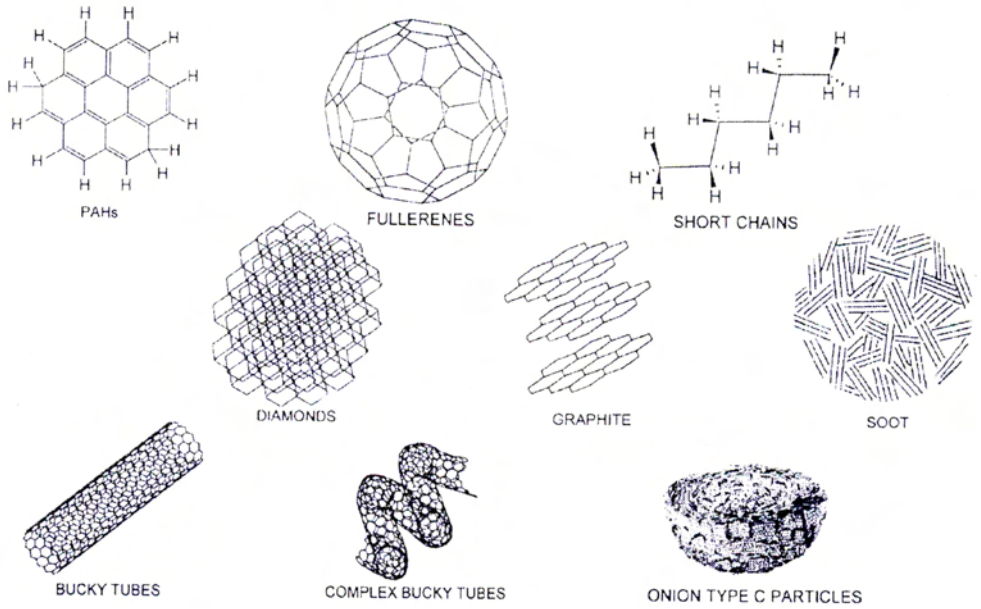

Figure 1: Some of the various forms of carbon that are likely present in gaseous and solide state in the interstellar matter and in solar system material (from Ehrenfreund and Charnley, 2000).

where kalium nitrate has been added to graphite electrodes, that some of K atoms finished in C_{60} molecules and the new compound is named $K@C_{60}$. One of interesting properties of complex carbon forms is also possibility of six angles graphite structure to form nanotubes (see Ebbesen and Ajayan, 1992). Consequently, carbonaceous dust in the interstellar medium may show strong diversity. In Fig. 1 (from Ehrenfreund and Charnley, 2000) are shown the chemical structures of some carbon compounds that are likely present in space.

Later, C_{60} and C_{70} have been identified on Earth in shock produced brechias of the Sudbury impact structure in Ontario (Becker et al, 1994), and in the geological strata of the Cretaceous-Tertiary and the Permian-Triassic boundary layers, associated with bolide impacts (Becker, 1999; Becker et al, 2000, 2001, Botta and Bada, 2002; Pizzarellos et al, 2001). Fullerenes have been detected as well in an impact crater on a spacecraft (Di Brozolo et al, 1994) and in meteorites (see de Vries et al, 1993; Becker et al, 1993; Foing and Ehrenfreund, 1997, Becker and Bunch, 1997; Becker, 1999 and Becker et al. 1999).

The presence of carbon onions in acid residues of the Allende meteorite (see e.g. Ehrenfreund and Charnley, 2000)suggested that higher fullerenes or nanotubes may be present in meteorites. In this meteorite Becker et al. (1999) have found C_{100} and C_{400}. The higher fullerenes have also been isolated from the Murchinson carbonaceous residue, and measurements of noble gases (helium, neon, and argon) in both

the Murchinson and Allende fullerenes by Becker et al. (2000) indicate that these molecules are extraterrestrial in origin.

It was supposed that hydrogen may inhibite the fullerenes growth mechanisms so that one should search C_{60} in hydrogen depleted space regions (Goeres and Sedlmayr, 1992). It has been shown in Gerhardt et al. (1987) however, that fullerenes may be formed when H and O are present. It has been pointed out as well (Kroto and Jura, 1992) the formation of fullerenes in space in relation to carbon dust.

Fullerenes may be formed in small amounts in envelopes of R Coronae Borealis stars (Goeres and Sedlmayr, 1992). Theoretical models show the possible formation of fullerenes in the diffuse interstellar gas with the help of formation of C_2-C_{10} chains from C^+ insertion, ion-molecule reactions, and neutral-neutral reactions (Bettens and Herbst, 1996, 1997).

Interstellar hydrogenated fulleranes (molecules such as family $C_{60}H_m$, m=1,2,...) have been discussed in Webster (1995), and C_{60}^+H was proposed to be most abundant of such molecules in space (Kroto and Jura, 1992). Iglesias-Groth and Breton (2000) suggested that suitable astronomical targets to search for fullerenes are not only carbon stars but also post-AGB stars, protoplanetary nebulae and dusty regions in the Galaxy.

5. DIFFUSE INTERSTELLAR BANDS, SPECTRA AND FULLERENES

One of the great unsolved astrophysical problems is the problem of the identification of the Diffuse Interstellar Bands (DIB) carriers (see Herbig, 1995 for a review). It was proposed in Kroto et al. (1985) and Leger et al. (1988) that the ion C_{60} is a possible DIB carrier. Foing and Ehrenfreund (1994, 1997) searched for C_{60}^+ in the diffuse medium in the infrared. They found two diffuse bands at 957.7 nm and 963.2 nm, in the spectra of 7 carbon rich stars, and in 1997 they proved that the positions of these bands in stellar spectra are coincident within 0.1 percent with laboratory measurements of C_{60}^+ in neon matrix, obtained by Fullara et al. (1993). This was the first evidence of the possible presence of C_{60}^+ around carbon rich stars.

This result motivated Moutou et al. (1999) to use ISO data to search for 7.1 and 7.5 micrometers vibrational emission lines of C_{60}^+ in NGC 7023. They placed an upper limit on C_{60}^+ in NGC 7023 of ¡ 0.3% of interstellar carbon (Moutou et al, 1999; see also Sellgren, 2001). Searches for C_{60} in the interstellar matter througth its UV absorption band at 386 nm, have placed limits of ¡ 0.01% of cosmic carbon abundance in C_{60} (Snow and Seab, 1989; Somerville and Bellis, 1989).

Garcia-Lario et al. (1999) attribute the 21 micrometer dust features observed in the C-rich protoplanetary nebula IRAS 16594-4656 to fullerenes, which may be formed during dust fragmentation. However, many different carrier species have been proposed for this broad strong emission band (e.g. Webster, 1991, 1993, 1995; Hill et al, 1998, see also Ehrenfreund and Charnley, 2000).

Another family of fullerenes which could be relevant to clarify the origin of the DIBs and the unidentified infrared emissions in astronomical objects are the buckyonions or multishell fullerenes (see e.g. Iglesias-Groth and Breton, 2000).

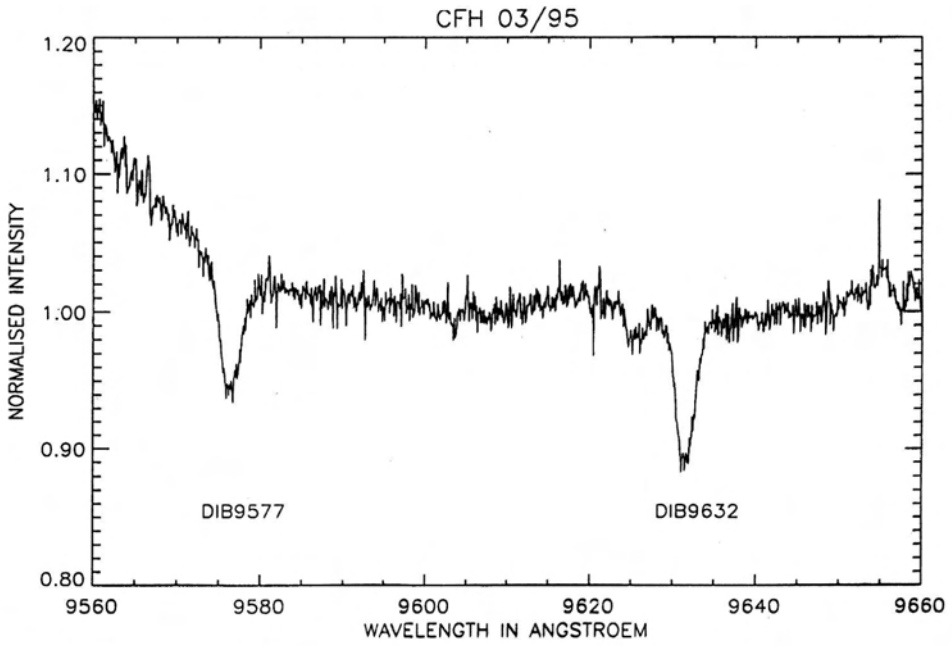

Figure 2: Telluric corrected spectrum of HD183143 carbon rich star observed by Canadian French Telescope at Hawai (CFT) in March 1995. The two DIB's at 9577 and 9632 Å are confirmed with the same width of 2.86 Å consistent with the C_{60}^+ assignment and expected rotational contour broadening with temperature 60±10 K. This Fig. is from Foing and Ehrenfreund (1997) article with the first possible confirmation of the presence of C_{60}^+ ion in carbon rich star spectra.

It was demonstrated as well that doping of C_{60} with C_{70} provokes interesting changements in the spectrum. It has been stated in Pichler et al. (1991), that the optical absorption spectrum of the C_{60}/C_{70} mixture is qualitatively similar with the interstellar extinction curve for photon energies less than 4 eV, so that carbon clusters might be present in space as well as C_{60} and C_{70} mixture. In any case, the investigation of the spectral properties of the C_{60} and C_{70} mixtures in different proportions, with eventual addition of other fullerenes, will contribute to to our knowledge on the fullerene abundance in space.

References

Alexander, A.J., Kroto, H.W., Walton, D.R.M.: 1976, *J. Mol. Spectrosc.*, **62**, 175.
Allamandola, L.J., Tielens, A.G., Barker, J.R.: 1985, *Astrophys. J.*, **290**, L25.
Avery, L.W., Broten, N.W., MacLeod, J.M., Oka, T., Kroto, H.W.: 1976, *Astrophys. J.*, **205**, L173.
Becker, L.: 1999, *Astrophys. Space Sci. Libr.*, **236**, 377.
Becker, L., Bunch, T.E.: 1997, *Meteoritics*, **32**, 479.
Becker, L., Bunch, T.E., Allamandola, L.J.: 1999, *Nature*, **400**, 228.

Becker, L., McDonald, G.D., Bada, J.L.: 1993, *Nature*, **361**, 595.
Becker, L., Poreda, R., Bunch, T.E.: 2000, *Proc. Nat. Acad. Sci.*, **97**, 2979.
Becker, L. et al.: 1994, *Science*, **265**, 642.
Becker, L. et al.: 2000, *Proc. Natl. Acad. Sci. USA*, **97**, 2979.
Becker, L. et al.: 2001, *Science*, **291**, 1530.
Bell, M.B., Kwok, S., Feldman, P.A., Matthews, H.E.: 1982, *Nature*, **295**, 389.
Bettens, P.R., Herbst, E.: 1996, *Astrophys. J.*, **468**, 686.
Bettens, P.R., Herbst, E.: 1997, *Astrophys. J.*, **478**, 585.
Botta, O., Bada, J.L.: 2002, *Surveys in Geophysics*, **23**, 411.
Broten, N.W., Oka, T., Avery, L.W., MacLeod, J.M., Kroto, H.W.: 1978, *Astrophys. J.*, **223**, L105.
Čelebonović, V.: 1992, *Bull. Astron. Belgrade*, **146**, 41.
Cheung, A.C., Rank, D.M., Avery, L.W., Townes, C.H., Thornton, D.C., Welch, W.J.: 1968, *Phys. Rev. Lett.*, **21**, 1701.
Cheush, I.: 1999, *Aerospace Research in Bulgaria*, **15**, 157.
de Vries, M.S., Reihs, K., Wendt, H.R., Golden, W.G., Hunziker, H.E., Fleming, R., Peterson, E., Chang, S,: 1993, *Geochimica et Cosmochimica Acta*, **57**, 933.
Di Brozolo, F.R., Bunch, T.E., Fleming, R.H., Macklin, J.: 1994, *Nature*, **369**, 6475.
Ebbesen, T.W., Ajayan, P.M.: 1992, *Nature*, **358**, 2200.
Ehrenfreund, P., Charnley, S.B.: 2000, *Ann. Rev. Astron. Astrophys.*, **38**, 427.
Foing, B.H., Ehrenfreund, P.: 1994, *Nature*, **369**, 296.
Foing, B.H., Ehrenfreund, P.: 1997, *Astron. Astrophys.*, **317**, L59.
Fulara, J., Jakobi, M., Maier, J.P.: 1993, *Chem. Phys. Lett.*, **211**, 227.
Garcia-Lario, P., Manchado, A., Ulla, A., Manteiga, M.: 1999, *Astrophys. J.*, **513**, 941.
Gerhardt, P., Loffler, S., Homann, K.P.: 1987, *Chem. Phys. Lett.*, **137**, 306.
Goeres, A., Sedlmayr, E.: 1992, *Astron. Astrophys.*, **265**, 216.
Herbig, E.: 1975, *Astrophys. J.*, **196**, 129.
Herbig, G.H.: 1995, *Ann. Rev. Astron. Astrophys.*, **33**, 19.
Hill, H.G.M., Jones, A.P., d'Hendecourt, L.B.: 1998, *Astron. Astrophys.*, **336**, L41.
Hufman, D.R.: 1977, *Adv. Phys.*, **26**, 129.
Iglesias-Groth, S., Breton, J.: 2000, *Astron. Astrophys.*, **357**, 782.
Kirby, C., Kroto, H.W., Walton, D.R.M.: 1980, *J. Mol. Spectrosc.*, **83**, 26.
Krätschmaher, W., Lamb, L.D., Frostiropulos, K., Huffman, D.R.: 1990a, *Nature*, **347**, 354.
Krätschmaher, W. et al.: 1990b, in *Dusty Objects in the Universe*, Kluwer, Dordrecht, 89.
Kroto, H.W.: 1981, *Int. Rev. Phys. Chem.*, **1**, 309.
Kroto, H.W.: 1982, *Chem. Soc. Rev.*, **11**, 435.
Kroto, H.W., Heath, J.R., O'Brien, S.C., Curl, R.F., Smalley, R.E.: 1985, *Nature*, **318**, 162.
Kroto, H.W., Heath, J.R., O'Brien, S.C., Curl, R.F., Smalley, R.E.: 1987, *Astrophys. J.*, **314**, 352.
Kroto, H.W., Jura, M.: 1992, *Astron. Astrophys.*, **263**, 275.
Kroto, H.W., Kirby, C., Walton, D.R.M., Avery, L.W., Broten, N.W., Mac Leod, J.M., Oka, T.: 1978, *Astrophys. J.*, **219**, L133.
Kroto, H.W., Mc Kay, K.: 1988, *Nature*, **331**, 328.
Leger, A., d'Hendecourt, L., Verstraete, L., Schmidt, W.: 1988, *Astron. Astrophys.*, **203**, 415 .
Léger, A., Puget, J.L.: 1984, *Astron. Astrophys. Lett.*, **137**, L5.
Moutou, C., Sellgren, K., Verstraete, L., Léger, A.: 1999, *Astron. Astrophys.*, **347**, 949.
Pichler, K., Graham, S., Gelsen, O.M., et al.: 1991, *J. Phys. Cond. Matter*, **3**, 9259.
Pizzarello, S. et al.: 2001, *Science*, **293**, 2236.
Sellgren, K.: 2001, *Spectrochimica Acta A*, **57**, 627.
Snow, T.P., Seab, C.G.: 1989, *Astron. Astrophys.*, **213**, 291.
Somerville, W.B., Bellis, J.G.: 1989, *Monthly Notices of The Royal Astronomical Society*, **240**, P41.
Turner, B.E.: 1989, *Space Sci. Rev.*, **51**, 235.

Ugarte, D.: 1992, *Nature*, **359**, 707.
Ugarte, D.: 1993, *Europhys. Lett.*, **22**, 45.
Webster, A.S.: 1991, *Nature*, **352**, 412.
Webster, A.S.: 1993, *Monthly Notices of The Royal Astronomical Society*, **263**, 385.
Webster, A.: 1995, in *Diffuse Interstellar Bands*, eds. A. Tielens, T. Snow, Kluwer, 349.
Weiss, F.D. et al.: 1988, *J. Am. Chem. Soc.*, **110**, 4464.

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БЕОГРАДСКА АСТРОНОМСКА ОПСЕРВАТОРИЈА У 2001. ГОДИНИ

МИЛАН С. ДИМИТРИЈЕВИЋ

Астрономско друштво "Руђер Бошковић", 11000 Београд, Србија

Резиме. Дат је преглед активности сарадника Астрономске опсерваторије у Београду и важнијих дешавања у 2001. години.

С обзиром да од стране новог главног и одговорног уредника издања Астрономске опсерваторије није било разумевања за објављивање публикације о Београдској астрономској опсерваторији у 2001. години, овде се у скраћеном облику дају подаци од интереса за историју наше најстарије астрономске установе.

У 2001. години, сарадници Астрономске опсерваторије објавили су 95 библиографских јединица као резултат свога научног рада. Од тога је 24 рада објављено у међународним часописима, 3 у књигама међународних издавача, 8 у националним часописима, 3 у циркуларима, 3 су прегледне и монографске публикације, а било је и 10 позваних предавања и 25 прилога на међународним конференцијама, 2 предавања по позиву и 11 прилога на националним конференцијама. Одбрањене су 4 магистарске и 2 докторске тезе.

Штампане су Публикације број 70 и 71 и Serbian Astronomical Journal 162 и 163. Наша издања шаљу се у 133 институције у 46 земаља и 15 институција и библиотека у нашој земљи. Издата је видеокасета са ТВ серијом од две епизоде "Астрономска опсерваторија". За ову сврху Општина Звездара дала је 15000 дин, на чему се посебно захваљујемо њеном председнику Петру Моравцу.

Сарадници Опсерваторије објавили су 1 уџбеник, 16 прилога у новинама и часописима, 1 превод, 2 интервјуа а у овом тексту је регистровано и 11 емисија на радију и телевизији. На Опсерваторији је одржано 23 предавања а сарадници су 39 пута били предавачи изван ове установе, доприносећи културном животу у нашој средини.

На 12 конференција у иностранству 7 људи је укупно учествовало 15 пута а на 6 конференција у земљи, 7 људи 10 пута.

Надамо се да ће комплетна библиографија радова и других прилога, као и опис различитих активности, допринети бољем познавању и разумевању овог периода историје наше најзначајније астрономске институције.

Да би се бар делимично одржао континуитет са публикацијама о Београдској астрономској опсерваторији за 1995 - 2000, осим буџета, који је овога пута на српском, пошто је од већег значаја за истраживаче у нашој средини, остали прилози су у истом облику као и у ранијим годинама, односно заглавља и објашњења су првенствено на енглеском. Такође је задржана нумерација прилога из комплетно припремљене публикације за 2001, према структури претходних публикација. Пошто су из оригиналног рукописа изостављена поглавље 1. SOME OF THE MAIN RESULTS OF THE OBSERVATORY'S RESEARCH ACTIVITY, са прегледом и анализом најзначајнијих научних резултата, као и поглавље 2. EQUIPMENT AND FACILITIES, а буџет је овде представљен на српском, библиографија је нумерисана као одељак 4 према оригиналном рукопису. Такође су у одељцима 7. PUBLISHING, 9. MEMBERSHIP IN INTERNATIONAL AND NATIONAL SCIENTIFIC SOCIETIES AND BODIES, 13. INTERNATIONAL SCIENTIFIC COLLABORATION, 14.1 LECTURING ON THE UNIVERSITY LEVEL и 16. STAFF AND ORGANISATION, дате само измене и допуне у односу на 2000, као и промене настале током 2001. године. E-mail адресе су изостављене пошто то у оваквом приступу није од значаја. Поред тога, изостављена је и фото-хроника догађаја у 2001, која је требало да буде на крају, а припремљене фотографије, које је углавном снимио Миодраг Дачић, предате су Милану Радованцу за архив Астрономске опсерваторије.

Да зборник радова конференције “Развој астрономије код Срба III” не бисмо додатно оптерећивали, анализу изнетих података и њихово упоређивање са претходним и наредним (2002, 2003) годинама, препустићемо будућим истраживачима.

БУЏЕТ АСТРОНОМСКЕ ОПСЕРВАТОРИЈЕ У 2001. ГОДИНИ

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4. BIBLIOGRAPHY[1]

4.1 Articles published in international scientific journals

1. Albayrak, B, Demircan, O., Djurašević, G., Erkapić, S., Ak, H.: 2001, *A LIGHT AND PERIOD STUDY OF SV CAMELOPARDALIS*, Astronomy and Astrophysics, **376**, 158-164.
2. Ćirković, M. M., Samurović, S.: 2001, *COSMOLOGICAL CONSTANT AND THE FATE OF THE DDM THEORY*, Astronomy and Astrophysics, **373**, 377-380.
3. Dimitrijevich, M. S., Popovich, L. Ch.: 2001, *MODIFICIROVANNYJ POLUEMPIRICHESKIJ METOD RASCHETA PARAMETROV SHTARKOVSKOGO USHIRENIYA SPEKTRAL'NYKH LINIJ (OBZOR)*, Zhurnal Prikladnoj Spektroskopii, **68**, 685-690.
4. Dimitrijevich, M. S., Saha-Brecho, S.: 2001, *SHTARKOVSKOE USHIRENIE SPEKTRAL'NYKH LINIJ Ar VIII*, Zhurnal Prikladnoj Spektroskopii, **67**, 286-288.
5. Dimitrijević, M. S., Sahal-Bréchot, S.: 2002, *STARK BROADENING OF In II SPECTRAL LINES*, Physica Scripta, **65**, 83-95.
6. Djurašević, G., Rovithis-Livaniou, H., Rovithis, P.: 2000, *LONG-TERM ACTIVITY OF THE ECLIPSING BYNARY AB ANDROMEDAE*, Astronomy and Astrophysics, **364**, 543-551.
7. Djurašević, G., Rovithis-Livaniou, H., Rovithis, P., Erkapić, S., Milovanović, N.: 2001, *A PHOTOMETRIC STUDY OF THE W UMa-TYPE SYSTEM U PEGASI*, Astronomy and Astrophysics, **367**, 840-848.
8. Djurašević, G., Zakirov, M., Eshankulova, M., Erkapić, S.: 2001, *A PHOTOMETRIC STUDY OF THE MASSIVE BINARY RY Sct*, Astronomy and Astrophysics, **374**, 638-654.

[1] У публикацијама за године 1995-2000, као и у оригиналном рукопису публикације за 2001, овај одељак носи број 4, па смо га и овде задржали да би се олакшало упоређивање са прегледима за раније године и имао увид у оригиналну структуру припремљене књиге.

9. Doyle, J. G., Jevremović, D., Short, C. I., Hauschildt, P. H., Livingston, W., Vince, I.: 2001, *SOLAR Mn I 5432/5395 Å LINE FORMATION EXPLAINED*, Astronomy and Astrophysics, **369**, L13-L16.
10. Giuricin, C., Samurović, S., Girardi, M., Mezzetti, M., Marinoni, C.: 2001, *THE REDSHIFT-SPACE TWO-POINT CORRELATION FUNCTIONS OF GALAXIES AND GROUPS IN THE NEARBY OPTICAL GALAXY SAMPLE*, Astrophysical Journal, **554**, 857-872.
11. Jankov, S., Vakili, F., Domiciano de Souza Jr., A., Janot-Pacheco, E.: 2001, *INTERFEROMETRIC-DOPPLER IMAGING OF STELLAR SURFACE STRUCTURE*, Astronomy and Astrophysics, **377**, 721-734.
12. Knežević Z., Milani, A.: 2001, *SYNTHETIC PROPER ELEMENTS FOR OUTER MAIN BELT ASTEROIDS*, Celestial Mechanics and Dynamical Astronomy, **78**, 17-46.
13. Milosavljević, V., Dimitrijević, M. S., Djeniže, S.: 2001, *STARK WIDTHS OF THE Ne II, Ne III, AND Ne IV SPECTRAL LINES*, Astrophysical Journal Supplement Series, **135**, 115-124.
14. Milovanović, N., Popović, L. Č., Dimitrijević, M. S.: 2000, *BELDATA - THE DATABASE OF BELGRADE ASTRONOMICAL OBSERVATORY*, Baltic Astronomy, **9**, 595-598.
15. Popović, L. Č., Mediavilla, E. G., Muñoz, J. A.: 2001, *THE INFLUENCE OF MICROLENSING ON SPECTRAL LINE SHAPES GENERATED BY A RELATIVISTIC ACCRETION DISC*, Astronomy and Astrophysics, **378**, 295-301.
16. Popović, L. Č., Milovanović, N., Dimitrijević, M. S.: 2001, *THE ELECTRON-IMPACT BROADENING EFFECT IN HOT STAR ATMOSPHERES: THE CASE OF SINGLY- AND DOUBLY-IONIZED ZIRCONIUM*, Astronomy and Astrophysics, **365**, 656-659.
17. Popović, L. Č., Milovanović, N., Dimitrijević, M. S.: 2000, *THE IMPORTANCE OF ELECTRON-IMPACT BROADENING IN HOT STAR ATMOSPHERES: THE CASE OF Zr II AND Zr III LINES*, Baltic Astronomy, **9**, 656-657.
18. Popović, L. Č., Simić, S., Milovanović, N., Dimitrijević, M. S.: 2001, *STARK BROADENING EFFECT IN STELLAR ATMOSPHERES: Nd II LINES*, Astrophysical Journal Supplement Series, **135**, 109-114.
19. Popović, L. Č., Stanić, N., Kubičela, A., Bon, E.: 2001, *THE STRUCTURE OF THE AKN 120 EMITTING REGION: THE LINE SHAPES AND LONG-TERM H beta LINE PROFILE VARIATION*, Astronomy and Astrophysics, **367**, 780-787.
20. Srećković, A., Dimitrijević, M. S., Djeniže, S.: 2001, *STARK BROADENING IN O III SPECTRUM*, Astronomy and Astrophysics, **371**, 354-359.
21. Tankosić, D., Popović, L. Č., Dimitrijević, M. S.: 2000, *STARK BROADENING OF HEAVY ELEMENT SPECTRAL LINES IN HOT STARS: Au II, Co II, Ti II AND Co III*, Baltic Astronomy, **9**, 662-663.

22. Tankosić, D., Popović, L. Č., Dimitrijević, M. S.: 2001, *ELECTRON-IMPACT BROADENING PARAMETERS FOR Ra II SPECTRAL LINES*, Physica Scripta, **63**, 54-61.
23. Tankosić, D., Popović, L. Č., Dimitrijević, M. S.: 2001, *ELECTRON - IMPACT STARK BROADENING PARAMETERS FOR Ti II AND Ti III SPECTRAL LINES*, Atomic Data and Nuclear Data Tables, **77**, 277-310.
24. Vokrouhlický D., Brož, M., Farinella, P., Knežević, Z: 2001, *YARKOVSKY-DRIVEN LEAKAGE OF KORONIS FAMILY MEMBERS AND THE CASE OF 2953 VYSHESLAVIA*, Icarus **150**, 78-93.

4.2 Contributed papers in proceedings of international conferences published by international publishers

1. Ćirković, M. M., Samurović, S., Milošević-Zdjelar, V.: 2001, *QSO ABSORPTION LINES, GASEOUS INFALL AND STAR FORMATION*, Proceedings of the conference "Galaxy Disks and Disk Galaxies", eds. J. G. Funes, S. J. and E. M. Corsini, ASP Conference Series, Astronomical Society of Pacific, **230**, 627-628.
2. Ćirković, M. M., Samurović, S., Milošević-Zdjelar, V.: 2001, *MICROLENSING RESULTS AND REMOVING THE BARYONIC DEGENERACY*, Proceedings of the conference "Gravitational Lensing: Recent Progress and Future Goals", eds. T. G. Brainerd, C. S. Kochanek, ASP Conference Series, Astronomical Society of the Pacific, **237**, 253-254.
3. Milošević-Zdjelar, V., Samurović, S., Ćirković, M. M.: 2001, *MICROLENSING, FLATTENING, Ω_B AND h: FROM ASSUMPTIONS, VIA DATA TO TENTATIVE CONCLUSIONS*, Proceedings of the conference "Gravitational Lensing: Recent Progress and Future Goals", eds. T. G. Brainerd, C. S. Kochanek, ASP Conference Series, Astronomical Society of the Pacific, **237**, 265-266.

4.3 Articles in national scientific journals and books

1. Ćirković, M. M., Radujkov, M.: 2001, *ON THE MAXIMAL QUANTITY OF PROCESSED INFORMATION IN THE PHYSICAL ESCHATOLOGICAL CONTEXT*, Serbian Astronomical Journal, **163**, 53-56.
2. Dimitrijević, M. S., Manimanis, V. N.: 2001, *TO ASTEROSKOPEIO TOU BELIGRADIOU*, Periskopio (Athens), No 246, January 2001, 88-93.
3. Dimitrijević, M. S., Sahal - Bréchot, S.: 2001, *STARK BROADENING PARAMETER TABLES FOR In II* (Part II), Serbian Astronomical Journal, **163**, 35-47.
4. Ninković, S.: 2001, *AN ALTERNATIVE MASS MODEL FOR GALACTIC DARK CORONAE*, Serbian Astronomical Journal, **163**, 1-3.
5. Olević, D., Jovanović, P.: 2001, *A FIRST AND 11 RECALCULATED ORBITS OF DOUBLE STARS*, Serbian Astronomical Journal, **163**, 5-19.

6. Popović, G. M.: 2001, *MICROMETER MEASUREMENTS OF DOUBLE STARS (Series 53)*, Serbian Astronomical Journal, **163**, 49-51.
7. Popović, G. M., Olević, D., Pavlović, R., Jovanović, P.: 2001, *THE ANALYSIS OF TOTAL SOLAR ECLIPSE OBSERVATIONS ON AUGUST 11th, 1999 IN KIKINDA*, Serbian Astronomical Journal, **163**, 57-59.
8. Trajkovska, V.: 2000, *ASTRONOMSKI SADRŽAJI U UDŽBENICIMA U SRBIJI U DRUGOJ POLOVINI XIX VEKA (ASTRONOMICAL SUBJECTS IN TEXTBOOKS IN THE SECOND HALF* OF THE 19th CENTURY IN SEBIA, Flogiston, No 9, 19-49.

4.4 Review articles and monographic texts in national journals and books

1. Dimitrijević, M. S.: 2000, *BELGRADE ASTRONOMICAL OBSERVATORY IN 1999*, Publ. Astron. Obs. Belgrade, **69**, 1-154.
2. Dimitrijević, M. S.: 2001, *LINE SHAPES INVESTIGATIONS IN YUGOSLAVIA AND SERBIA V (1997-2000) (Bibliography and citation index)*, Publ. Astron. Obs. Belgrade, **70**, 1-326.
3. Dimitrijević, M. S.: 2001, *BELGRADE ASTRONOMICAL OBSERVATORY IN 2000*, Publ. Astron. Obs. Belgrade, **71**, 1-128.

4.5 Invited lectures and progress reports in international conferences

1. Dimitrijević, M. S.: 2000, *STARK BROADENING DATA FOR ASTROPHYSICAL PLASMA INVESTIGATIONS*, Joint European and National Astronomy Meeting JENAM-2000, 9th European and 5th Euro-Asian Astronomical Society Conference, 'European Astronomy at the Turn of the Millennium', Moscow, Russia, May 29 - June 3, 2000, Abstracts, European Astronomical Society, Euro-Asian Astronomical Society, 206.
2. Dimitrijević, M. S.: 2001, *SOLAR PLASMA AND STARK BROADENING INVESTIGATIONS*, Regional meeting on Solar physics: Solar researches in the South-Eastern European countries: Present and perspectives, Bucharest 24-28 April 2001, Programme and abstracts, 13.
3. Dimitrijević, M. S.: 2001, *ASTRONOMY IN SERBIA*, Balkan Meeting of Young Astronomers, 25-29 September 2000, Belogradchik, Bulgaria, Proceedings, eds. A. Antov, R. Konstantinova-Antova, R. Bogdanovski, M. Tsvetkov, Bulgarian Academy of Sciences, Institute of Astronomy, Belogradchik Astronomical Observatory, Belogradchik, 2001, 20-33.
4. Dimitrijević, M. S.: 2001, *STARK BROADENING IN ASTROPHYSICS*, The Physics of Ionized Gases: invited lectures, topical invited lectures and progress reports, 20th SPIG - 20th Summer School and International Symposium on the Physics of Ionized Gases 4-8 September 2000, Zlatibor, eds. N. Konjević, Z. Petrović, G. Malović, Sveske Fizičkih nauka - SFIN, Series A: Conferences, No A1, Institute of Physics, Belgrade, 433-452.

5. Jevremović, D.: 2001, *BALMER LINES IN STELLAR FLARES*, The Physics of Ionized Gases: invited lectures, topical invited lectures and progress reports, 20th SPIG - 20th Summer School and International Symposium on the Physics of Ionized Gases 4-8 September 2000, Zlatibor, eds. N. Konjević, Z. Petrović, G. Malović, Sveske Fizičkih nauka - SFIN, Series A: Conferences, No A1, Institute of Physics, Belgrade, 465-480.
6. Knežević, Z.: 2001, *CHAOS IN THE MOTION OF ASTEROIDS*, 5th Hellenic Astronomical Conference organized by the Hellenic Astronomical Society 20 - 22 September 2001, Fodele Crete, Hellas, Book of abstracts, 1.
7. Mihajlov, A. A., Dimitrijević, M. S., Ignjatović, L.: 2001, *INFLUENCE OF CHEMI-IONIZATION AND CHEMI-RECOMBINATION PROCESSES ON THE PLASMA KINETICS IN THE SOLAR ATMOSPHERE*, Regional meeting on Solar physics: Solar researches in the South-Eastern European countries: Present and perspectives, Bucharest 24-28 April 2001, Programme and abstracts (2001), 15.
8. Mijatović, M., Trajkovska, V.: 2001, *MAKSIM TRPKOVIĆ AND THE REFORM OF THE JULIAN CALENDAR*, Balkan Meeting of Young Astronomers, 25-29 September 2000, Belogradchik, Bulgaria, Proceedings, eds. A. Antov, R. Konstantinova-Antova, R. Bogdanovski, M. Tsvetkov, Bulgarian Academy of Sciences, Institute of Astronomy, Belogradchik Astronomical Observatory, Belogradchik, 2001, 34-42.
9. Popović, L. Č., *MICROLENSING INFLUENCE ON SPECTRAL LINE SHAPES OF AGNs: ACCRETION DISK RADIATION*, Balkan Meeting of Young Astronomers, 25-29 September 2000, Belogradchik, Bulgaria, Proceedings, eds. A. Antov, R. Konstantinova-Antova, R. Bogdanovski, M. Tsvetkov, Bulgarian Academy of Sciences, Institute of Astronomy, Belogradchik Astronomical Observatory, Belogradchik, 2001, 69-78.
10. Vince, I.: 2001, *SOLAR PHYSICS DURING THE LAST THREE DECADES AT ASTRONOMICAL OBSERVATORY IN BELGRADE*, Regional meeting on Solar physics: Solar researches in the South-Eastern European countries: Present and perspectives, Bucharest 24-28 April 2001, Programme and abstracts, 13.

4.6 Contributed papers and communications in international conferences

1.Bon, E., Ćirković, M.: 2001, *NEW PROPOSITION FOR REDATING OF MITHRAIC TAUROCTONY SCENE*, Astronomische Gesellschaft, Abstract Series, **18**, 261.
2. Bon, E., Popović, L. Č., Mediavilla, E. G.: 2001, *THE SHAPE OF III Zw2 H alpha LINE: EVIDENCE OF KEPLERIAN RELATIVISTIC DISK*, Astronomische Gesellschaft, Abstract Series, **18**, 222.
3. Ćirković, M. M.: 2001, *COSMOLOGICAL FINE-TUNING, TWO VERSIONS OF THE DESIGN HYPOTHESIS AND PHYSICAL ESCHATOLOGY*, International Symposium Science and Religion: Antagonism or Complementarity?, Bucharest 8-11 Novembre 2001, 16.

4. Damljanovic, G., De Biasi, M. S.: 2001, *THE CHANGES OF PARAMETERS OF CHANDLER NUTATION AND ANNUAL OSCILLATION BY USING FEW KINDS OF POLAR MOTION DATA*, Proceedings of the "Journées 2000 Systéms de Référence Spatio -- Temporels, J2000, a fundamental epoch for origins of reference systems and astronomical models", ed. N. Capitaine, Observatoire de Paris, CNRS, Paris, France, 266 - 270.
5. Damljanovic, G., De Biasi, M. S., Gerstbach, G.: 2001, *CLASSICAL ASTROMETRY LONGITUDE AND LATITUDE DETERMINATION BY USING CCD TECHNIC*, Journées 2001 Systéms de Référence Spatio - Temporels, "Influence of geophysics, time and space reference frames on Earth rotation studies", 24 - 26 September, 2001, Royal Observatory of Belgium, Brussels.
6. Dimitrijević, M. S.: 2001, *MILUTIN MILANKOVIĆ (1879-1958) AND HIS CONTRIBUTION TO THE EUROPEAN ASTRONOMY*, Astronomische Gesellschaft, Abstract Series, **18**, 133.
7. Dimitrijević, M. S.: 2001, *DEVELOPMENT OF ASTRONOMY IN SERBIA IN THE 20th CENTURY*, Astronomische Gesellschaft, Abstract Series, **18**, 263.
8. Dimitrijević, M. S.: 2001, *SCIENCE AND RELIGION: COMPLEMENTARITY IN THE FIGHT AGAINST ASTROLOGY*, International Symposium Science and Religion: Antagonism or Complementarity?, Bucharest 8-11 Novembre 2001, 16.
9. Dimitrijević, M. S., Mihajlov, A. A.: 2001, *INFLUENCE OF ION-ATOM COLISIONAL QUASIMOLECULAR COMPLEXES ON DB WHITE DWARF PLASMA PROPERTIES*, Astronomische Gesellschaft, Abstract Series, **18**, 192.
10. Dimitrijević, M. S. Milosavljević, V., Djeniže, S.: 2001, *IONIZED NEON SPECTRAL LINES STARK WIDTHS FOR STELLAR PLASMA RESEARCH AND MODELING*, Astronomische Gesellschaft, Abstract Series, **18**, 193.
11. Dimitrijević, M. S., Srećković, A., Djeniže, S.: 2001, *STARK WIDTHS OF ASTROPHYSICALLY IMPORTANT O III SPECTRAL LINES*, Astronomische Gesellschaft, Abstract Series, **18**, 193.
12. Djordjević, R., Trajkovska, V., Ninković, S., Ćirković, M. M.: 2001, *ORIGINS OF PHILOSOPHY OF SCIENCE IN SERBIA: ENTROPY DISPUTE*, XXI International Congress of History of Science, 8-14 July, 2001, Mexico Sity. Mexico, 73.
13. Giuricin, G., Samurović, S., Girardi, M., Mezzetti, M., Marioni, C.: 2000, *CLUSTERING OF GALAXIES AND GROUPS IN THE NOG SAMPLE* Constructing the Universe with Clusters of Galaxies, IAP 2000 meeting, Paris, July 2000, eds. F. Durret, D. Gerbal, 1-7 (without numeration).
14. Jovanović, P.: 2001, *SOLAR ACTIVITY AS A CAUSE OF THE 50-DAY AND 120-DAY OSCILLATIONS IN THE EARTH'S ROTATION*, Astronomische Gesellschaft, Abstract Series, **18**, 137.
15. Knežević Z., Milani, A.: 2001, *THE HIGHLY ACCURATE ASTEROID PROPER ELEMENTS*, In: Asteroids 2001: From Piazzi to the 3rd millennium, Abstracts, 211.

16. Knežević Z., Pavlović, R.: 2001, *YOUNG AGE FOR THE VERITAS ASTEROID FAMILY CONFIRMED?*, In: Asteroids 2001: From Piazzi to the 3rd millennium, Abstracts, 212.
17. Ninković, S.: 2001, *GLOBULAR CLUSTERS INTRIGUING SUBGALAXIAN STELLAR SYSTEMS*, Balkan Meeting of Young Astronomers, 25-29 September 2000, Belogradchik, Bulgaria, Proceedings, eds. A. Antov, R. Konstantinova-Antova, R. Bogdanovski, M. Tsvetkov, Bulgarian Academy of Sciences, Institute of Astronomy, Belogradchik Astronomical Observatory, Belogradchik, 2001, 88.
18. Ninković, S.: 2001, *ON SOME CONCRETE POTENTIALS FOR SPHERICALLY SYMMETRIC STELLAR SYSTEMS*, In: Stellar Dynamics from Classic to Modern, eds. L. P. Ossipkov, I. I. Nikiforov, Sankt Petersburg State University, Sankt Petersburg, 314-316.
19. Olević, D., Cvetković, Z., Dačić, M.: 2001, *KINEMATICS OF A SAMPLE OF VISUAL DOUBLE STARS*, Balkan Meeting of Young Astronomers, 25-29 September 2000, Belogradchik, Bulgaria, Proceedings, eds. A. Antov, R. Konstantinova-Antova, R. Bogdanovski, M. Tsvetkov, Bulgarian Academy of Sciences, Institute of Astronomy, Belogradchik Astronomical Observatory, Belogradchik, 2001, 95.
20. Popović, L. Č.: 2001, *THE LINE SHAPES OF Fe K alpha AND UV LINES OF NGC 3516: THE PARAMETERS OF AN ACCRETION DISC*, Astronomische Gesellschaft, Abstract Series, **18**, 223.
21. Rovithis, P., Livaniou, H., Djurašević, G.: 2001, *THE ECLIPSING BINARY RZ Com*, Proceedings of the 4th Astronomical Conference, 16-18 September 1999, Samos, Greece, edited by J. Seimenis, 319-323.
22. Trajkovska, V.: 2001, *MAKSIM TRPKOVIĆ'S REFORM OF THE CALENDAR AND PAN-ORTHODOX CONGRESS IN CONSTANTINOPLE 1923*, XXI International Congress of History of Science, 8-14 July, 2001, Mexico Sity. Mexico, 263.
23. Vince, I.: 2001, *ABOUT THE Mn I 539.47 nm SOLAR SPECTRAL LINE*, Regional meeting on Solar physics: Solar researches in the South-Eastern European countries: Present and perspectives, Bucharest 24-28 April 2001, Programme and abstracts, 14.
24. Vince, O., Vince, I.: 2001, *TEMPERATURE SENSITIVITY DETERMINATION OF THE Mn I 539.47 nm LINE FROM SOLAR LIKE STARS SPECTRA OBSERVED AT ROZHEN OBSERVATORY*, Regional meeting on Solar physics: Solar researches in the South-Eastern European countries: Present and perspectives, Bucharest 24-28 April 2001, Programme and abstracts, 14.
25. Vitas, N., Vince, I., Vince, O.: 2001, *THE HYPERFINE PROFILE OF THE Mn I 539.47 nm SOLAR SPECTRAL LINE*, Regional meeting on Solar physics: Solar researches in the South-Eastern European countries: Present and perspectives, Bucharest 24-28 April 2001, Programme and abstracts, 14.

4.7 Invited lectures in national conferences

1.Димитријевић, М. С.: 2000, *КОСМОЛОГИЈА НА РАЗМЕЂИ МИЛЕНИЈУМА*, Зборник предавања са Републичког семинара о настави физике, Друштво физичара Србије, 18-25.
2. Димитријевић, М. С.: 2001, *АСТРОНОМИЈА У СРБА 1850-1918*, Зборник радова научног скупа "Природне и математичке науке у Срба 1850 - 1918", Нови Сад, 30 - 31. октобар 2000, САНУ - Огранак у Новом Саду, Универзитет у Новом Саду, Матица Српска, Нови Сад, 59-69.

4.8 Contributed papers and communications in national conferences

1. Димитријевић, М. С.: 2001, *ХЕМИЈА ВАСИОНЕ*, Априлски дани просветних радника Србије; Дванаести семинар за професоре хемије, Београд 9. и 10. априла 2001, Хемијски факултет и Српско хемијско друштво, Београд 2001, 5-6.
2. Dimitrijević, M., Theodossiou, E.: 2001, *CALENDAR OF THE GREEK ORTHODOX CHURCH*, 5th Hellenic Astronomical Conference organized by the Hellenic Astronomical Society 20 - 22 September 2001, Fodele Crete, Hellas, Book of abstracts, 171.
3. Jovanović, B.: 2001, *ON APPROXIMATING BY SUMS OF TRIGONOMETRIC AND EXPONENTIAL FUNCTIONS*, Proceedings of the 10th Congress of Yugoslav Mathematicians, Belgrade, 21-24.01.2001, ed. Z. Kadelburg, Faculty of Mathematics, University of Belgrade, 371-378.
4. Jovanović, P., Djurović, D., Pejović, N.: 2001, *WAVELET TRANSFORMS AND THEIR APPLICATIONS*, Proceedings of the 10th Congress of Yugoslav Mathematicians, Belgrade, 21-24.01.2001, ed. Z. Kadelburg, Faculty of Mathematics, University of Belgrade, 379-387.
5. Knežević, Z., Milani, A.: 2001, *SYNTHETIC THEORY OF ASTEROID MOTION: PROPER ELEMENTS AND CHAOS*, Proceedings of the 10th Congress of Yugoslav Mathematicians, Belgrade, 21-24.01.2001, ed. Z. Kadelburg, Faculty of Mathematics, University of Belgrade, 389-393.
6. Ninković, S.: 2001, *ON THE GALACTOCENTRIC ORBITS*, Proceedings of the 10th Congress of Yugoslav Mathematicians, Belgrade, 21-24.01.2001, ed. Z. Kadelburg, Faculty of Mathematics, University of Belgrade, 401-403.
7. Нинковић, С., Трајковска, В.: 2001, *НАСТАВА ГЕОГРАФИЈЕ У СРБИЈИ У ДРУГОЈ ПОЛОВИНИ XIX ВЕКА*, Зборник радова научног скупа "Природне и математичке науке у Срба 1850 - 1918", Нови Сад, 30 - 31. октобар 2000, САНУ - Огранак у Новом Саду, Универзитет у Новом Саду, Матица Српска, Нови Сад, 195-197.
8. Pavlović, R., Knežević, Z.: 2001, *NEKHOROSHEV STABILITY OF ASTEROID MOTION*, Proceedings of the 10th Congress of Yugoslav Mathematicians, Belgrade, 21-24.01.2001, ed. Z. Kadelburg, Faculty of Mathematics, University of Belgrade, 405-408.

9. Popović, L. Č., Dimitrijević, M. S., Simić, S., Milovanović, N.: 2001, *THE ELECTRON - IMPACT BROADENING EFFECT IN STELLAR ATMOSPHERES: RARE EARTH ELEMENTS*, 5th Hellenic Astronomical Conference organized by the Hellenic Astronomical Society 20 - 22 September 2001, Fodele Crete, Hellas, Book of abstracts, 79.
10. Rovithis - Livaniou, H., Djurašević, G., Georgiades, N., Rovithis, P., Erkapić, S.: 2001, *CAN SPOT ACTIVITY SOLVE THE PROBLEM OF ABNORMAL GRAVITY IN SEMI-DETACHED SYSTEMS?*, 5th Hellenic Astronomical Conference organized by the Hellenic Astronomical Society 20 - 22 September 2001, Fodele Crete, Hellas, Book of abstracts, 81.
11. Трајковска, В., Нинковић, С.: 2001, *ЈЕДАН ПРЕДЛОГ О РЕОРГАНИЗАЦИЈИ ТЕХНИЧКОГ ФАКУЛТЕТА ОБЈАВЉЕН У "ОДЈЕКУ" 1891.*, Зборник радова научног скупа "Природне и математичке науке у Срба 1850 - 1918", Нови Сад, 30 - 31. октобар 2000, САНУ - Огранак у Новом Саду, Универзитет у Новом Саду, Матица Српска, Нови Сад, 231-238.

4.9 Theses

1. Бон, Е.: 2001, *СТРУКТУРА ЕМИСИОНЕ ОБЛАСТИ КОД АКТИВНЕ ГАЛАКСИЈЕ III ZW 2*, Магистарска теза (M.Sc. Thesis), Математички факултет, Универзитет у Београду, 1-107.
2. Миловановић, Н.: 2001, *ДОПРИНОС ШТАРКОВОГ ШИРЕЊА ИНТЕРПРЕТАЦИЈИ СПЕКТАРА СР ЗВЕЗДА*, Магистарска теза (M.Sc. Thesis), Математички факултет, Универзитет у Београду, 1-87.
3. Самуровић, С.: 2001 *РОТАЦИОНЕ КРИВЕ СПИРАЛНИХ ГАЛАКСИЈА И МАСИВНИ НЕУТРИНИ*, Магистарска теза (M.Sc. Thesis), Математички факултет, Универзитет у Београду, 1-103.
4. Skuljan, Lj.: 2001, *R CORONAE BOREALIS STARS: CHARACTERISTICS OF THEIR DECLINE PHASE*, PhD Thesis, University of Canterbury, New Zealand, 1-225.
5. Николић, С.: 2001 *МОЛЕКУЛСКИ ОБЛАЦИ У ОБЛАСТИ ЦЕФЕЈА*, Докторска теза (PhD Thesis), Математички факултет, Универзитет у Београду, 1-133+XVII.
6. Марковић-Кршљанин, С.: 2001 *ПОЛАРИЗАЦИЈА ПРОМЕНЉИВИХ ЗВЕЗДА ПОСМАТРАНИХ СА БЕОГРАДСКЕ ОПСЕРВАТОРИЈЕ*, Магистарска теза (M.Sc. Thesis), Математички факултет, Универзитет у Београду, 1-57.

4.10 Circulars

1. Protitch-Benishek, V., Benishek, Vl.: 2001, *PRECISE CCD OBSERVATIONS OF MINOR PLANETS: 19356, 20790, 20898 DURING THE PERIOD 14-19 of JANUARY 2001*, Minor Planet Circular Nos. 42025-42026.

2. Protitch-Benishek, V., Benishek, Vl.: 2001, *PRECISE CCD ASTROMETRIC POSITIONS OF COMET C/2000 SV74 (LINEAR)*, Minor Planet Circular Nos. 43807-43809.
3. Protitch-Benishek, V., Benishek, Vl.: 2001, *PRECISE CCD ASTROMETRIC POSITIONS OF COMET C/2000 WM1 (LINEAR)*, Minor Planet Circular Nos. 43810, 43811, 43812.

4.11 Text - books

1. Милан Димитријевић, Александар Томић: Астрономија за IV разред гимназије (четврто издање) (Astronomy for IV class of the secondary school (fourth edition)), Завод за уџбенике и наставна средства, Београд, 2001, 1-134.

4.12 Contributions in newspapers, professional and popularizing literature

1. Еди Бон, Дејан Урошевић: Тотално помрачење Сунца 11. августа 1999. године - Палићко језеро (The 11th August 1999 total Solar eclipse - Palić lake), Васиона, No 1-3, 2000, 45.
2. Дарко Јевремовић: Порука г. Дарка Јевремовића из Армага Др Милану Димитријевићу (Message of Darko Jevremović from Armagh to Dr Milan Dimitrijević), Bilten, Rotary Club Belgrade Old City, No 89, 28.03.2001, 3.
3. Милан М. Ћирковић, Весна Милошевић-Здјелар, Дејан Илић: Међузвездана материја од А до Б. I део: Фазе међузвездане материје и молекулски гас (Interstellar matter from A to B. The first part: Phases of interstellar matter and molecular gas), Васиона, No 1-2, 2001, 19.
4. Милан М. Ћирковић: Амир Д. Ацел: Божија једначина, Поларис, Београд, 2000 (Amir D. Acel: The equation of God, Polaris, Belgrade, 2000), Васиона, No 1-2, 2001, 33.
5. Милан С. Димитријевић: Летње рачунање времена у 2001 години (The summer time in 2001), Васиона, No 1-2, 2001, 44.
6. Милан С. Димитријевић: Поздравна беседа председника 2001/2002. на примопредаји дужности 27. јуна 2001. (Greeting speech of president 2001/2002 on the inauguration on 27. june 2001), Bilten No 103, Rotary club Belgrade Old city, 4.07.2001, 3.
7. Одабрао (choosen by) Милан С. Димитријевић: Мало поезије (Мали човек..., Гордана Нинковић, Сав космос..., Издишем спокој..., Ања Аранђеловић) (Some poetry (Little man..., Gordana Ninković, All universe..., I expire tranquility..., Anja Arandjelović)), Васиона, No 3, 2001, 76.
8. Милан С. Димитријевић: Физика прионских болести (Physics of prionic deseases), Bilten No 107 (108), Rotary club Belgrade Old city, 8.08.2001, 2.
9. Милан С. Димитријевић: Канарска острва (Canary islands), Bilten No 107 (108), Rotary club Belgrade Old city, 8.08.2001, 3.

10. Милан С. Димитријевић: Александар Саша Поповић, Васиона, No. 4, 2001, 98.
11. Милан С. Димитријевић: Потпуно помрачење Сунца 11. августа 1999. и активности наших чланова у медијима (Total Solar Eclipse of 11 August 1999 and Activities of our Fellows in Media), Васиона, No. 5, 2001, 117.
12. Милан С. Димитријевић Мало поезије: Гордан Ранитовић Златни извор; Откривање тајни (Some Poetry: Gordan Ranitović Golden source; Discovery of Secrets), Bilten, Rotary Club Belgrade Old City, No 113, 12.09.2001, 21.
13. Милан С. Димитријевић: Предавање Проф. Милана Димитријевића од 17. октобра 2001. године; Нобелова награда за физику 2001; Нобелова награда за физику 2001 и велики праскови у течном хелијуму (The lecture of Prof. Milan Dimitrijević from 17th October 2001 year; The Nobel prize for Physics for 2001; The Nobel prize for Physics for 2001 and Big Bangs in liquid Helium), Bilten, Rotary Club Belgrade Old City, No 119, 31.10.2001, 6.
14. Милан С. Димитријевић: Текст предавања Проф. Милана С. Димитријевића; Ђорђе Станојевић први српски астрофизичар (The text of the lecture of Prof. Milan Dimitrijević; Djordje Stanojević the first serbian astrophysicist, Bilten, Rotary Club Belgrade Old City, No 122, 21.11.2001, 3.
15. Milan S. Dimitrijević: Milorad B. Protitch (1911-2001), Newsletter, European Astronomical Society, No. 22, December 2001, 15.
16. Лука Ч. Поповић: Тамна материја у васиони (Dark matter in the Universe), Bulletin of the Rotary club Belgrade - Old City, No 82, 7.02.2001, 2.

4.13 Translations

1. Alejandro Oscoz Abad (Translated by Luka Č. Popović): НЕО (Објекти у близини Земље) (NEO (Near Earth Objects)), Васиона, No. 4, 2001, 77.

4.14 Interviews

1. Слободанка Андрић: Галаксија и земаљске катастрофе; Нису нестали само диносауруси (The Galaxy and Earth's catastrophies; Not only dinosauri have disapeard), (Милан М. Ћирковић), Политика, 11.11.2001, 12.
2. Слободанка Андрић: Галаксија и земаљски катастрофизам; Велика гужва у свемиру (The Galaxy and Earth's catastrophysm; Big crowd in Space), (Милан М. Ћирковић), Политика, 12.11.2001, 12.

4.15 Articles in newspapers on astronomical observatory, its activity and activity of its fellows

1. У овом броју (In this number), (Милан С. Димитријевић, Лука Ч. Поповић), Bulletin of the Rotary club Belgrade - Old City, No 78, 10.01.2001, 2.
2. Šta se događalo u prvoj polovini Rotarijanske 2000/2001. godine (What happened in the first half of the Rotarian year 2000/2001), (Милан С.

Димитријевић, Дарко Јевремовић), Bulletin of the Rotary club Belgrade - Old City, No 79, 17.01.2001, 2.
3. У овом броју (In this number), (Милан С. Димитријевић, Лука Ч. Поповић), Bulletin of the Rotary club Belgrade - Old City, No 82, 7.02.2001, 2.
4. M. E. Bailey: Poziv Prof. Dimitrijeviću iz Armagh opservatorije (Invitation for Prof. Dimitrijević from Armagh observatory), (Milan S. Dimitrijević), Bulletin of the Rotary club Belgrade - Old City, No 82, 7.02.2001, 10.
5. Проф. Др Бранислав М. Шеварлић (Читуља) (Certificate of death), (Astronomical Observatory), Политика 15.03.2001.
6. Слободанка Андрић: Смена годишњих доба на Северној Земљиној полулопти; Данас почиње пролеће (The change of seasons on the Earth's North hemispheres; Today begins the spring), (Миодраг Дачић), Политика, 20.03.2001, 12.
7. Скупштина града Београда и Политика обавештавају вас о културним манифестацијама идуће недеље у Београду. Задужбина Илије М. Коларца. Сала "Јосиф Панчић" (Assembly of the city of Belgrade and "Politika" inform you on the cultural manifestations in Belgrade. Foundation of Ilija M. Kolarac. Hall "Josif Pančić"), (Еди Бон, Милан С. Димитријевић, Лука Ч. Поповић), Политика, 1.04.2001, 31.
8. Задужбина Илије М. Коларца. Сала "Јосиф Панчић" (Foundation of Ilija M. Kolarac. Hall "Josif Pančić"), (Еди Бон, Милан С. Димитријевић, Лука Ч. Поповић), Политика, 5.04.2001, 29.
9. Јелена Милоградов-Турин: Семинар катедре за астрономију (Seminar of the Department of astronomy), (Иштван Винце), Васиона, No 1-2, 2001, 39.
10. Петар Вуца: Годишњица потпуног помрачења Сунца (Aniversary of the total Solar eclipse), (Милан С. Димитријевић, Лука Ч. Поповић), Васиона, No 1-2, 2001, 39.
11. Милан Јеличић: II летњи астрономски сусрети (II summer astronomical meetings), (Лука Ч. Поповић, Милан С. Димитријевић, Милан М. Ћирковић, Ненад Миловановић), Васиона, No 1-2, 2001, 41.
12. Слободанка Андрић: У Астрономској опсерваторији на Звездари; Годишњица колевке српске науке (In Astronomical observatory on Zvezdara Anniversary of the craddle of Serbian science), (Милан С. Димитријевић, Милорад Протић, Дарко Јевремовић, Александар Кубичела), Политика, 7.04.2001, 15.
13. Маринко Бошњак едитор: Центар за развој и економску политику 1992-1997, У: 55 година планирања: 1946-2000 (Center for development and economical policy1992-1997, In: 55 years of planing: 1946-2000), (Милан С. Димитријевић), Савезни завод за економску политику, Београд, 2001, 111.
14. M. Breger: Wien, Institut für Astronomie der Universität Wien, (Milan S. Dimitrijević), Mitteilungen der Astronomischen Gesellschaft, No 82, Hamburg 1999; (Gäste, 723), 721.
15. M. Breger: Wien, Institut für Astronomie der Universität Wien, Mitteilungen der Astronomischen Gesellschaft, No 83, Hamburg 2000 (Gäste, 749), 747.

16. Танјуг: Одлуком Владе Републике Србије; Нови споменици културе (By the decision of the Government of Republic of Serbia; New monuments of culture), (Belgrade Astronomical Observatory), Политика, 12.06.2001, 16.
17. Government of Republic of Serbia, vice president Žarko Korać: Odluka o utvrdjivanju Astronomske opservatorije u Beogradu za spomenik kulture (Decision on the proclamation of Belgrade Astronomical observatory for cultural heritage monument), Службени гласник Републике Србије, No 32, 7.06.2001, 27.
18. Александар Правдић: Решење о именовању чланова Управног одбора Физичког факултета у Београду (Decision on the nomination of Directorial board members of the Faculty of Physics in Belgrade), (М. С. Димитријевић), Службени гласник Републике Србије, No 38, 29.06.2001, 36.
19. Обавештење о покретању поступка за избор у звање (Anouncement on candidates for new academic ranks), (Предраг Јовановић, Миодраг Дачић, Дарко Јевремовић, Лука Поповић), Политика, 6.07.2001, 24.
20. И. Цветковић: Најстарија научна институција у Београду од посебног националног значаја, запуштена и руинирана; Опсерваторија усред депоније (Oldest scientific institution in Belgrade of particular national interest, uncared-for and ruined; Observatory in the middle of rubbish-heap), (M. S. Dimitrijević, L. Č. Popović (on the photo), V. Protić-Benišek (on the photo)), Блиц, 9.07.2001, 26.
21. М. Богдановић: На врху града; Звездарница окружена депонијама (On the top of the city; Observatory surrounded with rubbish heap, (М. С. Димитријевић), Политика, 10.07.2001, 15.
22. ДСЋ: Министар Драган Домазет у посети Опсерваторији на Звездари; Буџет не покрива основне трошкове (Minister Dragan Domazet in visit on Observatory on Zvezdara; Budget do not cover basic expences), (M. S. Dimitrijević, L. Č. Popović (on the photo)), Глас Јавности, 10.07.2001, 13.
23. Ј. Јевтовић: Астрономска опсерваторија кубури са беспарицом; И звезде паре траже (Astronomical observatory make hardly both ends meet due to shortage of money; Stars also ask money), (М. С. Димитријевић), Вечерње Новости, 10.07.2001, 15.
24. Милан Јеличић: Митологија и космологија (Mithology and Cosmology), (М. М. Ћирковић), Васиона, No 3, 2001, 68.
25. Милан Јеличић: Шта нам причају астрономски спектри? (What tel us astronomical spectra?), (М. С. Димитријевић, Л. Ч. Поповић, Е. Бон), Васиона, No 3, 2001, 68.
26. Милан Јеличић: Одбрана магистарске тезе (Defense of M.Sc thesis), (С. Самуровић), Васиона, No 3, 2001, 69.
27. Милан Јеличић: Обележена 114. годишњица Астрономске опсерваторије (Marked 114 aniversary of Astronomical Observatory), (М. С. Димитријевић, Д. Јевремовић, А. Кубичела, М. Дачић), Васиона, No 3, 2001, 70.

28. Милан Јеличић: Нови продори савремене космологије (New achievments of the contemporary cosmology), (М. М. Ћирковић, С. Нинковић), Васиона, No 3, 2001, 68.
29. Јарослав Францисти: Свечано отварање планетаријума на Петроварадинској тврђави (Solemn opening of Planetarium on Petrovaradin forteress), (М. С. Димитријевић, Л. Ч. Поповић), Васиона, No 3, 2001, 71.
30. Сарадници: 18. Београдски астрономски викенд (18. Belgrade astronomical weekend), (M. S. Dimitrijević, I. Vince, A. Kubičela, G. Popović, S. Ninković. Only on the photo: L. Č. Popović, N. Vranešević, N. Stanić), Васиона, No 3, 2001, 73.
31. Владимир Ћулум: Настанак звезда из међузвездане материје (Creation of stars from interstellar matter), (М. М. Ћирковић), Васиона, No 3, 2001, 68.
32. В.Б.Б.: Занимљиво предавање о универзуму; Зашто је ноћно небо тамно? (An interesting lecture on the Universe; Why the night sky is dark?), (М. С. Димитријевић), Наша Реч, Лесковац, 13.07.2001, 7.
33. Јован Миљковић: Астрономско друштво у Лесковцу (Astronomical society in Leskovac), (М. С. Димитријевић), Политика, 20.07.2001, 21.
34. Александар Правдић: Решење о разрешењу чланова Управног одбора Астрономске опсерваторије у Београду (Decision on dismissal of Directorial board members of the Belgrade Astronomical observatory), (Г. Поповић, Л. Ч. Поповић, И. Винце, С. Јанков), Службени гласник Републике Србије, No 43, 17.07.2001, 14.
35. Александар Правдић: Решење о именовању чланова Управног одбора Астрономске опсерваторије у Београду (Decision on the nomination of Directorial board members of the Belgrade Astronomical observatory), (Г. Поповић, Л. Ч. Поповић, И. Винце, С. Јанков), Службени гласник Републике Србије, No 43, 17.07.2001, 26.
36. Милан Р. Милановић: Предговор (Foreword), (M. S. Dimitrijević), In: Сергије Димитријевић: Структурне промене у пољопривреди Србије средином 20. века (Structure changes in Serbia's agriculture by the middle of the 20th century), Задужбина Андрејевић, Посебна издања, 29, (2001), 31.
37. Preface, (M. S. Dimitrijević), Balkan Meeting of Young Astronomers, 25-29 September 2000, Belogradchik, Bulgaria, Proceedings, eds. A. Antov, R. Konstantinova-Antova, R. Bogdanovski, M. Tsvetkov, Bulgarian Academy of Sciences, Institute of Astronomy, Belogradchik Astronomical Observatory, Belogradchik, 2001, 7.
38. Memorandum, (M. S. Dimitrijević), Balkan Meeting of Young Astronomers, 25-29 September 2000, Belogradchik, Bulgaria, Proceedings, eds. A. Antov, R. Konstantinova - Antova, R. Bogdanovski, M. Tsvetkov, Bulgarian Academy of Sciences, Institute of Astronomy, Belogradchik Astronomical Observatory, Belogradchik, 2001, 240.
39. Photos, (M. Dačić, M. S. Dimitrijević, S. Ninković, D. Olević, N. Milovanović), Balkan Meeting of Young Astronomers, 25-29 September 2000, Belogradchik, Bulgaria, Proceedings, eds. A. Antov, R. Konstantinova-Antova, R.

Bogdanovski, M. Tsvetkov, Bulgarian Academy of Sciences, Institute of Astronomy, Belogradchik Astronomical Observatory, Belogradchik, 2001, 241.
40. Јарослав Францисти: Планетаријум на Петроварадинској тврђави (The Planetarium on the Petrovaradin Forteress), (М. С. Димитријевић), Васиона, No. 4, 2001, 80.
41. Јован Миљковић: У изгледу оснивање астрономског друштва у Лесковцу (In view the foundation of Astronomical society in Leskovac), (М. С. Димитријевић), Васиона, No. 4, 2001, 99.
42. Слободанка Андрић: Професор прави Сунчане сатове; Тихи гласови времена (Professor makes Sundials; Calm voices of time), (Vojislav Mišković, Astronomical Observatory), Политика, 7.10.2001, 12.
43. Љ. Н.: Институт за Физику; Сећање на Живојина Ћулума (Institute of Physics Memories on Professor Ćulum), (Милан С. Димитријевић), Дневник, Нови Сад, 10.10.2001, 5.
44. С. Михајловић: Сећање на Живојина Ћулума (Memories on Professor Ćulum), (Милан С. Димитријевић), Грађански Лист, Нови Сад, 10.10.2001, 4.
45. Јелена Милоградов - Турин: Брдо Стојковић и историја ваздушног камења (The Hill Stojković and the History of Air Stones), (М. Дачић, М. Ђокић, Л. Ч. Поповић), Флогистон, No 11, 2001, 15.
46. Јован Д. Кечкић: О питању календара и његовој историји (The Question of Calendar and its History), (В. Трајковска), Флогистон, No 11, 2001, 47.
47. Вељко А. Вујичић: О уопштењу Њутнове силе гравитације (About Generalization of Newton's Gravitational Force), (М. Дачић, М. С. Димитријевић), Флогистон, No 11, 2001, 77.
48. Милорад Протић (Читуља) (Certificate of death), (Astronomical Observatory), Политика 31.10.2001, 27.
49. Соња Видојевић: XIX Београдски астрономски викенд (XIX Belgrade Astronomical Weekend), (М. С. Димитријевић, М. М. Ћирковић, Л. Ч. Поповић), Васиона, No. 5, 2001, 135.
50. I. A. Egorova, M. I. Ryabov: Vtoraya Odesskaya Letnyaya astronomicheskaya shkola molodykh uchenykh (The Second Odessa Summer Astronomical School of Young Scientists), (M. S. Dimitrijević), Astrokur'er, Informacionnoe izdanie Mezhdunarodnogo Astronomicheskogo Obshchestva, Oktyabr' 2001 g., 9.
51. Конкурс за избор директора Астрономске опсерваторије (Competition for the election of Astronomical Observatory Director), (Astronomical Observatory), Политика, 5.11.2001, 27.
52. Рад Академије у 2000. години; I Извршни одбор председништва; Учешће на научним скуповима, студијски боравци и предавања (Work of Academy in 2000; I Executive Board of Presidium; Participation on scientific meetings, missions and lectures), (М. С. Димитријевић, Л. Ч. Поповић), Годишњак CVII за 2000, САНУ, Београд, 2001, 92.
53. 3. Скупштине; Ванредно заседање (Assemblies; Extraordinary session), (М. С. Димитријевић), Годишњак CVII за 2000, САНУ, Београд, 2001, 133.

54. 4. Одељење за математику, физику и гео-науке; Састав и организација одељења (Department for mathematics, physics and geo-sciences; Staff and organization of Department), (М. С. Димитријевић), Годишњак CVII за 2000, САНУ, Београд, 2001, 139.
55. Сања Степановић, editor: Никола Коњевић; дописни члан (Nikola Konjević; correspondent member), (M. C. Димитријевић), Годишњак CVII za 2000, SANU, Beograd, 2001, 359.
56. Реч Уредника (Word of Editor), (G. Popović, Photo), Београдски пчелар, No 11, 2000, 122.
57. E-mail порука из Индије (E-mail message from India), (M. C. Димитријевић), Bilten, Rotary Club Belgrade Old City, No 119, 31.10.2001, 13.
58. Катица (Стевановић) Хедрих: Академик Татомир Анђелић (1903-1993) (Academician Tatomir Andjelić (1903-1993)), (M. C. Димитријевић, С. Саџаков, И. Винце), Живот и дело српских научника 6 (Life and work of serbian scientists 6), ed. M. R. Sarić, Биографије и Библиографије VI, Српска академија наука и уметности, САНУ, Београд, 2000, 435.
59. Milan Kurepa, Jaroslav Labat: History of SPIG meetings, (M. S. Dimitrijević), The Physics of Ionized Gases: invited lectures, topical invited lectures and progress reports, 20th SPIG - 20th Summer School and International Symposium on the Physics of Ionized Gases 4-8 September 2000, Zlatibor, eds. N. Konjević, Z. Petrović, G. Malović, Sveske Fizičkih nauka - SFIN, Series A: Conferences, No A1, Institute of Physics, Belgrade, 483.
60. Wolfgang R. Dick: Special Colloquium: European Astronomy in the 20th Century, (M. S. Dimitrijević, E. Bon, M. Ćirković), Newsletter, European Astronomical Society, N0 22, December 2001, 15.
61. Планете Сунчевог система; 22. октобар 1999; Амфитеатар Педагошке академије (The Planets of the Solar System; 22nd October 1999: Amphiteater of the Pedagogical Academy), (Л. Č. Поповић), ГЕА - Информативни билтен, Природњачко друштво "Геа Вршац", Вршац, No 1, 2001, 6.
62. Наташа Трифуновић: Посета XIX Београдском астрономском викенду; 23. јун 2001; Београд (The Visit to the XIX Belgrade astronomical weekend; 23th Jun 2001, Belgrade), (M. S. Dimitrijević (Photo), L. Č. Popović), ГЕА - Информативни билтен, Природњачко друштво "Геа Вршац", Вршац, No 1, 2001, 17.
63. Photo of participants, (S. Ninković), In: Stellar Dynamics from Classic to Modern, eds. L. P. Ossipkov, I. I. Nikiforov, Sankt Petersburg State University, Sankt Petersburg, page after 458.
64. Ксенија Марицки Гаћански: Антика у Југославији - Области и рецепција (Београд, 23. септембар 2000) (Antique in Yugoslavia - domains and reception (Belgrade, 23 September 2000)), (M. S. Dimitrijević), Зборник Матице српске за класичне студије, No 2, Нови Сад 2000, 236.

5. LECTURES HELD BY THE OBSERVATORY FELLOWS AND GUESTS

5.1. Lectures held at the astronomical observatory

1. 30.03.2001; Миодраг Дачић, Зорица Цветковић, Горан Дамљановић, Ђуро Божичковић: Приказ астрометријске активности на Астрономској опсерваторији последњих деценија; посебно одређивања ширине, дужине, времена, као и добијања координата звезда из терестричких посматрања (Review of the astrometrical activity on Astronomical Observatory during last decades; especially of the latitude, longitude and time determination as well as of the determination of stellar coordinates from terrestrial observations), (For students of geodesy with assistant Vukan Ogrizović).
2. 4.04.2001; Evencio Mediavilla: Gravitational lenses.
3. 11.04.2001; Милан С. Димитријевић: Штарково ширење у астрофизици и истраживања у Југославији његовог утицаја на профиле спектралних линија (Stark broadening in astrophysics and investigations in Yugoslavia of its influence on spectral line shapes).
4. 18.04.2001; Милан С. Димитријевић: Утицај квазимолекуларних јон-атомских комплекса на својства слабо јонизоване астрофизичке плазме (Influence of quasimolecular ion-atom complexes on the properties of weakly ionized astrophysical plasmas).
5. 27.04.2001; Миодраг Дачић, Зорица Цветковић: Историја и активност Астрономске опсерваторије у Београду (History and Activity of the Belgrade Astronomical Observatory), (For the students and professors of the secondary school from Novi Sad).
6. 28.04.2001; Миодраг Дачић: Историја и активност Астрономске опсерваторије у Београду (History and Activity of the Belgrade Astronomical Observatory), (For the students and professors of the secondary school from Novi Sad).
7. 18.05.2001; Миодраг Дачић, Зорица Цветковић: Историја и активност Астрономске опсерваторије у Београду (History and Activity of the Belgrade Astronomical Observatory), (For the students of the Niš Faculty of Sciences with Professor Dragan Gajić).
8. 22.05.2001; Миодраг Дачић, Зорица Цветковић: Историја и активност Астрономске опсерваторије у Београду (History and Activity of the Belgrade Astronomical Observatory), (For the pupils and professors of the primary school from Niš).
9. 29.05.2001; Миодраг Дачић: Необичне небеске појаве у последњем миленијуму видљиве са подручја Ресаве (Unusual celestial events in the last millenium which could be observed from the Resava region), Days of Sindjelić: "Mythological Resava", Svilajinac.
10. 25.07.2001; Милан С. Димитријевић: Астроспектроскопија I (Astrospectroscopy I), For the team of the project: Influence of collisional processes on astrophysical plasma lineshapes).

11. 27.07.2001; Милан С. Димитријевић: Астроспектроскопија II (Astrospectroscopy II), (For the team of the project: Influence of collisional processes on astrophysical plasma lineshapes).
12. 30.07.2001; Милан С. Димитријевић: Механизми ширења спектралних линија (Spectral line broadening mechanisms), (For the team of the project: Influence of collisional processes on astrophysical plasma lineshapes).
13. 1.08.2001; Милан С. Димитријевић: Штарково ширење неводоничних спектралних линија (Stark broadening of non-hydrogenic spectral lines), (For the team of the project: Influence of collisional processes on astrophysical plasma lineshapes).
14. 3.08.2001; Yuri Valentinovich Ralchenko: Quantum calculations of electron-impact broadening in multiply charged ions.
15. 6.08.2001; Милан С. Димитријевић: Штарково ширење у астрофизици (Stark broadening in astrophysics), (For the team of the project: Influence of collisional processes on astrophysical plasma lineshapes).
16. 9.08.2001; Милан С. Димитријевић: Модификовани семиемпиријски прилаз (Modified semiempirical approach), (For the team of the project: Influence of collisional processes on astrophysical plasma lineshapes).
17. 5.10.2001; Миодраг Дачић, Зорица Цветковић: Историја и активност Астрономске опсерваторије у Београду (History and Activity of the Belgrade Astronomical Observatory), (For the students and professors of the secondary school from Šabac).
18. 10.10.2001; Слободан Нинковић: Галактоцентричне путање - резултати израчунавања (Galactocentric paths - results of calculations).
19. 17.10.2001; Милан С. Димитријевић: Астрофизички значајни апроксимативни методи за израчунавање параметара Штарковог ширења (Astrophysically important approximate methods for Stark broadening parameter calculations).
20. 20.10.2001; Миодраг Дачић: Мерење времена (The time measurement), (For the students and professors of the primary school from Beli Potok).
21. 24.10.2001; Милан С. Димитријевић: Регуларности и систематски трендови параметара Штарковог ширења и астрофизички значај њиховог изучавања (Regularities and systematic trends of Stark broadening parameters and astrophysical meaning of their investigation).
22. 7.11.2001; Лука Ч. Поповић: Микрогравитациона сочива и емисионе линије квазара: Најновији резултати (Microgravitational lenses and quasar emission lines: The most recent results).
23. 14.11.2001; Дејан Урошевић: Проблем емпиријске Σ-D релације (The Problem of Empirical Σ-D Relation).

5.2. Lectures held by the observatory's felows outside the astronomical observatory

1. 11.01.2001; Slobodan Jankov: Imagerie Doppler-Intérférométrique d'étoiles Université Joseph Fourier / Laboratoire d'Astrophysique, Grenoble, France (http://www-laog.obs.ujf-grenoble.fr).
2. 25.01.2001; Slobodan Jankov: Imagerie Tomographique de pulsations non-radiales, Université de Nice.
3. 26.01.2001; Слободан Нинковић: Тамна materija (Dark matter), "Ilija M. Kolarac" foundation, Belgrade.
4. February, 2001; Zoran Knežević: On the age of Veritas asteroid family, Institute for Astronomy, University of Vienna, L. Figl - Observatory for Astrophysics.
5. February, 2001; Gojko Djurašević: Gravity darkening effect in semidetached close binary systems, University of Athens, Athens, Greece.
6. 7.02.2001; Лука Ч. Поповић: Тамна материја у васиони (Dark matter in the universe), Rotary Club - Београд Стари град (Belgrade Old city).
7. 12.02.2001; Миодраг Дачић: Одређивање положаја небеских тела (семинар за младе астрономе - четири часа) (Determination of the celestial bodies position (Seminar for young astronomers - four lessons)), Research center Petnica, Valjevo.
8. 16.02.2001; Војислава Протић Бенишек: Мала тела Сунчевог система - Зашто и како их посматрати? (Minor Solar System bodies - Why and how observe them?), Research center Petnica, Valjevo.
9. 23.02.2001; Milan S. Dimitrijević: Stark broadening in Astrophysics, University of St. Andrews, St. Andrews, Scotland.
10. 28.02.2001; Milan S. Dimitrijević: Processes involving ion-atom complexes in weakly ionized astrophysical plasmas, Armagh Observatory, Armagh, Northern Ireland.
11. March, 2001; Зоран Кнежевић: Хаос у кретању астероида (Chaos in the asteroid motion), Research center Petnica, Valjevo.
12. 6.03.2001; Milan S. Dimitrijević: Stark broadening in Astrophysics, Trieste Observatory, Trieste, Italy.
13. 4.04.2001; Милан С. Димитријевић: Зашто је васиона оваква каква је и где су ту ванземаљци (Why the universe is just so it is and where are extraterrestrials), Rotary Club - Београд Стари град (Belgrade Old city).
14. April, 2001; Зоран Кнежевић: Старост астероидне фамилија Веритас (Age of asteroid family Veritas), Mathematical Faculty, Belgrade.
15. 5.04.2001; Милан С. Димитријевић, Лука Ч. Поповић, Еди Бон: Шта нам причају астрономски спектри (What are telling us astronomical spectra), "Ilija M. Kolarac" foundation, Belgrade.
16. 9.04.2001; Милан С. Димитријевић: Хемија васионе (Chemistry of the Universe), April days of teachers; Twelfth seminar for teachers of chemistry, Chemical Faculty, Belgrade.

17. 11.05.2001; Милан С. Димитријевић: Зашто је васиона оваква каква је и где су ту ванземаљци (Why the universe is just so it is and where are extraterrestrials), People's library "Jovan Popović", Kikinda.
18. 22.05.2001; Milan S. Dimitrijević: Spectral lines shapes: Line indentification and broadening mechanisms, Institute for Astronomy, University of Vienna, L. Figl - Observatory for Astrophysics.
19. 5.06.2001; L. Č. Popović, E. G. Mediavilla, J. A. Muñoz, M. S. Dimitrijević: The influence of microlensing on X-ray emission lines generated by an AGN accretion disc, GLITP Workshop on Gravitational Lens Monitoring, 4-6 June, La Laguna, Tenerife, Canary Islands, Spain.
20. 18-22 June 2001; Zoran Knežević: Probing the Nekhoroshev structure of the asteroid belt, Third Meeting on Celestial Mechanics, Villa Mondragone, Italy
21. 22.06.2001; Милан С. Димитријевић: Спектри нам причају о васиони (Spectra tell us about universe), XIX Belgrade Astronomical Weekend, Planetarium.
22. 23.06.2001; Лука Ч. Поповић: Гравитациона сочива - "Васионски" телескопи (Gravitational lenses - "Space" telescopes), XIX Belgrade Astronomical Weekend, Planetarium.
23. 6.07.2001; Милан С. Димитријевић: Зашто је ноћно небо тамно (Why the night sky is dark), Leskovac, Secondary School.
24. 25.07.2001; Милан С. Димитријевић: Канарска острва (Canary islands), Rotary club Belgrade - Old city.
25. 1.08.2001; Милан С. Димитријевић: Физика прионских болести (Physics of prion diseases), Rotary club Belgrade - Old city.
26. 22.08.2001; Милан С. Димитријевић: Пут у Одесу и Николајев (Journey to Odessa and Nikolaev), Rotary club Belgrade - Old city.
27. 8.09.2001; Милан Ћирковић: Катастрофизам и утицај Галаксије на Сунчев систем (Catastrophism and the influence of Galaxy on the Solar system), IV Summer Astronomical Meetings: "Influence of cosmical surrounding on the Earth and the Solar system", Planetarium.
28. 15.09.2001; Војислава Протић - Бенишек: Блиски сусрети астероида са Земљом (Near encounters of asteroids with the Earth), IV Summer Astronomical Meetings: "Influence of cosmical surrounding on the Earth and the Solar system", Planetarium.
29. 26.09.2001; Воја Антонић, Миодраг Дачић, Милан С. Димитријевић: Астрологија: Телескопима против хороскопа (Astrology: With telescopes against horoscopes), Galery "Stepenik", Belgrade.
30. 9.10.2001; Милан Ћирковић: Fred Hoyle и савремена космологија (Fred Hoyle and contemporary cosmology), "Historical and Epistemological Researches in Natural Sciences", Institute of Physics, Zemun.
31. 10.10.2001; Милан С. Димитријевић: Астрофизика данас и сутра (Astrophysics today and tommorow), Природно-Математички факултет, Нови Сад.

32. 15-19.10.2001; Srdjan Samurović: Dark Matter in Early-type Galaxies with X-Ray halos. A Spectroscopic Study of Dynamics and Abundance Indices, Italian National School for Astrophysics: "Chemical evolution of galaxies - high resolution spectroscopy" 15-19. October, 2001, Internacional Center for Theoretical Physics "Abdus Salam", Grignano (Trieste), Italy.
33. 21.11.2001; Милан С. Димитријевић: Ђорђе Станојевић први српски астрофизичар (Djordje Stanojević the first serbian astrophysicist), Rotary club Belgrade - Old city.
34. 5.12.2001; Milan S. Dimitrijević: Astronomy and Astrology, Space Research Institute of Bulgarian Academy of Sciences, Sofia.
35. 7.12.2001; Milan S. Dimitrijević: Influence of collisions with charged particles on astrophysical spectral line shapes, Astronomical Observatory, Sofia.
36. 7.12.2001; Milan S. Dimitrijević: Astronomy and Astrology, Astronomical Observatory, Sofia.
37. 20.12.2001; Srdjan Samurović: Dark Matter in Early-type Galaxies with X-Ray Halos, "Astronomy in Trieste", Trieste, Italy.
38. 26.12.2001; Војислава Протић Бенишек: Академик В. В. Мишковић - 25 година од смрти (Academician V. V. Mišković - 25 years since his death), Museum of Nikola Tesla, Belgrade.
39. 27.12.2001; Слободан Јанков: Интерферометријско осликавање звезданих површина (Interferometric imaging of stellar surfaces), Department of Astronomy, Mathematical Faculty, Belgrade.

6. TV AND RADIO EMISSIONS

1. М. Дачић је редовно достављао обданице за Радио Београд, Радио Суботицу и Радио Футог (M. Dačić supplied regularly data on the length of day and night for Radio Belgrade, Radio Subotica and Radio Futog).
2. Поводом потпуног помрачења Месеца 9. јануар (On the 9 January total Moon eclipse), М. Дачић, Радио "Палма Плус", Јагодина.
3. Реприза I емисије серије "Сунце наша звезда", аутор сценарија и водитељ Милан С. Димитријевић, ТВ Београд: I емисија "Прича о Сунцу": 22. и 23. I 2001 (Reproduction of the first part of the Series of 4 parts "Sun our star", the author of scenario and emission host Milan S. Dimitrijević, TV Belgrade I: I part "Story about Sun": 22 and 23 I 2001).
4. О Астрономској опсерваторији и Звездари (On Astronomical Observatory and Zvezdara), В. Протић Бенишек, Радио Звездара, 8.03.2001 17h-19h.
5. Гласније (Поводом 10 година од специјалног броја часописа "Галаксија" посвећеног 2001. години) (Lowder (On the occasion of the 10 year from the special number of "Galaksija (Galaxy)" journal dedicated to the year 2001)), М. С. Димитријевић, Радио Београд II, 14.04.2001 12h.
6. Београде добро јутро (О Астрономској опсерваторији) (Belgrade good morning (On Astronomical observatory), М. С. Димитријевић, ТВ Студио Б, 18.07.2001, 7h.

7. Београде добар дан (О Астрономској опсерваторији, репризa) (Belgrade good day (On Astronomical observatory, reproduction)), М. С. Димитријевић, ТВ Студио Б, 18.07.2001, 16h.
8. Ролетна (О Астрономској опсерваторији), (Window blind (On Astronomical Observatory)), М. Дачић, Л. Ч. Поповић, БК Телеком, 18.07.2001, 22h.
9. Window blind (О Астрономској опсерваторији, репризa), (РОЛЕТНА (On Astronomical Observatory, reproduction)), М. Дачић, Л. Ч. Поповић, БК Телеком, 19.07.2001, 13h 20m.
10. Астрономска опсерваторија у Београду: 65 година од проналаска мале планете Србија, емисија: Ово је Србија, (Belgrade Astronomical Observatory: 65 years from the minor planet Serbia discovery, the emission: This is Serbia), В. Протић Бенишек, ТВ Београд 1, 23.09.2001 9h30m - 10h.
11. Репризa серије "Сунце наша звезда", аутор сценарија и водитељ Милан С. Димитријевић, ТВ Београд: I емисија "Прича о Сунцу": 5.12.2001, II емисија "Панорама појава на Сунцу" 12.12.2001, III емисија "Атмосфера Сунца" 19.12.2001, IV емисија "Утицај Сунца на Земљу" 26.12.2001 (Series of 4 parts"Sun our star", the author of scenario and emission host Milan S. Dimitrijević, TV Belgrade I: I part "Story about Sun": 5.12.2001, II part "Panorame of phenomens on the Sun" 12.12.2001, III part "Atmospheres of the Sun" 19.12.2001, IV part "Solar influence on the Earth" 26.12.2001).

7. PUBLISHING (CHANGES AND ADDITIONS DURING 2001)

7.1. Editions of the astronomical observatory

No changes with respect of the book for 2000 (Publ. Astron. Obs. Belgrade Vol. 71, 2001).

7.2 Editions wherein fellows of astronomical observatory are at editorial boards or scientific councils

3. Biblioteka "DISSERTATIO" (Edition "DISSERTATIO") Задужбина "Андрејевић" ("Andrejević" Foundation) M. S. Dimitrijević - president of the Editorial Board and member of the Scientific Council of the Foundation.
   3.1 Др Катина Цветковић, ОСНОВНИ ПОСТУЛАТИ У ЛЕЧЕЊУ АРТРОГРИПОЗЕ КОД ДЕЦЕ, No. 120, 2000.
   3.2 Др Милица Пејовић - Милованчевић, ПОРЕМЕЋАЈ ПОНАШАЊА ДЕЦЕ И ОМЛАДИНЕ - МОРАЛНИ И ПСИХОПАТОЛОШКИ АСПЕКТИ, No. 121, 2001.
   3.3 Др Ксенија Јанковић, ДРОБЉЕЊЕ ОПЕКА КАО АГРЕГАТ ЗА БЕТОН, No. 122, 2001.
   3.4 Др Дејан Марковић, БИО КОМПАТИБИЛНОСТ ГЛАС - ЈОНОМЕР ЦЕМЕНТА, No. 123, 2001.

3.5 Др Силвана Д. Марковић, ФИТОХЕМИЈСКО ПРОУЧАВАЊЕ ВРСТА РОДА HIERACIUM L., No. 124, 2001.
3.6 Др Драган М. Игњатовић, ИЗБОР ПОМОЋНЕ МЕХАНИЗАЦИЈЕ ЗА ПОВРШИНСКЕ КОПОВЕ ЛИГНИТА, No. 125, 2001.
3.7 Др Драгослава Стојиљковић, АЗОТНИ ОКСИДИ ПРИ САГОРЕВАЊУ ДОМАЋИХ ЛИГНИТА, No. 126, 2001.
3.8 Др Ђуро Кутлача, ОЦЕЊИВАЊЕ ТЕХНОЛОШКОГ НИВОА ФИРМИ СЕКТОРА НАЦИОНАЛНЕ ЕКОНОМИЈЕ, No. 127, 2001.
3.9 Др Ђуро Мацут, ИНСУЛИНСКА СЕНЗИТИВНОСТ У ДИЈАБЕТЕСУ ТИП 1, No. 128, 2001.
3.10 Др Гојко Јоксимовић, АНАЛИЗА КВАРОВА КАВЕЗНОГ ИНДУКЦИОНОГ МОТОРА, No. 129, 2001.
3.11 Бојан Ј. Илић, СТРАТЕГИЈЕ ФОРМИРАЊА ЦЕНА У УСЛОВИМА ДИСКОНТИНУИТЕТА, No. 130, 2001.
3.11 Др Љубинка Јанковић Величковић, САВРЕМЕНИ АСПЕКТ ДИЈАГНОСТИКЕ КАРЦИНОМА ПРОСТАТЕ, No. 131, 2001.
3.12 Др Татјана С. Радосављевић, ЕНТЕРОИНСУЛАРНА ОСОВИНА У ПОРТО - КАВНОМ ШАНТУ, No. 132, 2001.
3.13 Др Оливера Станојловић, АНИМАЛНИ МОДЕЛИ ЕПИЛЕПСИЈЕ - АНТИЕПИЛЕПТИЦИ, No. 133, 2001.
3.14 Др Зоран Машић, ДИНАМИЧКА ЧВРСТОЋА - ОСОБИНА ЧОВЕКА, No. 134, 2001.
3.16 Др Дејан Коматина, ОТВОРЕНИ ТОКОВИ ГУСТИХ МЕШАВИНА - ТЕОРИЈА И ЕКСПЕРИМЕНТ, No. 135, 2001.
3.17 Др Вилма Јовичић, САВРЕМЕНА ДИЈАГНОСТИКА ЛАЈМСКЕ БОРЕЛИОЗЕ, No. 136, 2001.
3.18 Др Кристина Гопчевић, ТОКСИН ПОСКОКА - ОТРОВ И ЛЕК, No. 137, 2001.
3.19 Др Драган Петровић, ДИНАМИКА СУДАРА ВАГОНА, No. 138, 2001.
3.20 Др Дрина Јанковић, p - AMINOHIPURNA КИСЕЛИНА: ОБЕЛЕЖАВАЊЕ И МОГУЋНОСТИ КЛИНИЧКЕ ПРИМЕНЕ, No. 139, 2001.
3.21 Др Наташа Вавић, ХЕМОСТАЗА У ТРАНСПЛАНТАЦИЈИ ЈЕТРЕ, No. 140, 2001.

6. Библиотека "ACADEMIA" (Edition "ACADEMIA") Задужбина "Андрејевић" ("Andrejević" Foundation) M. S. Dimitrijević - member of the Scientific Council of the Foundation.
6.1 Мр Горан Ристић, ГРАД НА ДЕПОНИЈИ, No 50, 2000.
6.2 Мр Андреја Самчовић, ПОДОПСЕЖНО КОДОВАЊЕ СЛИКА, No 51, 2000.
6.3 Мр Каролина Смиљанић Радотић, КО КОНТРОЛИШЕ ИМУНИТЕТ НА НИВОУ ГРАФТА?, No 52, 2000.
6.4 Мр Мирослава Стопић, ЕТНОСЕЛО - КУЛТУРНА ВРЕДНОСТ СРБИЈЕ, No 53, 2001.

6.5 Мр Ивана Теодоровић, ИНДЕКС МЕТАЛОЗАГАЂЕЊА; ПРИЛОГ МОНИТОРИНГУ ПОВРШИНСКИХ ВОДА, No 54, 2001.
6.6 Мр Мирослав Свирчевић, СВИТАЊЕ ДЕМОКРАТИЈЕ У ВЕСТМИНСТЕРУ, No 55, 2001.
6.7 Мр Сунчица Мацура Миловановић, РОМСКА ДЕЦА И ШКОЛА; КАКО ИСТОПИТИ ГРУДВУ?, No 56, 2001.
6.8 Мр Јелена Врањешевић, ПРОМЕНА СЛИКЕ О СЕБИ: АУТОПОРТРЕТ АДОЛЕСЦЕНЦИЈЕ, No 57, 2001.
6.9 Мр Тамара Чавић, О ИЗБЕГЛИШТВУ - ПСИХОСОЦИЈАЛНИ АСПЕКТИ, No 58, 2001.
6.10 Мр Бранко Миљановић, МАКРОЗООБЕНТОС РЕКА КОЛУБАРЕ, ОБНИЦЕ И ЈАБЛАНИЦЕ, No 59, 2001.
6.11 Мр Маја Шурбатовић, ТУМОР НЕКРОЗИС ФАКТОР α-TNFα У СЕПСИ, No 60, 2001.
6.12 Мр Бранислав Станковић, ТЕРАПИЈА АМБИОПИЈЕ, No 61, 2001.
6.13 Мр Татјана Јевтовић Стоименов, МАКРОФАГ И ИМУНОМОДУЛАТОРИ, No 62, 2001.
6.14 Мр Ђенђи Мајор, ПРИНУДНО СЛЕТАЊЕ, No 63, 2001.
6.15 Мр Радмила Драгутиновић Митровић, АНАЛИЗА ПАНЕЛ СЕРИЈА, No 64, 2001.
6.16 Мр Александар П. Симић, ЕРОЗИВНИ ЕЗОФАГИТИС И ДУОДЕНОГАСТРИЧНИ РЕФЛУКС, No 65, 2001.
6.17 Мр Драгана Лончар Стојиљковић, БЕТА БЛОКАТОРИ И АНЕСТЕЗИЈА, No 66, 2001.
6.18 Мр Светлана Кргић, КВАЛИТЕТ ЖИВОТА ШКОЛСКЕ ДЕЦЕ И ОМЛАДИНЕ, No 67, 2001.
6.19 Мр Небојша Петровић, ПУТЕВИ ИСТРАЖИВАЊА АУТОРИТАРНОСТИ, No 68, 2001.
6.20 Мр Снежана Ускоковић Марковић, ЗЕМНОАЛКАЛНЕ СОЛИ WPA, No 69, 2001.

7. Библиотека "ПОСЕБНА ИЗДАЊА" (Edition "POSEBNA IZDANJA") Задужбина "Андрејевић" ("Andrejević" Foundation) M. S. Dimitrijević - member of the Scientific Council of the Foundation
7.1 Др Александар Маликовић, ВИДНО ПОЉЕ КОРЕ ВЕЛИКОГ МОЗГА ЧОВЕКА, No 16, Београд, 2001.
7.2 Мр Наташа Церибашић Љубомировић, СТРЕС И МЛАДИ, No 17, Београд, 2001.
7.3 Мр Љиљана Петровић Рацков, DERMATO POLIMIOZITIS СА ВАНМИШИЋНИМ СИНДРОМОМ, No 18, Београд, 2001.
7.4 Мр Саша Љубенковић, ЗАШТИТА ТАНКОГ ЦРЕВА У РАДИОТЕРАПИЈИ, No 19, Београд, 2001.
7.5 Др Драган И. Темељковски, ЗАВОЈНЕ ПРЕСЕ СА ВАРИЈАБИЛНИМ МОМЕНТОМ ИНЕРЦИЈЕ ЗАВРТЊА, No 20, Beograd, 2001.

7.6 Сергије Димитријевић, КОМУНИСТИЧКА ПАРТИЈА ЈУГОСЛАВИЈЕ У ЛЕГИТИМНОМ ПЕРИОДУ ЊЕНОГ ПОСТОЈАЊА ОД 1919 - 1921. ГОДИНЕ, No 21, Београд, 2001.
7.7 Др Војислав Митић, СТРУКТУРА И ЕЛЕКТРИЧНА СВОЈСТВА Ba Ti O_3-КЕРАМИКЕ, No 22, Београд, 2001.
7.8 Мр Дијана Милашиновић Марић, АРХИТЕКТА ЈАН ДУБОВИ No 23, Београд, 2001.
7.8 Мр Гордана Брун, ОБРАЗОВАЊЕ И ВАСПИТАЊЕ ЗА ОПСТАНАК, No 24, Београд, 2001.
7.9 Мр Бранислав Марковић, СЕЛФ ПСИХОЛОГИЈА И РАДНИ САВЕЗ, No 25, Београд, 2001.
7.10 Проф. др Јован Б. Душанић, НОВАЦ, No 26, Београд, 2001.
7.11 Проф. др Драгиша Милошев, УТИЦАЈ ТЕМПЕРАТУРЕ НА ФОРМИРАЊЕ ЗРНА ПШЕНИЦЕ, No 27, Београд, 2001.
7.12 Др Љубица Мандић, НЕБЛАГОВРЕМЕНА ЖАЛБА У ВАНПАРНИЧНОМ ПОСТУПКУ, No 28, Beograd, 2001.
7.13 Сергије Димитријевић, СТРУКТУРНЕ ПРОМЕНЕ У ПОЉОПРИВРЕДИ СРБИЈЕ СРЕДИНОМ 20. ВЕКА, No 29, Београд, 2001.
7.14 Др Милан Р. Милановић, СЛУШНИ АПАРАТИ И ТЕШКА ОШТЕЋЕЊА СЛУХА, No 30, Beograd, 2001.
7.15 Мр Мирјана Веселиновић Јовановић, ХИПЕРАКТИВНО ДЕТЕ, No 31, Beograd, 2001.
7.16 Др Десимир Ж. Вучић, ЦИКЛИЧНА СПЕКТРАЛНА АНАЛИЗА СИГНАЛА, No 32, Beograd, 2001.
7.17 Др Марија Тоскић Радојичић, ПРЕПАРАТИ ЗА ДЕКОНТАМИНАЦИЈУ ПЕРКУТАНОГ ТРОВАЊА S - ИПЕРИТОМ И VX -ОМ, No 33, Beograd, 2001.

10. Библиотека: Народна књижевност Српске крајине, (Library: National Literature of Serbian Krajina) М. Радованац – Едитор.
10.1 Никола Беговић, СРПСКЕ НАРОДНЕ ПЈЕСМЕ ИЗ ЛИКЕ И БАНИЈЕ, No 2.

11. "Београдски пчелар", (Belgrade apiarist) Г. Поповић - Editor

7.3 Reviewing in international journals

Zoran Knežević for ICARUS (2), CELESTIAL MECHANICS AND DYNAMICAL ASTRONOMY (1) and SCIENCE (1).

8. ORGANIZATION OF CONFERENCES

1. Regional meeting on Solar physics: Solar researches in the South-Eastern European countries: Present and perspectives, Bucharest 24-28 April 2001. Scientific Organizing Committee I. Vince.

2. The second Odessa Astronomical Summer School for Young Scientists: Astronomy and beyond: Astrophysics, Astrochemistry and Astrobiology, Odessa, 12-17 August 2001. Scientific Organizing Committee M. S. Dimitrijević.

9. MEMBERSHIP IN INTERNATIONAL AND NATIONAL SCIENTIFIC SOCIETIES AND BODIES (CHANGEMENTS AND ADDITIONS DURING 2001)

9.1. Membership in international scientific societies

13. EuroScience Association, M. S. Dimitrijević, L. Č. Popović.
14. Philosophy of Science Association (Headquater in University of Chicago), M. Ćirković.
16. Academy of Nonlinear Sciences, Moscow, M. S. Dimitrijević (since 9.01.2001).

9.2. Membership in national astronomical and other professional societies and bodies

5. Society for the popularization of science, Novi Sad, M. S. Dimitrijević, Member of Presidential board and Co-Founder.

10. VISITING DIGNITARIES AND DISTINGUISHED GUESTS AT THE ASTRONOMICAL OBSERVATORY

9.05.2001, Berislav Kosijer, writer.
27.03-5.04.2001, Dr Evencio Mediavilla, Instituto de Astrofisica de Canarias, La Laguna, Tenerife, Spain.
5.07.2001, Petar Moravac, Lord Mair of Zvezdara Municipality.
9.07.2001, Dragan Domazet, Minister of Science, Technologies and Development of Serbia, Petar Moravac, Lord Mair of Zvezdara Municipality.
1-4.08.2001, Yuri Valentinovich Ralchenko, Weizmann Institute of Science, Rehovot, Israel.
20-22.10.2001, Dr Miltcho Tsvetkov, Institute of Astronomy of the Bulgarian Academy of Sciences, Sofia, Bulgaria.
20-22.10.2001, Dr Katja Tsvetkova, Institute of Astronomy of the Bulgarian Academy of Sciences, Sofia, Bulgaria.
20-22.10.2001, Hristo Lukarski, Institute of Cosmic Researches of the Bulgarian Academy of Sciences, Sofia, Bulgaria.

11. THE ATTENDANCE AT SCIENTIFIC CONFERENCES

1. 10th Congress of Yugoslav Mathematicians, Belgrade 21-24. January 2001, B. Jovanović, P. Jovanović, Z. Knežević, S. Ninković, R. Pavlović.
2. Прилози аналитичкој динамици - Управљање, стабилност и диференцијална геометрија (Contributions to analytical dynamics - Governing, stability and differential geometry), Beograd, 4.04.2001, М. С. Димитријевић.
3. Априлски дани просветних радника, Дванаести семинар за професоре хемије, Београд 9. и 10. април 2001, М. С. Димитријевић.
4. Regional meeting on Solar physics: Solar researches in the South-Eastern European countries: Present and perspectives, Bucharest 24-28 April 2001, M. S. Dimitrijević, I. Vince, O. Vince.
5. Научни пројекат "Сусрет цивилизација на Балкану", Осми међународни научни скуп "Југоисточна Европа: Политичке и културне концепције (XVI-XX), Београд, 9-11. мај 2001, В. Трајковска.
6. Митска Ресава, Свилајинац, 29.05.2001, М. Дачић.
7. GLITP Workshop on gravitational lens monitoring, La Laguna, Tenerife, Canary Islands, Spain, 4-6 June 2001, M. S. Dimitrijević, L. Č. Popović.
8. Asteroids 2001: From Piazzi to the 3rd millenium, Santa Flavia, Italy, 11-15 June 2001, Z. Knežević.
9. Third Meeting on Celestial Mechanics, Villa Mondragone, Italy, 18-22 June 2001, Z. Knežević.
10. The second Odessa Astronomical Summer School for Young Scientists: Astronomy and beyond: Astrophysics, Astrochemistry and Astrobiology, Odessa, 12-17 August 2001, M. S. Dimitrijević.
11. Atelier Porquerolles: Fourier Analysis and Hamiltonian Systems, Porquerolles, France, 9-15 September 2001, R. Pavlović.
12. Joint European and National Astronomical Meeting JENAM-2001, Munich, Germany, 10-15 September 2001, E. Bon, M. S. Dimitrijević, L. Č. Popović.
13. 5th Hellenic Astronomical Conference, Fodele Crete, 20-22 September, 2001, Z. Knežević.
14. Друштвено-политичка мисао Јована Скерлића, Београд, 27-28 септембар 2001, В. Трајковска.
15. Journées 2001 Systéms de Référence Spatio - Temporels "Influence of geophysics, time and space reference frames on Earth rotation studies", 24 - 26 September, 2001, Royal Observatory of Belgium, Brussels. G. Damljanović.
16. Italian National School for Astrophysics: "Chemical evolution of galaxies - high resolution spectroscopy", 15-19. October, 2001, Grignano (Trieste), Italy. S. Samurović.
17. International Symposium Science and Religion: Antagonism or Complementarity?, Bucharest 8-11 Novembre 2001, M. S. Dimitrijević.
18. Astronomy in Trieste, Trieste 20 Decembre 2001, S. Samurović.

12. VISITS TO SCIENTIFIC INSTITUTIONS

1. 1.01-31.12.2001, University of Massachusetts, Amherst, USA V. Živkov.
2. 1.01-31.12.2001, Department of Physics and Astronomy, University of Canterbury, Christchurch, New Zealand; Mt. John Observatory, New Zealand Lj. Skuljan.
3. 1.01-31.12.2001, University College, London, England, N. Vranešević.
4. 4.01-4.05.2001, University of Alabama, Huntsvil, Alabama, USA, D. Tankosić.
5. 15.01-15.05.2001, Armagh Observatory, Armagh, Northern Ireland, D. Jevremović.
6. 5.02-13.02.2001, University of Athens, Athens, Greece, G. Djurašević.
7. 7.02-7.04.2000, Department of Astronomy, Eötvös Lorand University, Budapest, Hungary, I. Vince.
8. February 2001 (1 week), Vienna Observatory, Vienna, Austria, Z. Knežević.
9. 15.02-9.03.2001, University College, London, England; St. Andrews University, St. Andrews, Scotland; Armagh Observatory, Armagh, Northern Ireland; Trieste Observatory, Trieste, Italy; Vienna Observatory, Vienna, Austria, M. S. Dimitrijević.
10. 19.02-19.03.2001, Instituto de Astrofisica de Canarias, La Laguna, Tenerife, Spain; Teide Observatory, Tenerife, Spain; Roque de los Muchachos Observatory, La Palma, Canary Islands, Spain, E. Bon, L. Č. Popović.
11. 1.04-31.12.2001, Onsala Space Observatory, Sweden, S. Nikolić.
12. 20.04.-20.07.2001, Observatoire de Côte d'Azure, Grass, France, S. Jankov.
13. 15.05-15.11.2001, Institute of Geodesy and Geophysics, Vienna University of Technology, Austria, G. Damljanović.
14. 18-23.05.2001, Astronomical Observatory, Vienna, Austria, M. S. Dimitrijević.
15. Jun 2001 (2 weeks), Dipartimento di matematica, Universitá di Pisa, Italy, Z. Knežević.
16. 1.06-10.06.2001, Instituto de Astrofisica de Canarias, La Laguna, Tenerife, Spain; Teide Observatory, Tenerife, Spain, M. S. Dimitrijević, L. Č. Popović.
17. 15.06-20.12.2001, Armagh Observatory, Armagh, Northern Ireland, D. Jevremović.
18. 22.06-22.12.2001, University of Alabama, Huntsvil, Alabama, USA, D. Tankosić.
19. 17-18.08.2001, Astronomical Observatory, Nikolaev, Ukraina, M. S. Dimitrijević.
20. September 2001 (1 week), Department of Physics, University of Thessaloniki, Thessaloniki, Greece, Z. Knežević.
21. 9.09-14.9.2001, Astrophysikalisches Institut Potsdam, Germany, L. Č. Popović.
22. October 2001 (3 weeks), Dipartimento di matematica, Universitá di Pisa, Italy, Z. Knežević.

23. 7-13.11.2001, Astronomical Observatory, Bucharest, Romania, M.S. Dimitrijević.
24. 4-7.12.2001, Space Research Institute of Bulgarian Academy of Sciences, Sofia, Bulgaria; Astronomical Observatory, Sofia, Bulgaria, M. S. Dimitrijević.
25. 11.12-31.12.2001, Weizmann Institute of Science, Rehovot, Israel, N. Milovanović.

13. INTERNATIONAL SCIENTIFIC COLLABORATION (CHANGEMENTS AND ADDITIONS DURING 2001)

AUSTRIA

Astro - geodesy project 6331: "CCD in astro - geodesy", Univ. Prof. Dr. G. Gerstbach of IGG TU Wien (Dept. of Advanced Geodesy (E128/1), Institute of Geodesy and Geophysics, Vienna University of Technology, Austria) (Goran Damljanović).

BULGARIA

Space Research Institute of Bulgarian Academy of Sciences, Sofia (M. S. Dimitrijević).
Astronomical Observatory, Sofia (M. S. Dimitrijević).

ISRAEL

Weizmann Institute of Science, Rehovot, Israel (N. Milovanović).

ITALY

Trieste Observatory (S. Samurović).

ROMANIA

Astronomical Observatory, Bucharest (Agreement on collaboration with Astronomical Institute of the Romanian Academy of Sciences, signed on 27. 04. 2001).
Astronomical Observatory, Cluj - Napoca (Agreement on collaboration with Astronomical Institute of the Romanian Academy of Sciences, signed on 27. 04. 2001).
Astronomical Observatory, Timisoara (Agreement on collaboration with Astronomical Institute of the Romanian Academy of Sciences, signed on 27. 04. 2001).

UKRAINE

Mykolayiv Observatory, Mykolayiv (Agreement on collaboration signed on 24. 04. 2001).

14. TEACHING ACTIVITY

14.1. Lecturing on the university level

No changements or additions during 2001.

14.2. Ph. D. and M. Sc. theses

1. Владимир М. Милосављевић ШТАРКОВО ШИРЕЊЕ СПЕКТРАЛНИХ ЛИНИЈА АТОМСКИХ СПЕКТАРА ИНЕРТНИХ ГАСОВА (STARK BROADENING OF SPECTRAL LINES OF NOBLE GAS ATOMIC SPECTRA), Ph. D. Thesis, Belgrade University, Faculty of Physics, 17. 05. 2001 (Milan S. Dimitrijević, President of the Jury).
2. Еди Бон СТРУКТУРА ЕМИСИОНЕ ОБЛАСТИ КОД АКТИВНЕ ГАЛАКСИЈЕ III ZW 2 THE EMISSION REGION STRUCTURE AT III ZW 2 ACTIVE GALAXY, M. Sc. Thesis, Belgrade University, Mathematical Faculty, 14. 05. 2001. (Luka Č. Popović, Co-Mentor, Ištvan Vince, Co-Mentor).
3. Силвана Николић МОЛЕКУЛСКИ ОБЛАЦИ У ОБЛАСТИ ЦЕФЕЈА MOLECULAR CLOUDS IN THE CEPHEUS REGION, Ph. D. Thesis, Belgrade University, Mathematical Faculty, 22. 11. 2001. (Ištvan Vince, Mentor).
4. Ненад Миловановић ДОПРИНОС ШТАРКОВОГ ШИРЕЊА ИНТЕРПРЕТАЦИЈИ СПЕКТАРА CP ЗВЕЗДА THE STARK BROADENING CONTRIBUTION TO CP STAR SPECTRA INTERPRETATION, M. Sc. Thesis, Belgrade University, Mathematical Faculty, 26. 11. 2001. (Milan S. Dimitrijević, Co-Mentor, Ištvan Vince, Co-Mentor).

14.3. Other pedagogical activities

1. M. Dačić, 20 lectures on Astronomy for students of the primary school "Josif Pančić, Belgrade.
2. M. Dačić, Four tests with 80 questions for competion on astronomy, for the primary and secondary school students.

15. MISCELANEOUS

15.1. Letter of thanks

Researcher's society "Vladimir Mandić - Manda" assigned on 17.03.2001 Letter of thanks to the Astronomical Observatory.

15.2. Charter

Belgrade association of apiarists assigned on 17. November 2001, on the occasion of the day of apiarists 12. November, Charters to Milan S. Dimitrijević and Sreten Stepanović.

15.3. Meritorious fellow

Belgrade association of apiarists nominated Georgije Popović on 17. November 2001, on the occasion of the day of apiarists 12, for Meritorious fellow.

15.2. Other

1. Miodrag Dačić, Luka Č. Popović Calculations of the Sun and Moon rising and setting, as well as Moon phases.
2. During 2001 Ištvan Vince prepared 37 expertises for courts.

16. SUPPLEMENT TO THE 1995 LIST OF INSTITUTIONS RECEIVING SERBIAN ASTRONOMICAL JOURNAL AND PUBLICATIONS OF THE ASTRONOMICAL OBSERVATORY OF BELGRADE

AZERBAIJAN: Shamakhy Astrophysical Observatory, Baku.

BULGARIA: Space Research Institute of the Bulgarian Academy of Science, Sofia.

SPAIN: Instituto de Astrophysica de Canarias, La Laguna, Tenerife

17. BELGRADE ASTRONOMICAL OBSERVATORY STAFF AND ORGANISATION (CHANGEMENTS AND ADDITIONS DURING 2001)

WINNERS OF THE ASTRONOMICAL OBSERVATORY PRIZE FOR 2001

1. Prize for Science: VLADIMIR ČADEŽ

2. Prize for Science for Young: DARKO JEVREMOVIĆ

3. Prize for the Contribution to the Development of the Astronomical Observatory (for fellows of Astronomical Observatory): ALEKSANDAR KUBIČELA

4. Prize for the Contribution to the Development of the Astronomical Observatory: ASTRONOMSKO DRUŠTVO "NOVI SAD" (ADNOS) - ASTRONOMICAL SOCIETY "NOVI SAD"

DIRECTORIAL BOARD

1. Up to 10 July 2001, the same as in 2000.

2. Since 10 July 2001.
Slobodan Vuković - President, Ištvan Vince - Vice President,
Trajko Angelov, Zoran Cekić, Slobodan Jankov, Ilija Lukačević, Georgije Popović, Luka Č. Popović.

JOINT SCIENTIFIC COUNCIL OF ASTRONOMICAL OBSERVATORY, GEOMAGNETIC INSTITUTE AND SEISMOLOGICAL INSTITUTE

Up to 4.10.2001, the same as in 2001.

SCIENTIFIC COUNCIL OF ASTRONOMICAL OBSERVATORY

1. Up to 4.10.2001, the same as in 2000.

2. Since 4.10.2001.
Gojko Djurašević - President, Mike Kuzmanoski - Vice President,
Trajko Angelov, Miodrag Dačić, Milan S. Dimitrijević, Stevan Djeniže, Slobodan Jankov, Darko Jevremović, Zoran Knežević, Ilija Lukačević, Slobodan Ninković, Nada Pejović, Georgije Popović, Luka Č. Popović, Ištvan Vince

STAFFF OF ASTRONOMICAL OBSERVATORY CHANGEMENTS IN 2001.

DEPARTMENT FOR ASTROPHYSICS

Dr Silvana Nikolić (Dr since 22.11.2001), Dr Ljiljana Skuljan (Dr since 19.06.2001), M.Sc. Edi Bon (M.Sc. since 14.05.2001), M.Sc. Snežana Marković-Kršljanin (M.Sc. since 29.03.2001), M.Sc. Nenad Milovanović (M. Sc. since 26.11.2001), M.Sc. Srdjan Samurović (M.Sc since 17.04.2001), M.Sc. Nataša Stanić (M.Sc. since), Zoran Simić (since 2.07.2001).

GENERAL SERVICES

Vladimir Benišek and Ljubiša Spasić have been engaged on the temporary positions.

Захвалница

Овај рад је урађен у оквиру пројекта 1471 *Историја астрономије код Срба*, код Министарства за науку и заштиту животне средине Републике Србије.

BELGRADE ASTRONOMICAL OBSERVATORY IN 2001

Review of activities of Belgrade Astronomical Observatory fellows and significant events during 2001 is presented.

Зборник радова конференције "Развој астрономије код Срба III"
Београд 25-28. април 2004,
уредник М. С. Димитријевић
Публ. Астр. друш. "Руђер Бошковић" бр. 6, 2005, 347-350

ДА ЛИ ЈЕ НОВОЈУЛИЈАНСКИ КАЛЕНДАР УСВОЈЕН У КОНСТАНТИНОПОЉУ 1923. ГОДИНЕ МИЛАНКОВИЋЕВ, МИЛАНКОВИЋ-ТРПКОВИЋЕВ ИЛИ ТРПКОВИЋ-МИЛАНКОВИЋЕВ?

МИЛАН С. ДИМИТРИЈЕВИЋ[1,2]

[1]*Астрономско друштво "Руђер Бошковић", Београд, Србија*
[2]*Астрономска опсерваторија, Волгина 7, 11160 Београд 74, Србија*

Резиме. Анализиран је допринос Милутина Миланковића и Максима Трпковића реформи Јулијанског календара усвојеној 1923. године у Константинопољу, са посебним осртом на предлог Барнабе Орианија из 1785. године да се побољша календар тако да у девет векова седам преступних година постану просте.

С обзиром на околности под којим је Свеправославни конгрес у Константинопољу донео одлуку о реформи Јулијанског календара те да је српска делегација пошла на њега са предлогом Максима Трпковића, у нашој научној јавности више пута је отварано питање да ли тамо усвојени календар треба звати Миланковићев, Миланковић-Трпковићев или Трпковић-Миланковићев. Тако на пример, Кечкић (2001) и Петровић (2002) називају овај календар Трпковић-Миланковићев а Мијатовић и Трајковска (2001, стр. 49) сматрају да је Конгрес усвојио предлог српске Патријаршије, заснован на Трпковићевом предлогу (његов модификовани пројекат). Наш циљ је да још једном размотримо овај проблем, анализирајући како је реформисани календар настао.

Патријарх Мелетије IV сазвао је 1923. године у Константинопољу Свеправославни конгрес, где је једна од важних тачака била реформа Јулијанског календара. У српској делегацији били су Митрополит црногорски и приморски Гаврило Дожић и Милутин Миланковић, Они су на овај скуп дошли са предлогом реформе календара, чији је аутор био Трпковић, који је предложио интеркалационо правило да су године са две нуле, којима се завршавају векови (секуларне) преступне само ако се приликом дељења броја стотина који садрже са 9, добије остатак 0 или 4. На тај начин ће се у 9 векова испустити 7 дана па ће календар бити ближи тропској години него Грегоријански, а пролећна равнодневица ће увек бити

21. марта или веома близу. Осим српске, предлог реформе календара поднела је и румунска делегација

Оформљена Научна комисија образложила је Конгресу оба предлога, који су после расправе били одбијени као неодговарајући. Основна замерка Трпковићевом предлогу поднетом од српске делегације, била је да ће разлика између Грегоријанског и новог календара бити један дан већ 2000, која према овом предлогу није преступна а према календару Католичке цркве јесте. На Конгресу је зато преовладало мишљење да Јулијански календар треба задржати без измена, само треба избацити 13 дана разлике. Тако се Јулијански и Грегоријански календар не би разликовали у следећих 177 година, пошто је 2000. преступна у оба. Сматрало се да је то боље решење од Трпковићевог, према коме би, после 77 година 2000, настала разлика од једног дана.

Конгрес је прешао на друга питања а Миланковић је добио задатак да сачини нови предлог. Он је Конгресу предложио друго интеркалационо правило[1] према коме су од секуларних година преступне оне где се дељењем броја стотина у њима са 9, добије остатак 2 или 6. На тај начин се добија календар прецизнији од Грегоријанског али идентичан са њим све до 2800, при чему пролећна равнодневица није фиксирана за 21. март, као ни у календару Католичке цркве. Разлика између два календара долази до изражаја када су у питању покретни празници који се везују за Ускрс. Антим, митроплит Визијски, предложио је да се датум ускрса одређује астрономским методама, уз помоћ Опсерваторија и Универзитета у Атини, Београду, Букурешту и Пулкову.[2]

Милутин Миланковић је извршио финалну редакцију реформе календара коју је усвојио Конгрес. Потписали су је Патријарх Мелетије IV, митрополит Кизички, Калиник, архиепископ Северне Америке, Александар, митрополит Црногорско-приморски Гаврило Дожић, митрополит Никејски Василије,

[1] У том светлу чудно звучи тврђење, изнето у раду Мијатовића и Трајковске (2001), да је Миланковић мислио да је његово интеркалационо правило боље па да је сугерисао да се оно усвоји ("Milanković thought that his intercalation rule is better and he suggested it to adopt." - стр. 49), као и њихов закључак да је Конгрес усвојио предлог српске Патријаршије, заснован на Трпковићевом предлогу (његов модификовани пројекат) ("... at the end the Congress adopted the proposition of the Serbian Patriarchy, based on the Trpković's proposal (his amodified project)"). Такво гледиште заступа и Јанковић који пише (Јанковић, 1984, стр. 108): "Свеправославни конгрес усвојио је предлог српске делегације, а то је уствари Трпковићев предлог. Миланковић је само унеколико изменио интеркалационо правило..."

[2] Трајковска (2005) некритички наводи у прилог своје тезе о ауторству календара усвојеног у Константинопољу 1923: "Он [Ј. Живковић - прим. М.С.Д.] сматра да накнадно одбацивање Трпковићевог пасхалног рачуна, а на основу Миланковићевог предлога да се калкулације за ту намену изврше на неколико опсерваторија, је било учињено са циљем да не би се [!-наведено како је Трајковска написала] помињао Трпковић."?!?

митрополит Драчки, Јаков, архимандрит Јулије Скрибан и професори В. Антонијадис и Милутин Миланковић.

Да би детаљније сагледали улогу Миланковића и Трпковића, осврнућемо се на питање побољшавања Јулијанског календара. Он је заснован на циклусу према коме је 4 тропске године g_{trop} приближно једнако 1461 дана, па се заснива на три године од 365 дана и четврте - преступне од 366 дана што чини 1461 дан. Ако означимо са N број преступних година које се завршавају са две нуле, а треба да постану просте и броја стотина T, када оне одбаце, добићемо да се поправка Јулијанског календара која је ближа тропској години може претставити на следећи начин (Lichtenberg, 1994): $g_{trop}=(1461/4) – (N/100T)$ дана, односно $N/T=(100 \text{ x } 1461/4) – 100 \text{ x } g_{trop.}$

Убацимо у горњу једначину заокружену вредност од 365,2422 дана и добијамо $N / T = 0.78$, т.ј. Јулијанско столеће треба да смањимо за 0.78 дана претварајући преступне године у просте.

Барнаба Ориани је 1785. године (Oriani, 1785) решио овоај проблем помоћу продужених фракција. Занимљиво је да је још Кристијан Хајгенс (1629 - 1695) (види Perron, 1929) применио овакав прилаз за дизајнирање погонских точкова за планетаријум, што је у основи врло сличан проблем.

Регуларна продужена фракција не негативног, реалног броја x је израз $x = a + 1/(b + 1/(c + ...))$ где су сви имениоци a, b, c,... природни бројеви. Највећи цео број који се садржи у x је a. Ако a није једнако x, b је највећи цео број садржан у $1/(x – a)$ итд. Регуларна продужена фракција се означава $x = [a,b,c,...]$ а сукцесивне приближне фракције су $[a]$, $[a,b]$, $[a,b,c]$... .

Ориани је показао да је низ приближних фракција за 0,78: $f_1=[0]=0$; $f_2=[0,1]=1/1=1$; $f_3=[0,1,3]=3/4=0.75$; $f_4=[0,1,3,1]=4/5=0.8$; $f_5=[0,1,3,1,1]=7/9=0.7$; $f_6=[0,1,3,1,1,5]=39/50=0.78$. За побољшање Грегоријанског и Јулијанског календара он је предложио (Oriani, 1785) да се у току 9 векова 7 секуларних преступних година претворе у просте, до чега је више од сто година касније дошао и Трпковић.[3] Ориани закључује да теоријски још бољи календар, заснован на односу 39/50 није практичан као претходни због много дужег временског периода у коме се врши корекција.[4]

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[3] Ово је чињеница до сада непозната нашим ауторима који су се бавили Миланковићевим календаром. Занимљива је изјава Трајковске (2005), да је моје изношење историјских чињеница "покушај да се умањи значај Трпковићевом пројекту" што је некоректно "према овој умној и племенитој личности." Да ли Трајковска можда сматра да историчар науке треба да сакрије историјске чињенице које не одговарају њеним тезама и да је то "коректно" бављење науком?

[4] Занимљиво је гледиште Ј. Живковића, које некритички преноси Трајковска (2005) да "за правилно решење календарског питања нема и не може бити бољег пројекта од Трпковићевог". То је само једно од тврђења у овом спису пренетом у Трајковска (2005) без икакве озбиљније анализе. На пример изјава Ј. Живковића да "такорећи за хиљаде векова неће настати потреба даљег поправљања календара" што на основу Миланковићеве анализе проблема (Миланковић, 1997) знамо да није тачно, може се опростити свештенику Живковићу, али теже астроному и историчару наука Трајковској, која такав текст нуди читаоцу у прилог својих теза.

Из изложеног видимо да је Трпковић, вероватно независно, дошао до решења да у току 9 векова треба избацити 7 дана, што је Ориани обелоданио 1785. године. Своје интеркалационо правило је засновао на жељи да пролећна равнодневица буде 21. марта, тј. као у доба Никејског сабора.[5] То је одбио Конгрес, чија је жеља била да календар што дуже иде у корак са Грегоријанским а да буде бољи од њега, што би Православну цркву довело у повољнији положај у преговорима о заједничком календару. Миланковић је понудио друго интеркалационо правило, извршио коначну редакцију предлога коме је по питању одређивања датума Ускрса допринос дао и Антим, митрополит Визијски и битно утицао да Конгрес прихвати овакво решење. Чињеница је да би без његовог учешћа, одлука Конгреса највероватније била да се задржи Јулијански календар с тиме да се избаци 13 дана разлике са Грегоријанским. Самим тим дилема којом се бави овај прилог не би постојала.

Сматрамо да изнете чињенице иду у прилог назива Миланковићев календар али ће се ово питање вероватно често поново отварати. Само код нас, јер у свету, реформисани календар се назива Новојулијански и разматрано питање се не поставља.

Литература

Јанковић, Ненад: 1984, Зборник радова VII националне конференције, 103.
Кечкић, Јован Д.: 2001, *Флогистон*, **11**, 47.
Lichtenberg, Heiner: 1994, *Sterne und Weltraum*, **33**, 194.
Mijatović, M., Trajkovska, V.: 2001, Balkan meeting of young astronomers, 25-29 september 2000, Belogradchik, Bulgaria, Proceedings, eds. A. Antov, R. Konstantinova-Antova, R. Bogdanovski, M. Tsvetkov, Belogradchik, 43.
Миланковић, Милутин: 1997, Реформа Јулијанског календара, у: Изабрана дела, књ. 5, Завод за уџбенике и наставна средства, Београд, 31-72.
Oriani, Barnaba: 1785, De usu fractionum continuarum ad inveniendos ciclos calendarii novi et veteris, Ephemerides Astronomicae Anni 1786, Mediolani (Milano), pp. 132-154.
Perron, Oskar: 1929, Die Lehre von den Kettenbrüchen, 2. verb. Auflg., München.
Петровић, Мирјана: 2002, *Флогистон*, **12**, 257.
Трајковска Веселка: 2005, овај зборник, стр. 335.

IS THE NEW JULIAN CALENDAR ADOPTED ON 1923 IN CONSTANTINOPLE MILANKOVIĆ-, MILANKOVIĆ-TRPKOVIĆ-, OR TRPKOVIĆ-MILANKOVIĆ- ONE?

Facts about the reform of the Julian calendar, adopted in 1923 in Constantinople, with contributions of Milutin Milanković, Maksim Trpković and Barnaba Oriani are analyzed.

[5] Напоменимо да је у доба Христовог рођења она била 23. марта.

Зборник радова конференције "Развој астрономије код Срба III"
Београд 25-28. април 2004,
уредник М. С. Димитријевић
Публ. Астр. друш. "Руђер Бошковић" бр. 6, 2005, 47-54

НАША ПРЕПИСКА О АСТРОНОМСКОЈ ОПСЕРВАТОРИЈИ У 1941. И 1942. ГОДИНИ

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[3]München, Germany

Резиме. Представљена је преписка аутора у којој се разматра питање времена које је Војислав Мишковић, директор Астрономске опсерваторије у Београду, провео 1941. као таоц на Бањици, борба 1941-1942. да спектрохелиограф остане на Астрономској опсерваторији и његова судбина.

Септембра 2002, један од аутора (М.С.Д.), добио је e-mail од другог (М.П.С.), у коме га је овај обавестио да пише књигу о истраживањима Сунца у Трећем рајху и замолио да га обавести да ли је директор Астрономске опсерваторије Војислав Мишковић био у току 1941. ухапшен и колико времена је био отсутан. После одговора на ово, следило је још неколико питања везаних за истраживани период. Овде је представљена поменута преписка у којој су расветљавана питања одвођења 1941. године Војислава Мишковића у логор на Бањици као таоца и руковођења Опсерваторијом у том периоду, као и његово организовање Службе Сунца, борба да спектрохелиограф остане на Опсерваторији и коначна судбина овог инструмента.

ПРЕПИСКА*

From mdimitrijevic@aob.aob.bg.ac.yu Date: Sat, 2 Nov 2002 19:24:50 +0100 (CET)

Dear Mr Seiler,

Thank you very much for your message from 10 september concerning V. Miskovic and sorry for late answer since I was not at the Observatory. I tried to

* Наведен је оригиналан текст уз нужне исправке очигледних грешака, као и убацивање специфичних латиничних слова.

investigate your question in more detail. In M. Indjić, Scientific activity of Academician Vojislav Mišković, Bulletin Astronomique de Belgrade No 154, 1996, 167 is stated that "he was detained as a hostage for two months in the Banjica prison in 1941." In my paper: M. S. Dimitrijević, Astronomy in Serbia (in Serbian), Publications of the Astronomical Observatory of Belgrade, No 64, 1999, 19 is stated that in 1936, Mišković with the help of M. B. Protić organizes the Service for Solar observations. In L. Č. Popović and M. Radovanac, Astronomical Observatory during the II world war (in Serbian) Publ. Astron. Obs. Belgrade No 71, 2002, 133 is stated that due to absence of astronomers, in July 1941, Mišković took himself Service on the Small refractor with the task to examine possibility to photograph regularly the Sun and to observe visible occultations. I checked in the Observatory archive and exist a period in November - December 1941 when doccuments have been signed not by Mišković but by Anton Bilimović and Miloš Radojčić. The last document signed by Mišković is dated 1st November 1941 and than he starts again to sign documents in the beginning of January 1942. It seems than, that in November and December 1941 he was detained as a hostage.

I will be very greateful to you if when your work will be published you send to me a copy.

I am sending to you my best wishes.

Milan S. Dimitrijević

From MPSeiler@aol.com Date: Thu, 7 Nov 2002 13:58:15 EST

Dear Mr. Dimitrijević,

Thank you very much for your answer which was very helpful. Do you have any information about the exact date that the spectroheliograph was taken away from Belgrade?

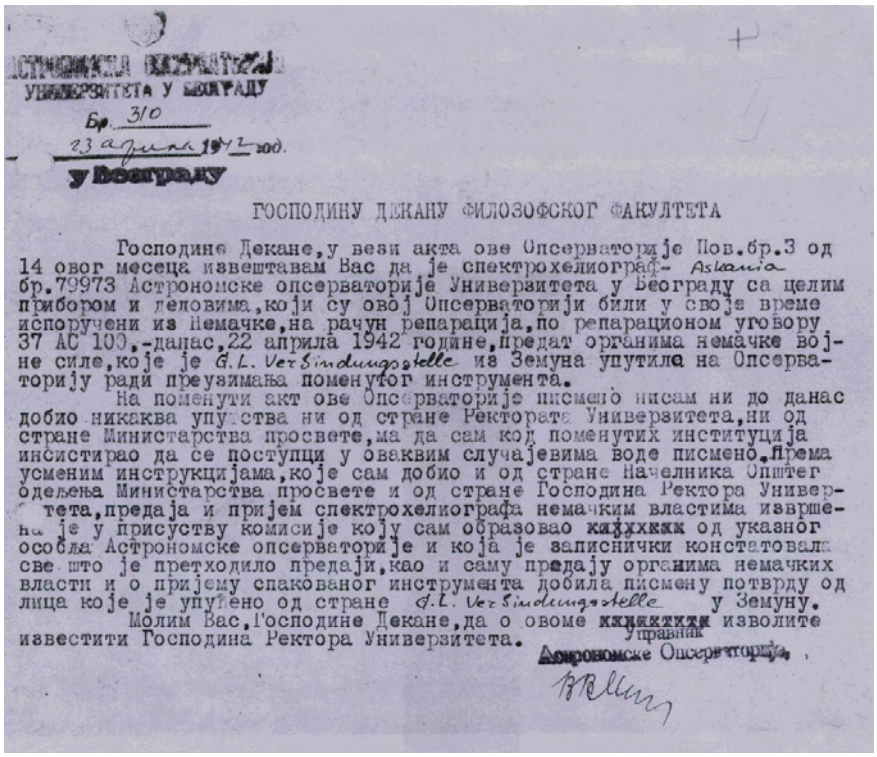
It is worthwhile to note that when the Germans came in June of 41, it was still packed in its original wooden box and was apparently never used, because a coelostat was missing. Kiepenheuer wanted to install a Coelostat in September. I suspect that the spectroheliograph did never work, since it was moved to the Meudon observatory workshop near Paris for adjustment in early 1942. The spectroheliograph and the comet finder were then moved to Syracuse in Sicily where a small solar observatory was erected near the beach. It operated from July 42 to June 43, until the Allies landed on the beaches. Apparently, it was plundered or destroyed during the battle.

If you send me your postal address, I will be glad to send you a copy of my work, once its published.

Best regards,

Michael P. Seiler

From mdimitrijevic@aob.aob.bg.ac.yu Date: Fri, 8 Nov 2002 18:06:02 +0100 (CET)



УНИВЕРЗИТЕТА У БЕОГРАДУ

Бр. 310

23 априла 1942 год.

у Београду

ГОСПОДИНУ ДЕКАНУ ФИЛОЗОФСКОГ ФАКУЛТЕТА

Господине Декане, у вези акта ове Опсерваторије Пов.бр.3 од 14 овог месеца извештавам Вас да је спектрохелиограф- Askania бр.79973 Астрономске опсерваторије Универзитета у Београду са целим прибором и деловима, који су овој Опсерваторији били у своје време испоручени из Немачке, на рачун репарација, по репарационом уговору 37 АС 100,-данас, 22 априла 1942 године, предат органима немачке војне силе, које је G.L. Ver Sindungsstelle из Земуна упутила на Опсерваторију ради преузимања поменутог инструмента.

На поменути акт ове Опсерваторије писмено нисам ни до данас добио никаква упутства ни од стране Ректората Универзитета, ни од стране Министарства просвете, ма да сам код поменутих институција инсистирао да се поступци у оваквим случајевима воде писмено. Према усменим инструкцијама, које сам добио и од стране Начелника Општег одељења Министарства просвете и од стране Господина Ректора Универзитета, предаја и пријем спектрохелиографа немачким властима извршена је у присуству комисије коју сам образовао ххххххх од указног особља Астрономске опсерваторије и која је записнички констатовала све што је претходило предаји, као и саму предају органима немачких власти и о пријему спакованог инструмента добила писмену потврду од лица које је упућено од стране G.L. Ver Sindungsstelle у Земуну.

Молим Вас, Господине Декане, да о овоме ххххххх изволите известити Господина Ректора Универзитета.

Управник

Астрономске Опсерваторије

Слика 1. Допис Војислава Мишковића Декану Филозофског факултета од 14. априла 1941.

Dear Mr Seiler

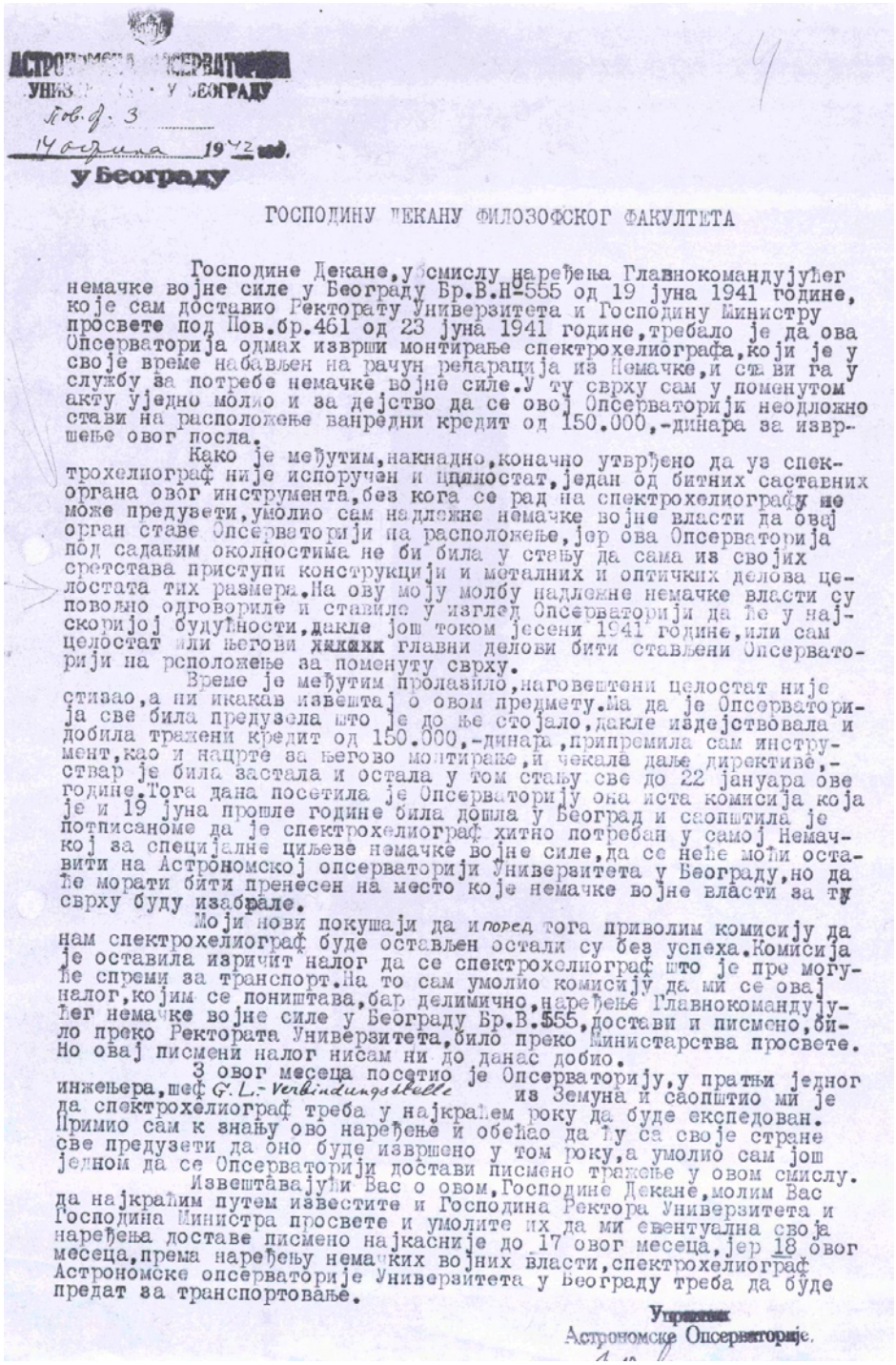
Thank you very much for your message. Concerning spectroheliograph, Miskovic struggled very hard to keep spectroheliograph in Belgrade and to obtain a credit of 150 000 dinars for the construction of a pavilion for this instrument. He succedeed to obtain promiss for credit and even received a promisse to obtain from Germany celostat in the autumn of 1941. However, a German commission who visited Observatory on 22. 01. 1942 decided to take it (Report No. 3, of 14. 04. 1942) and the spectroheliograph has been taken on 22. 04. 1942 (L. Č. Popović, M. Radovanac: 2002, Astronomical observatory during the Second world war (in serbian), Publ. Astron. Obs. Belgrade, No 72, 133).

My address is

Milan S. Dimitrijević Astronomical Observatory Volgina 7, 11160 Belgrade Yugoslavia

I am sending to you my best wishes.

Milan S. Dimitrijević



Астрономска опсерваторија
Универзитет у Београду
Бев. бр. 3
14 априла 1942 год.
у Београду

ГОСПОДИНУ ДЕКАНУ ФИЛОЗОФСКОГ ФАКУЛТЕТА

Господине Декане, у смислу наређења Главнокомандујућег немачке војне силе у Београду Бр.В.н-555 од 19 јуна 1941 године, које сам доставио Ректорату Универзитета и Господину Министру просвете под Пов.бр.461 од 23 јуна 1941 године, требало је да ова Опсерваторија одмах изврши монтирање спектрохелиографа, који је у своје време набављен на рачун репарација из Немачке, и стави га у службу за потребе немачке војне силе. У ту сврху сам у поменутом акту уједно молио и за дејство да се овој Опсерваторији неодложно стави на расположење ванредни кредит од 150.000,-динара за извршење овог посла.

Како је међутим, накнадно, коначно утврђено да уз спектрохелиограф није испоручен и цијелостат, један од битних саставних органа овог инструмента, без кога се рад на спектрохелиографу не може предузети, умолио сам надлежне немачке војне власти да овај орган ставе Опсерваторији на расположење, јер ова Опсерваторија под садањим околностима не би била у стању да сама из својих сретстава приступи конструкцији и металних и оптичких делова целостата тих размера. На ову моју молбу надлежне немачке власти су повољно одговориле и ставиле у изглед Опсерваторији да ће у најскоријој будућности, дакле још током јесени 1941 године, или сам целостат или његови главни делови бити стављени Опсерваторији на расположење за поменуту сврху.

Време је међутим пролазило, наговештени целостат није стизао, а ни икакав извештај о овом предмету. Ма да је Опсерваторија све била предузела што је до ње стојало, дакле издејствовала и добила тражени кредит од 150.000,-динара, припремила сам инструмент, као и нацрте за његово монтирање, и чекала даље директиве, ствар је била застала и остала у том стању све до 22 јануара ове године. Тога дана посетила је Опсерваторију она иста комисија која је и 19 јуна прошле године била дошла у Београд и саопштила је потписаноме да је спектрохелиограф хитно потребан у самој Немачкој за специјалне циљеве немачке војне силе, да се неће моћи оставити на Астрономској опсерваторији Универзитета у Београду, но да ће морати бити пренесен на место које немачке војне власти за ту сврху буду изабрале.

Моји нови покушаји да и поред тога приволим комисију да нам спектрохелиограф буде остављен остали су без успеха. Комисија је оставила изричит налог да се спектрохелиограф што је пре могуће спреми за транспорт. На то сам умолио комисију да ми се овај налог, којим се поништава, бар делимично, наређење Главнокомандујућег немачке војне силе у Београду Бр.В.555, достави и писмено, било преко Ректората Универзитета, било преко Министарства просвете. Но овај писмени налог нисам ни до данас добио.

З овог месеца посетио је Опсерваторију, у пратњи једног инжењера, шеф G. L.- Verbindungsstelle из Земуна и саопштио ми је да спектрохелиограф треба у најкраћем року да буде експедован. Примио сам к знању ово наређење и обећао да ћу са своје стране све предузети да оно буде извршено у том року, а умолио сам још једном да се Опсерваторији достави писмено тражење у овом смислу.

Извештавајући Вас о овом, Господине Декане, молим Вас да најкраћим путем известите и Господина Ректора Универзитета и Господина Министра просвете и умолите их да ми евентуална своја наређења доставе писмено најкасније до 17 овог месеца, јер 18 овог месеца, према наређењу немачких војних власти, спектрохелиограф Астрономске опсерваторије Универзитета у Београду треба да буде предат за транспортовање.

Управник
Астрономске Опсерваторије.

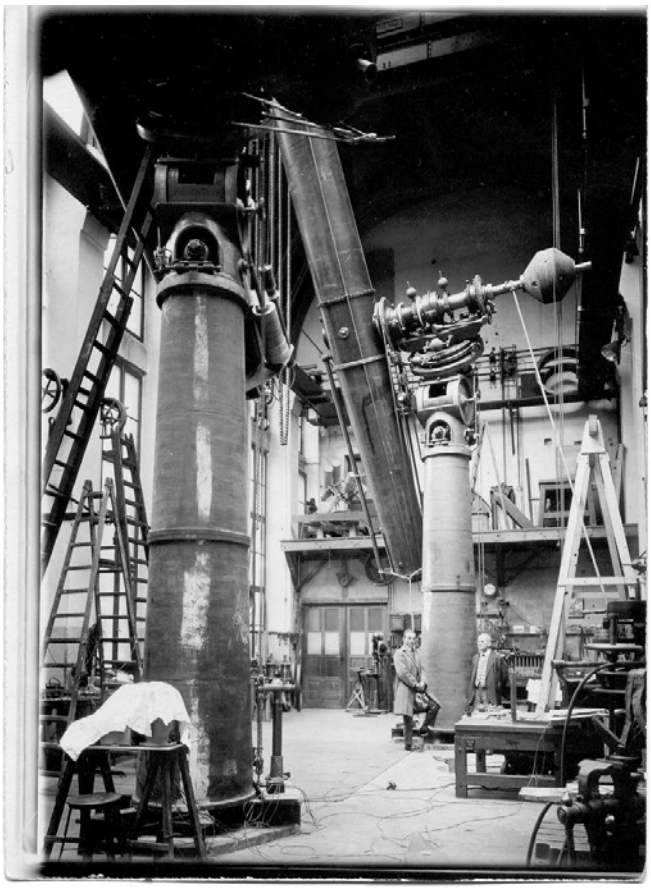
Слика 2. Допис Војислава Мишковића Декану Филозофског факултета од 23. априла 1941.

From MPSeiler@aol.com Date: Sat, 23 Nov 2002 13:41:03 EST

Dear Mr. Dimitrijević,

Thank you for your detailed e-mail and address. Before I can conclude the Belgrade chapter, I have one final question which I hope you will be able to answer. Based on local documents the coelostat was actually mounted by the Germans in September 41 in Belgrade, so that the spectroheliograph would have been operational. The documents also say that Yugoslav partisans have destroyed the coelostat mechanics soon afterwards, rendering the system inoperable. Can you confirm this ?

Best regards, Michael P. Seiler



Слика 3. Војислав Мишковић (са леве стране) 1930. године у фабрици Карл Цајс у Јени са рефрактором од 65 цм направљеним за Београдску опсерваторију.

From mdimitrijevic@aob.aob.bg.ac.yu Date: Fri, 29 Nov 2002 14:29:30 +0100 (CET)

Dear Mr. Seiler,

Thank you very much for your e-mail. I investigated your question in the Archyves of Belgrade Observatory and I found the following. During June, July and August 1941 Mišković have a real dyplomatic battle on two fronts: with German authorities for spectroheliograph, which Germans wanted to take and with Rectorat of the Belgrade University and Decanat of the Faculty of Phylosophy to obtain a credit of 150 000 dinars to construct a pavillion for it. He obtained from Germans a promiss that the missing celostat will arrive from Germany during the autumn of 1941. However the celostat never came to Observatory.

In his letter to Dean of the Phylosophycal Faculty dated 14th April 1942 (Confidential No 3), he said that he sent to Rectorat and Minister of Education (Confidential. No. 461 from 23rd June 1941) order of the Head of the German military power in Belgrade V-555 from 19th June 1941 that imediately Astronomical observatory should mount spectroheliograph and put it in the service of German military power. He remind that in order to do so he asked from Belgrade University a credit of 150 000 din for this job. Since after that it was found that celostat was not ordered with other equipment and is missing, he obtained promiss from German military authorities that in the near future, during autumn 1941, or the whole celostat or its principal parts will come to Observatory.

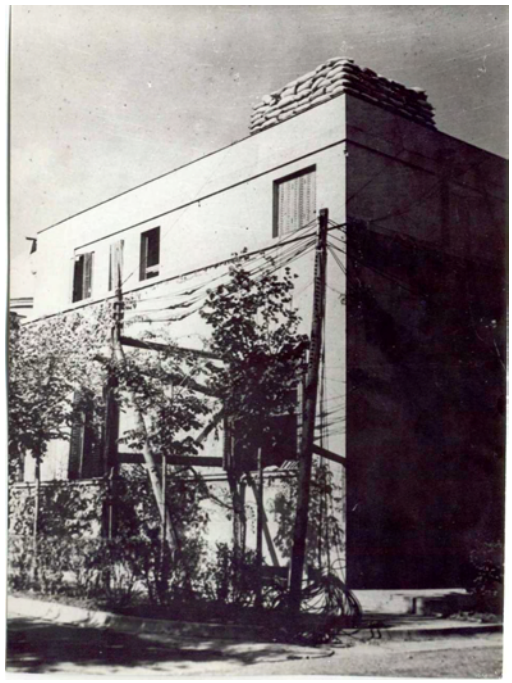
However neither celostat nor a report of this case never came to Observatory, until 22 January 1942 when the same comission which prepared order of 19 June came to Observatory, and told to him that spectroheliograph is urgently needed in Germany for special objectives of German military power, and that should be transported to the place which will be chosen by German military authorities.

On 3 April 1942, Opservatory visited the head of G. L. Verbindungsstelle from Zemun accompanied with an engineer and told that spectroheliograph should be expedited urgently. He asked a written order but without result. He inform Dean on this facts ask him to inform Rector and Minister of education and ask the written instruction since he should give spectroheliograph on 18 April 1942.

In the letter to the Dean dated 23 April 1942, he inform him that spectroheliograf Askania No 79973 with all equipment deliverd to Obsertvatory in accordance to reparation contract 37 AS 100, has been given on 22 April 1942 to German military organs from G. L. Verbindungsstelle from Zemun. Consequently, celostat was never delivered and mounted on Observatory and if it was destroyed by partisans during the transport from Germany, Miskovic never has been informed about that.

I am sending to you my best wishes and I am very interesting to receive in future your works on this and simillar subject.

Milan S. Dimitrijević



Слика 4. Немачка инсталација за противавионску одбрану на крову југоисточног крила главне зграде 1943. године.

From MPSeiler@aol.com Date: Thu, 12 Dec 2002 14:43:27 EST

Dear Mr. Dimitrijević,

Since you have helped me so good with information, maybe you can help me with historic photographs as well. To illustrate my publication I would be interested in photos of the observatory during Nazi occupation, especially if they would show Miskovic together with some of the German astronomers. Would this be available in your archives ?

Best regards, Michael P. Seiler

From mdimitrijevic@aob.aob.bg.ac.yu Date: Wed, 1 Jan 2003 11:44:35 +0100 (CET)

Dear Mr Seiler,

I wish you a happy, joyful, and successful New 2003 year with a lot of joy and realisation of all your plans.

Concerning photos, I was surprised that in our archive there is no photos from war period. I do not know the reasons. I can only assume that, since Observatory had also military importance, this was not allowed regularly, or since photos are

not a usuall archive material in an institution like this. However I succeded to find in family albums of old astronomers two photos which may be interesting for you. The first is taken in 1943 and represent a German anti air attack instalation on the roof on the south east wing of the Main building. The second represent Vojislav Miskovic in 1930, (he is on the left) in Karl Zeiss factory in Jena with the refractor 65cm finished for Belgrade Observatory.

If I can help you additionaly, do not hesitate to send me a message.

All the best

Milan S. Dimitrijević

From MPSeiler@aol.com Date: Wed, 1 Jan 2003 06:29:04 EST

Dear Mr. Dimitrijević,

Also to you all the best for the New Year 2003 and again thank you very much for all your help so far. It is really difficult to get photographs of the solar observatories made during the war and I believe you are right that this was because of military security reasons. It is also my experience that these are mainly in private files. Unfortunately, many people have died already and material of historical significance was thrown away by the families. All the more I am very thankful for your two photos, but maybe you can mail me the file with the Mišković photo in the same format as the second photo, since I cannot open it with any of the softwares that I have?

Best regards,

Michael P. Seiler

Захвалница

Један од аутора (М.С.Д.) захваљује се Милану Радованцу који му је помогао у налажењу одговарајућих архивских података и Војислави Протић – Бенишек чијом је љубазношћу добио две, у чланку поменуте, фотографије (Сл. 3 и 4).

Овај рад је урађен у оквиру пројекта 1471 *Историја астрономије код Срба*, код Министарства за науку и заштиту животне средине Републике Србије.

OUR EXCHANGE OF MESSAGES ON ASTRONOMICAL OBSERVATORY IN 1941 AND 1942

Author's messages considering the question when in 1941, Vojislav Mišković, director of Belgrade Astronomical Observatory, was as hostage in Banjica, are presented, as well as his strugle to keep the spectroheliograph on Observatory and the final destiny of this instrument.

Physics of
Ionized Gases
Edited by D.Veza

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SEMICLASSICAL AND APPROXIMATE METHODS FOR STARK-BROADENING INVESTIGATIONS OF ASTROPHYSICAL AND LABORATORY SPECTRA

Milan S. Dimitrijević
Astronomical Observatory, Volgina 7, 11050 Beograd, Yugoslavia

1. INTRODUCTION

As the typical information in astronomy is obtained by analyzing the radiation, the understanding of astrophysical spectral line shapes is of great importance. Spectral line shapes enter the analysis of a stellar spectrum essentially in two ways:

a) Selected lines from which we may derrive information about stellar parameters require reliable line shape theory and data of high accuracy for the contribution of main broadening mechanism.

b) For the bulk of (> 10°) lines, as well as for smaller contributions to the main broadening mechanisms, broadening parameters of only modest accuracy are sufficient and we need only the good average accuracy while the accuracy for a particular line is not so important.

Stellar spectroscopy depends on very extensive list of elements and line transitions with their atomic and line broadening parameters. It is difficult to state in general terms which are the relevant transitions since the atmospheric composition of a star is not known a priori, and many interesting groups of stars exist with very peculiar abundances as compared to the Sun.

The interest for a very extensive list of line broadening data is additionally stimulated by spectroscopy from space. In such a manner an extensive amount of spectroscopic information over large spectral regions of all kind of celestial objects has been and will be collected, stimulating the spectral-line-shape research.

Here is presented a review of semiclassical calculations of Stark broadening parameters and comparison of different semiclassical procedures is discussed, as well as the agreement with critically selected experimental data and more sophysticated, close coupling calculations. We also present approximate methods for the calculation of Stark broadening parameters, usefull especially in such astrophysical problems where large scale calculations and analyses must be performed and where a good average accuracy is expected.

2. STARK BROADENING IN ASTROPHYSICS

Among the various pressure broadening mechanisms, broadening due to interaction between emitter and charged particles (Stark broadening) is dominant in several cases. For $T_{eff} > 10^4$ K, hydrogen, the main constituent of a stellar atmosphera is mainly ionized, and the main collisional broadening mechanism for spectral lines is the Stark effect. This is the case for white dwarfs and hot stars of O, B and A0 type. Even in cooler star atmospheres as e.g./ Solar one, Stark broadening may be important. For example, the influence of Stark broadening within a spectral series increases with the increase of the principal quantum number of the upper level [1-3] and Stark broadening contribution may become significant in the Solar spectrum [4-6].

A good example are high member Balmer series lines, a powerful diagnostic tool in studying stellar atmospheres. In Ref. [7], profiles of Balmer series members with the principal quantum number n between 16 and 32 (strongly influenced by Stark effect) have been used to determine the electron density and the temperature over an active Solar region. In Fig. 1 we can see the precision of such measurement and conclude how it depends on details and accuracy of the Stark broadening theory.

An important problem where we need reliable Stark broadening data is also the determination of chemical abundances of elements from equivalent widths of absorption lines. Stark broadening data are also required for the estimation of the radiative transfer through the stellar plasmas, especially in subphotospheric layers and for opacity calculations. In such a case data for especially large numbers of lines are needed. An illustrative example might be the article on the calculation of opacities for classical cepheid models [8], where 11,996,532 spectral lines have been taken into account, and where Stark broadening is important. In order to give an impression on astrophysical needs in line broadening data, in Table 1 is given the distribution over atomic species of the number of spectral lines taken into account for opacity calculations in Ref. [8].

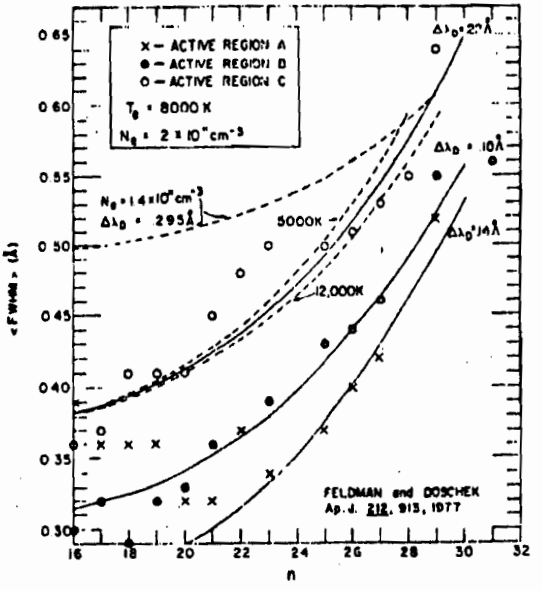

Figure 1. Stark broadening of high member series lines at 2'' above the limb over active regions. The electron density of 2 x 10^{11} cm^{-3} is an average of the actual values. The dashed curve with an electron density of 1.4 x 10^{11} cm^{-3} is fitted to the data at n = 29. Here, n is the principal quantum number of the upper atomic energy level, T_e is the electron temperature and full half width at half maximum of the corresponding spectral line is denoted as <FWHM> while with $\Delta\lambda_D$ is denoted Doppler width. The figure is taken from Ref. [7].

Another interesting case where Stark broadening is the dominant pressure broadening mechanism are radio recombination lines from interstellar clouds of ionized and neutral hydrogen. Here, the principal quantum numbers may be even several hundreds. In such atoms the optical electron is far from the nucleus and very sensitive to the weak electric field fluctuations. Consequently, the Stark broadening is the main collisional broadening mechanism in this case.

Table 1. The number of spectral lines of various atomic species taken into account for opacity calculations for classical cepheid models, by Iglesias, Rogers and Wilson [8].

Element	Number of spectral lines
H	45
He	45
C	638
N	54
O	2390
Ne	16030
Na	50170
Mg	105700
Al	145200
Si	133700
Ar	12560
Fe	11530000

3. SEMICLASSICAL METHOD

In a lot of cases such as e.g. complex spectra, heavy elements or transitions between more excited energy levels, the more sophysticated quantum mechanical approach is very difficult or even practically impossible to use and, in such cases, the semiclassical approach remains the most efficient method for Stark broadening calculations.

Within the semiclassical model, the radiating (absorbing) atom is described quantum mechanically while perturbers are classical particles with well defined velocity (v) and impact parameter (ρ). The system of classical perturbers acts on the quantum mechanical atom via classical, time dependent interaction potential. The Schrödinger equation which is satysfied by the atomic wave functions is usually solved using the second order non stationary perturbation theory.The existing large scale calculations of Stark broadening parameters were performed by using three differentcomputer codes, developed by (i) Jones, Benett and Griem [9-11], (ii) Sahal-Bréchot [12,13] and (iii) Bassalo, Cattani and Walder [14].

Within the frame of the semiclassical theory, half half width (w) and shift (d) of an isolated line may be expressed via S matrix as [e.g. 11]

$$w + id = N \int vf(v)dv \int 2\pi\rho d\rho \, (1 - S_{ii}(\rho,v)S_{ff}^{-1}(\rho,v))_{Av} \quad (1)$$

Here, N is the electron density, f(v) is the Maxwellian velocity distribution function for electrons, i and f denote

the initial and final atomic energy levels, and i′ and f′ are their corresponding perturbing levels, while $(\ldots)_{AV}$ denotes the angular average over the directions of the colliding electrons.

If one express the relevant inelastic cross sections via corresponding S matrix elements which are proportional to the transition probability $P_{jj'}$ [12,13], one obtains the formulae which enter the computer code of Sahal-Bréchot:

$$2w = N \int v f(v) dv \left[\sum_{i' \neq i} \sigma_{ii'}(v) + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_{el} \right], \quad (2)$$

$$d = N \int v f(v) dv \int_{R_3}^{R_D} 2\pi\rho \, d\rho \, \sin 2\phi_p \quad (3)$$

with

$$\sum_{j' \neq j} \sigma_{jj'}(v) = \frac{1}{2} \pi R_1^2 + \int_{R_1}^{R_D} 2\pi\rho \, d\rho \sum_{j' \neq j} P_{jj'}(\rho, v), \quad (4)$$

$$\sigma_{el} = 2\pi R_2^2 + \int_{R_2}^{R_D} 8\pi\rho \, d\rho \, \sin^2(\phi_p + \phi_q)^{1/2}. \quad (5)$$

The phase shifts ϕ_p and ϕ_q due respectively to the polarization potential (r^{-4}) and to the quadrupolar potential (r^{-3}) part, are given in the part 3 of Section 2 in the Ref. [12]. The contribution of resonances in the elastic cross sections is taken into account in the ion-line-width calculations according to Ref. [15]. The formulae for the ion impact broacdening are analogous but inelastic collisions are negligible.

In the computer code of Bassalo, Cattani and Walder, so called convergent theory, originally developed by Vainshtein and Sobel′man [16] has been used. Using the similarity between the Dyson series for S matrix perturbational development and Taylor series for exponential function, this method avoid the divergence in the integration over impact parameter when ρ tends to Ø [16].

Comprehensive calculations of Stark broadening parameters of non-hydrogenic neutral and singly ionized atom lines (helium through calcium and cesium) using the computer code of Jones, Benett and Griem, were published in 1971 and later in 1974 [9-11]. Using the same code [11] and the version adapted by Dimitrijevic for the case of multiply charged ions, data for Br I, Ge I, Hg I, Pb I, Rb I, Cd I, Zn I [17], O II [18], O III [19], C III [2Ø], C IV [2Ø,21], N II, N III, N IV [22], S III, S IV, Cl III [23] and Ti II, Mn II [24] have been published. Semiclassical calculations based on the method developed by Sahal-Bréchot [12,13] exist for

lighter elements such as C, N, Mg, Si (without the contribution of resonances [see e.g. 25 and References therein]. Data for alkali like ions Be II, Mg II, Ca II, Sr II and Ba II may be found in Ref. [15], while in Ref. [25] the semiclassical and experimental data for the low-excitation Si II lines have been compared. Recently, using the same computer code, extensive calculations for 79 neutral helium multiplets [27-31], 62 sodium [32-34], 51 potasium [35,36], and 61 lithium multiplets [37,38] for perturber densities 10^{13} - 10^{19} cm^{-3} become available. Data forF I [39], Ar II [40], Ga II, Ga III [41] also exist. Using this code, Lanz et al. [42] published recently a set of the Si II Stark broadening parameters required for stellar analysis.

Stark width values obtained by the code of Sahal-Bréchot are generally smaller (especially toward lower temperatures) than those obtained using the code according to Griem [11], due to the symmetrization procedure used by Sahal-Bréchot and due to different lower cut-offs. This difference becomes smaller if the contribution of resonances is taken into account. In the case of the Mg II resonance lines, the experimental data of Goldbach et al [43], chosen after the critical analysis [44] as very reliable, agree better with the results obtained using the procedure of Sahal-Bréchot, as well as a number of experimental data in the case of the Si II multiplet 1 [26] (see Fig. 2). However, a general conclusion is difficult to obtain [see e.g. Ref.29], since different assumptions involved in these two versions of the semiclassical method have different validity conditions.

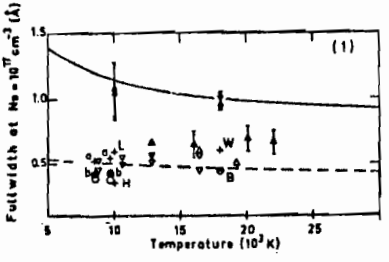

Fig. 2 Line widths for Si II multiplet 1 at electron density 10^{17} cm^{-3} vs temperature. Experimental data : ▲, Lesage et al [26]; ○, Konjević et al [45]; ▽, ▼, △, Purić et al [46-48]; ●, Lesage et al [49]; ◆, Chiang et Griem [50]. Theoretical data: (i) Semiclassical calculations: ——— Griem [11]; ----- Sahal-Bréchot [in Ref. 49]; (ii) Distorted wave calculations: ⊖ Blaha [in Ref. 50]; (iii) Semiempirical calculations: Konjević et al [45] treating perturbing levels together (+a) and individually (+b); Lesage et al [49] (+L); Hey [50] (+H); Jones [51] (+W).

Extensive calculations by Bassalo, Cattani and Walder obtained using the convergent semiclassical method exist for He I lines.

All three methods have been compared with critically selected experimental data for 13 He I multiplets [29]. In order to estimate the average accuracy of different methods, ratios of experimental and theoretical values have been averaged first in multiplet and then over the number of multiplets. Obtained results are presented in Table 2. One can see that the agreement between experimental and all three semiclassical calculations is within the limits of ±20%, what is the predicted accuracy of the semiclassical method [11].

Table 2. Average accuracy of different theoretical methods compared to Stark width (W_m) and shift (d_m) experimental data for helium lines. The results in parentheses are obtained by excluding the $2p^3D - 3d^3D$ line which exhibits a strong unexplained difference between d_m and the calculated shift (especially for d_{DSB} and d_{BG}). With DSB are denoted the data from Ref.[1] with BCW the data from Ref.[14] and with BGthe data from Ref[9] (also in Ref. [11]) (The table is from Ref. [29]).

	All experiments included	Experiments with C and D accuracy (according to Refs. [51, 52]) excluded
$(W_m/W_{DSB})_{av}$	1.17±0.04	1.17 ±0.02
$(W_m/W_{BCW})_{av}$	1.07±0.04	1.07±0.04
$(W_m/W_{BG})_{av}$	0.92±0.04	0.93±0.02
$(d_m/d_{DSB})_{av}$	1.20±0.13 (1.07±0.04)	1.13±0.03
$(d_m/d_{BCW})_{av}$	1.23±0.08 (1.27±0.07)	1.34±0.09
$(d_m/d_{BG})_{av}$	1.14±0.07 (1.07±0.04)	1.14±0.03

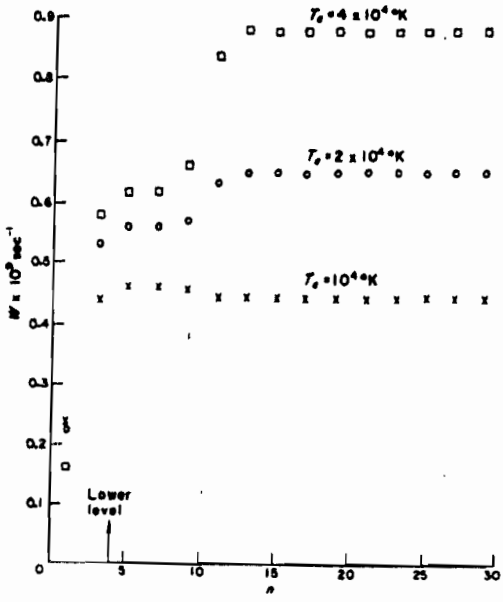

Fig.3. W vs. n number of perturbing levels used in calculation (Ar II, λ=4806 A) (From. Ref. [53]).

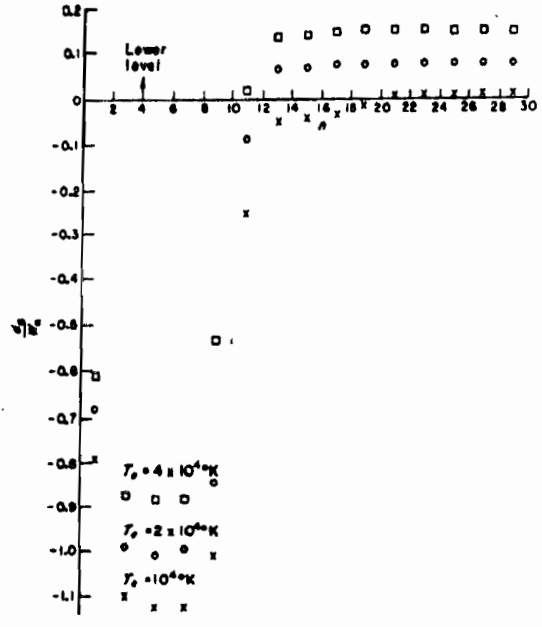

Fig. 4. d/W vs. number n of perturbing levels used in calculation (Ar II, λ=4806 A) (From. Ref. [53]).

Generally, the width data are more reliable than the shift data, since shift calculations are more sensitive to the small variations of various parameters. The reason is because shifts are smaller than widths and produced in average by more distant collisions. Roberts [53] performed an analysis of the width and shift values convergence (see Figs.3 and 4) in the function of the number of perturbing levels, demonstrating that in the case of the shift, even the sign may be changed if the unsufficient number of perturbing levels is used.

4. APPROXIMATE METHODS

Whenever line broadening data for a large number of lines are required, and the' high precision of every particular result is not so important, simple approximative formulae with good average accuracy may be very useful. Moreover, in the case of more complex atoms or multiply charged ions the lack of the accurate atomic data needed for more sophysticated calculations, makes that the reliability of the semiclassical results decreases. In such cases approximate methods might be very interesting.

We might devide all approximate methods for calculations of Stark broadening parameters in the three groups. In the first one are methods where the most complicated part of the calculation, the cross sections for the corresponding dipole transitions are calculated using averaged experimental [e.g. 54-60] or theoretical [61] data. In the second group, one might put methods where the most complicated part is obtained by the symplifications in the more sophysticated theory [e.g.11] or e.g. by interpolation between theoretically simpler limits [e.g. 63]. In the third group are the possibilities for the interpolation of new data by using regularities and systematic trends [e.g. 64-71].

For the astrophysical purposes, of particular interest might be the symplified semiempirical formula [58] for Stark widths of isolated, singly, and multiply charged ion lines applicable in the cases when the nearest atomic energy level (j'=i'or f')where a dipolly allowed transition can occur from or to initial (i) or final (f) energy level of the considered line, is so far, that the condition $x_{jj'} = E/|E_{j'} - E_j| \leq 2$ is satisfied. In such a cases full width at half maximum is given by the expression [58]:

$$W(A) = 2.2151\ 10^{-8}\ \frac{\lambda^2(cm)\,N(cm^{-3})}{T^{1/2}(K)}\ (0.9 - \frac{1.1}{Z})\ .$$

$$\sum_{j=i,f}\left(\frac{3n_j}{2Z}\right)^2 (n_j^2 - \ell_j^2 - \ell_j - 1) \qquad (6)$$

Here, N and T are the electron density and temperature respectively, E = 3kT/2 is the energy of perturbing electron, Z-1 is the ionic charge and n the effective principal quantum number. This expression is of interest for abundance calculations, as well as for stellar atmospherae research, since the validity conditions are often satysfied for stellar plasma conditions.

Similarly, in the case of the shift

$$d = 1.1076\ 10^{-8}\ \frac{\lambda^2(cm)\ N(cm^{-3})}{T^{1/2}(K)}\ (0.9 - \frac{1.1}{Z})\ \frac{9}{4Z^2}$$

$$\sum_{j=i,f} \frac{n_j\ \varepsilon_j^{*2}}{2\ell_j+1}\ \{\ (\ell_j + 1)\ [n_j^{*2} - (\ell_j + 1)^2] -$$

$$-\ \ell_j\ (n_j^{*2} - \ell_j^2)\ \},\qquad (7)$$

where ε_j = +1 if j = i and -1 if j = f.

If all levels $\ell_{i,f} \pm 1$ exist, an additional summation may be performed in equation (7) to obtain

$$d = 1.1076\ 10^{-8}\ \frac{\lambda^2(cm)\ N(cm^{-3})}{T^{1/2}(K)}\ (0.9 - \frac{1.1}{Z})\ \frac{9}{4Z^2}$$

$$\sum_{j=i,f} \frac{n_j\ \varepsilon_j^{*2}}{2\ell_j+1}\ (n_j^{*2} - 3\ell_j^2 - 3\ell_j^2 - 1).\qquad (8)$$

When the symplified semiempirical formula is not applicable, the good possibilities gives the modified semiempirical method [55, 56, 58-60]. In order to test the modified semiempirical approach, selected experimental data for 36 multiplets (7 different ion species) of triply-charged ions were compared with theoretical linewidths. The averaged values of the ratios of measured to calculated widths are as follows [55]: for doubly charged ions 1.06 ± 0.32 and for triply-charged ions 0.91± 0.42. Furthermore, in order to test the equations obtained for low temperature limit of modified semiempirical formula (symplified semiempirical formula), comparison is made between the linewidth results from equation (6), results obtained using the modified semiempirical formula and previously mentioned selected experimental results, in the case when equation (6) may be applied (32 multiplrts). The average ratio of experimental and calculated values from the modified semiempirical

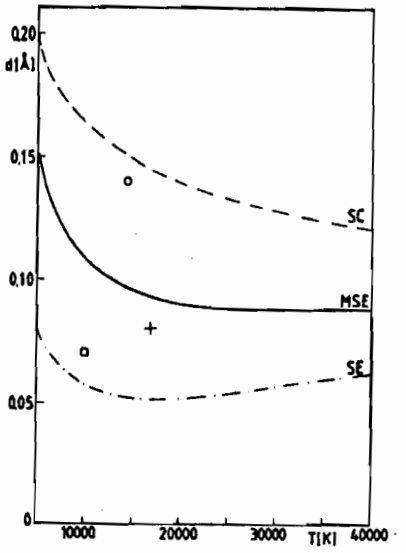

Fig. 5. Stark shifts for Mg II $3p^2P^o$ - $4s^2S$ multiplet. Calculations: MSE - modified semiempirical [59]; SE- semiempirical [59] according to Ref. [54]; SC- semiclassical [10]. Experimental points: + - Purić and Konjević [73]; o - Fleurier et al [15]. □ - Helbig and Kusch [74]; ■ - HÜhn and Kusch [75].(From Ref.[59].

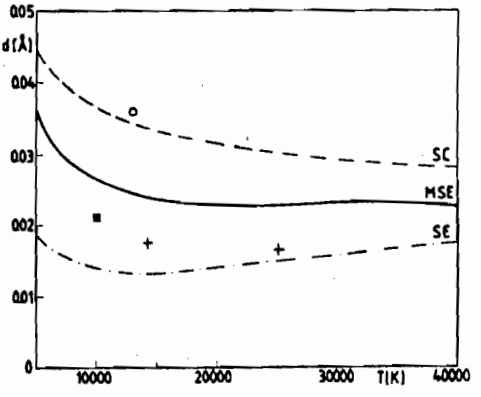

Fig. 6. Stark shifts for Ca II $4p^2P^o$- $5s^2S$ multiplet.Notation is the same as in Fig. 5. (From Ref. [59]).

approach and equation (6) are 1.Ø1 and 1.Ø4, respectively [58] Comparison is made also with the results of comprehensive width calculations for doubly and triply ionized atoms [56]. The discrepancy did not exceed ±3Ø% on the average [58]. Moreover, the modified semiempirical approach has been tested several times on numerous examples [72].

There is another field where approximative theories can be useful. That is the case of heavier elements. Atomic data for heavy element spectra are often insuficient for sophysticated semiclassical calculations. Moreover, the accuracy of usually applied approximations (e.g. Coulomb approximation) is lower for complex spectra. Additional time consuming sophystications (e.g. Thomas-Fermi model) are needed in order to achieve the same accuracy as in the case of lighter atoms. In such cases a reliable approximative method may be a useful tool for quick estimate of needed Stark widths.

5. REGULARITIES AND SYSTEMATIC TRENDS

When reliable data do not exist, the knowledge on regularities and systematic trends of line broadening parameters can be used for quick acquisition of new data especially when high accuracy of each particular value is not needed [see e.g. Refs. 64, 65, 76 and references therein].

The broadening of a line depends on both the dynamics of the individual emitter-perturber collisions and on the collective effect of all the perturbers interacting with the emitter. The relative importance of these factors depends on whether the perturber density is low or high. Line broadening depends also on the particle properties and consideration of the structure of emitting (or absorbing atom) indicates that similarities should exist for lines within a multiplet or supermultiplet. Widths also depend on perturber properties such as polarisability and should have a regular behaviour along spectral series, for corresponding transitions in homologous emitters, and for isoelectronic sequences.

Regularities and systemic trends for the widths of isolated non-hydrogenic spectral lines in plasmas have been studied recently in a number of papers [see for example 64-71, 76]. The aim of such studies is to find out if regularities and systematic trends can be used to predict line widths and to critically evaluate experimental data. As an example of possibilities of systematic trends investigations for quicq estimations and new data interpolations, regular behaviour of Stark widths and shifts within a spectral series of neutral potassium is presented in Figs. 7 and 8.

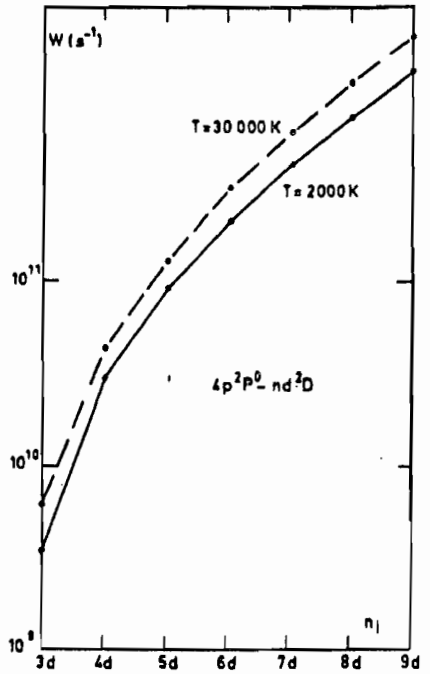

Fig.7. Semiclassical Stark ful halfwidths for K I $4p^2P^o$ - nd^2D lines as a function of n for the initial level and electron temperature. $N=1Ø^{15}cm^{-3}$(From Ref.[35]).

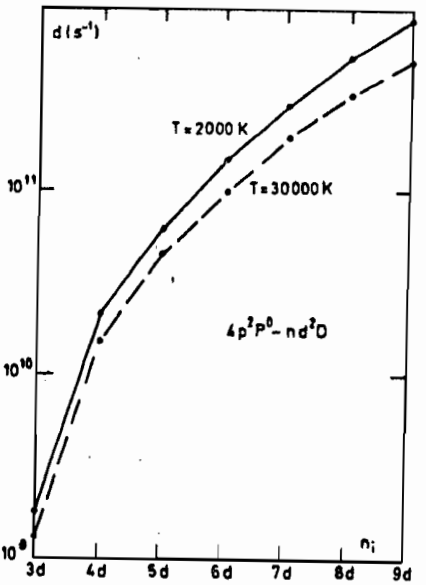

Fig. 8. As in Fig. 7 but for the shift (From Ref. [35]).

One must take into account however, that the validity of systematic trends and line broadening data is limited to the plasma conditions for which they are derrived and extrapolations are of low accuracy.

REFERENCES

[1] M.S.Dimitrijević, and S.Sahal-Bréchot, JQSRT 31, (1984) 301.
[2] M.S.Dimitrijević, and S.Sahal-Bréchot, Astron. Astrophys. 136, (1984) 289.
[3] M.S.Dimitrijević, and S.Sahal-Bréchot, JQSRT 34, (1985) 149.
[4] I.Vince, and M.S.Dimitrijević, Publ.Obs.Astron. de Belgrade No 33, (1985) 15.
[5] I.Vince, M.S.Dimitrijević, and V.Krčljanin, in Spectral Line Shapes III, ed. F.Rostas, W.de Gruyter, Berlin, New York (1985) p. 649.
[6] I.Vince, M.S.Dimitrijević, and V.Krčljanin, in Progress in Stellar Spectral Line Formation Theory, eds. J.Beckman and L.Crivelari, D.Reidel, Dordrecht, Boston, Lancaster (1985) p.373.
[7] U.Feldman, and G.A.Doschek, Astrophys.J. 212, (1977) 913.
[8] C.A.Iglesias, F.J.Rogers, and B.G.Wilson, Astrophys. J. 360, (1990) 221.
[9] S.M.Benett, and H.R.Griem, Calculated Stark Broadening Parameters for Isolated Spectral Lines from the Atom Helium through Calcium and Cesium, Univ. Maryland , Techn.Rep. No 71-097, College Park, Maryland (1971).
[10] W.W.Jones.S.M.Benett, and H.R.Griem, Calculated Electron Impact Broadening Parameters for Isolated Spectral Lines from Singly Charged Ions Lithium through Calcium, Univ. Maryland , Techn.Rep. No 71-128, College Park, Maryland(1971).
[11] H.R.Griem, Spectral Line Broadening by Plasmas, Academic Press, New York (1974).
[12] S.Sahal-Bréchot, Astron.Astrophys. 1, (1969) 91.
[13] S.Sahal-Bréchot, Astron.Astrophys. 2, (1969) 322.
[14] J.Bassalo, M.Cattani, and V.S.Walder, JQSRT 28, (1982) 75.
[15] C.Fleurier, S.Sahal-Bréchot, J.Chapelle, JQSRT 17, (1977) 595.
[16] L.A.Vainshtein, and I.I.Sobel'man, Opt.Spektrosk. 6, (1959) 279.
[17] M.S.Dimitrijević, and N.Konjević, JQSRT 30, (1983) 45.
[18] M.S.Dimitrijević, Astron.Astrophys. 112, (1982) 251.
[19] M.S.Dimitrijević, Publ.Obs.Astron.Sarajevo 1, (1980) 215.
[20] M.S.Dimitrijević, V ESCAMPIG, Dubrovnik (1980) p. 90.
[21] M.S.Dimitrijević, Bull.Obs.Astron.Belgrade 139, (1988) 31.

[22] M.S.Dimitrijević, and N.Konjević, JQSRT 25, (1981) 387.
[23] M.S.Dimitrijević, and N.Konjević, JQSRT 27, (1982) 203.
[24] M.S.Dimitrijević, in Sun and Planetary system, eds W.Fricke, G.Teleki, D.Reidel P.C., Dordrecht (1982) p. 101.
[25] S.Sahal-Bréchot, and S.Segre, in Highlights of Astronomy 2, ed. C. de Jager (1971) p.566.
[26] A.Lesage, Rathore,B.A., I.S.Lakićević, and J.Purić, Phys.Rev.A 28, (1983) 2264.
[27] M.S.Dimitrijević, and S.Sahal-Bréchot, JQSRT 31, (1984) 301.
[28] M.S.Dimitrijević, and S.Sahal-Bréchot, Astron. Astrophys. 136, (1984) 289.
[29] M.S.Dimitrijević, and S.Sahal-Bréchot, Phys.Rev.A 31, (1985) 316.
[30] M.S.Dimitrijević, and S.Sahal-Bréchot, Astron. Astrophys.Suppl.Series 82, (1990) 519.
[31] M.S.Dimitrijević, and S.Sahal-Bréchot, Bull.Obs. Astron.Belgrade 141, in press.
[32] M.S.Dimitrijević, and S.Sahal-Bréchot, JQSRT 34, (1985) 149.
[33] M.S.Dimitrijević, and S.Sahal-Bréchot, JQSRT in press.
[34] M.S.Dimitrijević, and S.Sahal-Bréchot, Bull.Obs. Astron.Belgrade 142, (1990) in press.
[35] M.S.Dimitrijević, and S.Sahal-Bréchot, JQSRT 38, (1987) 37.
[36] M.S.Dimitrijević, and S.Sahal-Bréchot, Bull.Obs. Astron.Belgrade (1990) in press.
[37] V.Vujnovic, C.Vadla, V.Lokner, and M.S.Dimitrijević, Astron.Astrophys. 123, (1983) 249.
[38] M.S.Dimitrijević, and Truong-Bach, Z.Naturforsch. 41a, (1986) 772.
[39] M.S.Dimitrijević, and M.C.Artru, XIII Symp.Phys. Ioniz.Gases, Sibenik (1986) p.317.
[40] T.Lanz, M.S.Dimitrijević, and M.C.Artru, Astron. Astrophys. 192, (1988) 249.
[41] C.Goldbach, G.Nollez, P.Plomdeur, and J.P.Zimmermann, Phys.Rev.A 25, (1982) 2596.
[42] N.Konjević, M.S.Dimitrijević, and W.L.Wiese, J.Phys. Chem.Ref.Data 13, (1984) 649.
[43] N.Konjević, J.Purić, Lj.Ćirković, and J.Labat, J.Phys.B 3, (1970) 999.
[44] J.Purić, S.Djeniže, J.Labat, and Lj.Ćirković, Z.Phys. 267, (1974) 71.
[45] J.Purić, S.Djeniže, J.Labat, and Lj.Ćirković, and I. Lakicevic, VIII SPIG, Dubrovnik (1976).
[46] J.Purić, A.Lesage, and V.Knežević, IX SPIG, Dubrovnik (1978).
[47] A.Lesage, S.Sahal-Bréchot, and M.H.Miller, Phys.Rev.A 16, (1977) 1617.
[48] T.Chiang, and H.R.Griem, Phys.Rev.A 18, (1978) 1169.
[49] J.D.Hey, JQSRT 18, (1977) 425.
[50] W.W.Jones, Phys.Rev.A 7, (1973) 1826.

[51] N.Konjević, and J.R.Roberts, J.Phys.Chem.Ref.Data 5, (1976) 209.
[52] N.Konjević, M.S.Dimitrijević, and W.L.Wiese, J.Phys. Chem.Ref.Data 13, (1984) 619.
[53] D.E.Roberts, JQSRT 8, (1968) 1241.
[54] H.R.Griem, Phys.Rev 165, (1968) 258.
[55] M.S.Dimitrijević, and N.Konjević, JQSRT 24, (1980) 451.
[56] M.S.Dimitrijević, and N.Konjević, in Spectral Line Shapes, Ed.B.Wende, W. de Gruyter, Berlin, New York, (1981) p. 211.
[57] M.S.Dimitrijević, and N.Konjević, Astron.Astrophys. 102, (1981) 93.
[58] M.S.Dimitrijević, and N.Konjević, Astron.Astrophys. 172; (1987) 345.
[59] M.S.Dimitrijević, and V.Kršljanin, Astron.Astrophys. 165, (1986) 269.
[60] M.S.Dimitrijević, Astron.Astrophys.Suppl.Series 76, (1988) 53.
[61] M.J.Seaton, J.Phys.B 20, (1987) 6431.
[62] J.D.Hey, and R.J.Bryan, JQSRT 17, (1977) 221.
[63] M.S.Dimitrijević, and N.Konjević, Astron.Astrophys. 163, (1986) 297.
[64] W.L.Wiese, and N.Konjević, JQSRT 28, (1982) 185.
[65] M.S.Dimitrijević, and G.Peach, Astron.Astrophys. 236, (1990) 261.
[66] M.S.Dimitrijević, Astron.Astrophys. 145, (1985) 439.
[67] M.S.Dimitrijević, and M.M.Popović, Astron.Astrophys. 217, (1989) 201.
[68] J.Purić, I. Lakićević, and V.Glavonjić, Phys.Lett. 76a, (1980) 128.
[69] I.S.Lakićević, and J.Purić, in Spectral Line Shapes II, ed. K.Burnett, de Gruyter, Berlin, New York, (1983) p 147.
[70] Y.Vitel, M.Skowronek, M.S.Dimitrijević, and M.M.Popović, Astron.Astrophys. 200, (1988) 285.
[71] S.Djeniže, A.Srećković, M.Platiša, R.Konjević, J.Labat, J.Purić, Phys.Rev.A 42, (1990) 2379.
[72] M.S.Dimitrijević, in Accuracy of Element Abundances from Stellar Atmospheres (ed. R.Wehrse), Lecture Notes in Physics 358, (Springer: Berlin-Heidelberg), (1990) pp. 31-45.
[73] J.Purić, and N.Konjević, Z.Phys. 249, (1972) 440.
[74] V.Helbig, and H.J.Kusch, Astron.Astrophys. 20, (1972) 299.
[75] R.Hühn, and H.J.Kusch, Astron.Astrophys. 28, (1973) 159.
[76] N.Konjević, and M.S.Dimitrijević, in Spectral Line Shapes I.(ed. B.Wende), W.de Gruyter, Berlin, New York (1981) p. 211.

SOME REGULARITIES WITHIN THE STARK WIDTHS OF RESONANCE LINES OF ALKALI-LIKE HOMOLOGOUS ATOMS AND IONS

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Common regularities for the Stark widths of the resonance lines of neutral alkali-metal, singly ionized alkali earth-metal and B III, Al III, Ga III, In III and Tl III atoms and ions respectively have been found and discussed.

The first attempt to find possible regularities in the Stark broadening and shift parameters of spectral lines was undertaken by Purić and Ćirković [1] and Purić et al. [2]. The existence of regularities within the width and shift values of lines of singly ionized ions of alkali earth-metals as a homologous group of atoms was pointed out.

In the recently published paper by Purić et al. [3] regularities within the Stark broadening parameters of resonance lines of alkali-metals were found and discussed. Here we present evidence for the existence of certain common regularities in the Stark widths of the resonance lines of neutral alkali-metal atoms, singly ionized alkali earth-metal ions and B III, Al III, Ga III, In III and Tl III ions. Regularities were found to exist within every mentioned group and also among all groups examined.

Singly ionized alkali earth-metal atoms and doubly ionized B, Al, Ga, In, and Tl ions are isoelectronic with corresponding neutral alkali-metal atoms. Since they have the same optical electron configuration, under the same plasma conditions they show similar Stark broadening effects, which is demonstrated by the linear dependence of W(Å) on Z (cf. fig. 1). In particular, the difference in slopes of the linear dependences (which amounts to a factor of 4) for neutral alkali-metals and singly ionized alkali earth-metals might be related to the difference in the atomic core change.

In order to show the existence of some regularities within these three homologous groups, we use the experimental data given by Purić et al. [3] and Lakićević et al. [4] for alkali-metal resonance lines and by Fleurier et al. [5] for singly ionized alkali earth-metal resonance lines (by chance available at the same electron temperature T_e = 15000 K and electron density $N_e = 10^{17}$ cm^{-3}). We used Jones et al.'s [6] theoretical values for these two groups of elements where available. We also calculated the Stark widths for Rb I, B III, Al III, Ga III, In III and Tl III using Griem's semi-empirical approach [7] (see table 1). Stark widths of Be II, Mg II, Ca II, Sr II and Ba II resonances were calculated by a computer code developed by Jones and kindly supplied by Professor Griem. Values for Be II and Mg II are in perfect accordance with interpolated

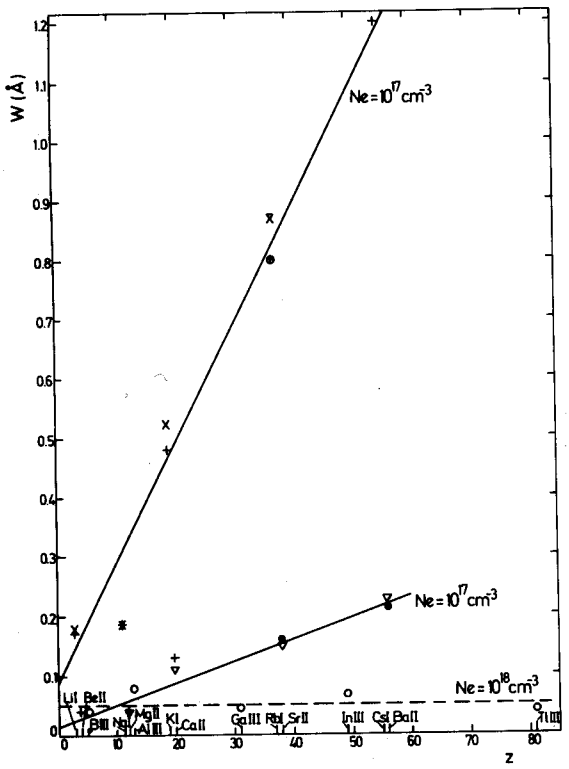

Fig. 1. Experimental and theoretical Stark half-halfwidths of resonance lines of neutral alkali-metals and of alkali-like ions against nuclear charge number Z. Experimental results: ×, Purić et al. [3], ⧖, Lakićević et al. [4], ▽, Fleurier et al. [5]. Semiclassical calculations: +, Jones et al. [6], •, our results. Our semiempirical calculations: ⊕.

values from Jones et al.'s [6] work. The value for Ca II is slightly smaller (4%) probably because of a different set of energy levels, and because a different subroutine was used. For the Stark half-halfwidths of Sr II and Ba II we obtained 0.159 and 0.214 (Å) respectively, for T_e = 15000 K and $N_e = 10^{17}$ cm^{-3}.

All the above-mentioned results are plotted in fig. 1 against nuclear charge number Z. From this figure one can conclude that a linear dependence of W(Å) on Z

Table 1
Semiempirical Stark half-halfwidths W(Å) of several alkali-like ions resonance at T_e = 15000 K and $N_e = 10^{18}$ cm^{-3}.

Elements	B III	Al III	Ga III	In III	Tl III
Transition	2s–2p	3s–3p	4s–4p	5s–5p	6s–6p
W(Å)	0.047	0.079	0.047	0.068	0.042

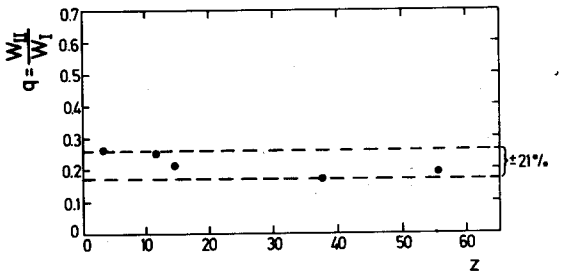

Fig. 2. Ratio W_{II}/W_I against nuclear charge number Z.

exists for all three groups of homologous atoms, Moreover, one can see that the ratio $q = W_{II}/W_I$ (here I refers to alkali- and II to alkali earth-metal resonance lines) is constant within ±21%, as can be seen from fig. 2. This means that the difference in core charge of the corresponding isoelectronic alkali- and alkali earth-metal atoms gives rise to a difference of almost a factor of four in the Stark width of their resonance lines.

One can also see from fig. 1 that W(Å) as a function of Z is nearly constant for the third group of homologous atoms. Although there is a lack of experimental data, this suggests (in the limits of the validity of Griem's semiempirical approach [7] that the influence of the atomic charge number is not critical for the alkali-like resonance lines of multiply ionized atoms.

Finally, one can conclude that the linear dependence of W(Å) on the nuclear charge number Z seems to be universal for the resonance lines of the investigated groups of homologous atoms. It will be of interest to continue with efforts both in theory and experiment in order to obtain further Stark broadening parameters for alkali-like ions. Then it would be possible to check further the existence of the noted regularities.

References

[1] J. Purić and Lj. Ćirković, Proc. 9th Intern. Conf. on Physics of ionized gases (Prague, 1973), Contributed Papers, p. 398.
[2] J. Purić, Lj. Ćirković and J. Labat, Fizika 6 (1974) 211.
[3] J. Purić, J. Labat, Lj. Ćirković, I. Lakićević and S. Djeniže, J. Phys. B10 (1977) 2375.
[4] I. Lakićević, J. Purić and J. Labat, Proc. XIIIth Intern. Conf. on Phenomena in ionized gases (Berlin, 1977) p. 123.
[5] C. Fleurier, S. Sahal-Brechot and J. Chapelle, JQSRT 17 (1977) 595.
[6] W.W. Jones, S.M. Bennet and H.R. Griem, Univ. of Maryland Technical Report No. 71-128.
[7] H.R. Griem, Phys. Rev. 165 (1968) 258.

Plasma broadening and shifting of spectral lines along the isoelectronic sequence of boron

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Temperature dependence of the Stark widths (N III and F V) and shifts (N III and O IV) of the $3s^2S$-$3p(^1S)^2P^0$ and $3p^2P^0$-$3d(^1S)^2D$ transitions have been studied theoretically using the impact semiclassical method and experimentally observed in the plasma of a low pressure pulsed arc. Plasma electron densities were determined from the width of the He II P_α line while electron temperatures were measured from the relative line intensities. To estimate the influence of different ions on the width and shift of lines, evaluations of the plasma composition data were performed and, in conjunction with our theoretical results, the contribution of ion broadening was estimated. Within the estimated uncertainties experimental Stark widths agree well with the results of our semiclassical electron impact widths in the studied electron temperature range. For the conditions of the present experiment, estimated contribution of the ion broadening has never exceeded five percent of the total width. So within the precision of this experiment it was not possible to detect its presence with certainty. Along the boron isoelectronic sequence the experimental widths and shifts agree with semiclassical electron impact data predictions. In the case of O IV lines the inclusion of *the energy levels with different parent terms* in our semiclassical calculations of the Stark widths and shifts improved the agreement between theory and experiment considerably. Comparisons of the experimental widths with simple theoretical formulas for estimation of plasma broadened linewidths show an agreement within estimated uncertainties. [S1063-651X(96)00307-8]

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I. INTRODUCTION

Knowledge of the Stark width and shift dependence upon the temperature of the charged perturbers in the plasma is of importance for testing of the theory and for the reliable diagnostics of laboratory and astrophysical plasmas. Namely, the dependence of the Stark broadening parameters upon the electron concentration N_e has been tested in a number of experiments (see, e.g., Refs. [1] and [2] and references therein) while the dependence of these parameters upon the electron temperature T_e in a wider temperature range is tested only in a few cases. Usually, experimental results are reported for a single electron temperature and in most of the cases when comparison with another experiment is performed, temperature dependence of the Stark broadening parameter is neglected. This is justified by assuming weak dependence of the width w and shift d upon electron temperature T_e. This assumption may be used only in a small temperature range whose magnitude depends upon the shape of $w(T_e)$ and $d(T_e)$ curves (see, e.g., comparison between experimental and theoretical results in Figs. 1–4). Furthermore, the usual assumption that, in comparison with the electron impact contribution to the width or shift of ionized atom lines, one can neglect the contribution of ions, may not be correct (see, e.g., theoretical results for widths and shifts of O IV lines in Ref. [3] and Table I). This ion contribution may change the Stark broadening parameters and maybe temperature dependence at elevated temperatures. To answer quantitatively the above questions both theoretical and experimental study of the plasma broadened spectral line parameters of multiply ionized atoms are required.

Here, we present the results of experimental and theoretical study of the broadening and shift of the analogous transitions along the isoelectronic sequence of boron. These type of studies, which are very convenient for the testing of theory (similar energy level structure of the emitter with gradual increase of the ionic charge), also enables determination of the Stark width and/or shift dependence upon spectroscopic charge number Z of the emitter. This also is of importance for the estimation of the broadening parameters for the ions with no available data. An early study of the experimental line widths along isoelectronic sequence was performed in [4]. Although the analysis was based only on the few experimental data it was clearly demonstrated that the widths decrease strongly with increasing ionic charge [4]. Since then several publications have reported experimental measurements of the Stark widths and shifts of the analogous transitions along isoelectronic sequences [5–8]. In all the experiments gradual decrease of the Stark widths with an increase of Z is detected. A Z^{-1} scaling of the Stark widths was found for $3s-3p$ transitions in Li-like ions (up to $Z=6$) [5]. In another experiment this study is extended to higher ionized species (up to $Z=8$) and systematic deviations of the line widths from the theoretically expected Z^{-2} scaling is detected [7]. In a recent experiment [8] along boron isoelectronic sequence, $3s$-$3p$ and $3p$-$3d$ transitions, considerable widths deviations are detected for $Z=5$ and $Z=6$ from those predicted by some theoretical calculations. Recent experimental studies of the Stark shifts of the $4s$-$4p$ transition along the P isoelectronic sequence (S II, Cl III, and Ar IV) also showed a gradual decrease of shifts with increase of Z [6] (see also [9]). Furthermore, the change of the sign of the

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TABLE I. This table shows Stark broadening parameters for the $3s^2S$-$3p(^1S)^2P^0$ and the $3p^2P^0$-$3d(^1S)^2D$ multiplets of *N* III, *O* IV, and *F* V for the perturber density of 10^{17} cm^{-3} and temperatures from 10 000 up to 300 000 K. Transition and averaged wavelengths for the multiplet in Å are also given. If one divides the *C* value by the Stark width value, we obtain an estimate for the maximum perturber density (in cm^{-3}) for which the line may be treated as isolated and the tabulated data may be used. Brackets in the table enclose powers of ten.

Perturber density$=1\times10^{17}$ cm^{-3}					
Perturbers are:		Electrons		Protons	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
N III $3s$-$3p$	10 000	0.474	0.116[−02]	0.388[−02]	−0.131[−02]
4100.5 Å	20 000	0.339	−0.682[−02]	0.786[−02]	−0.268[−02]
$C=0.36E+21$	30 000	0.283	−0.743[−02]	0.105[−01]	−0.370[−02]
	50 000	0.231	−0.625[−02]	0.137[−01]	−0.506[−02]
	100 000	0.183	−0.832[−02]	0.168[−01]	−0.697[−02]
	150 000	0.162	−0.742[−02]	0.183[−01]	−0.773[−02]
N III $3p$-$3d$	10 000	0.584	−0.827[−02]	0.101[−01]	−0.409[−02]
4639.9 Å	20 000	0.424	−0.857[−02]	0.229[−01]	−0.916[−02]
$C=0.46E+21$	30 000	0.355	−0.752[−02]	0.325[−01]	−0.132[−01]
	50 000	0.290	−0.688[−02]	0.436[−01]	−0.191[−01]
	100 000	0.229	−0.940[−02]	0.586[−01]	−0.268[−01]
	150 000	0.205	−0.764[−02]	0.641[−01]	−0.304[−01]
Perturbers are:		He II		He III	
N III $3s$-$3p$	10 000	0.597[−02]	−0.129[−02]	0.710[−02]	−0.232[−02]
4100.5 Å	20 000	0.103[−01]	−0.253[−02]	0.149[−01]	−0.512[−02]
$C=0.36E+21$	30 000	0.127[−01]	−0.344[−02]	0.203[−01]	−0.725[−02]
	50 000	0.156[−01]	−0.466[−02]	0.267[−01]	−0.102[−01]
	100 000	0.178[−01]	−0.583[−02]	0.334[−01]	−0.142[−01]
	150 000	0.191[−01]	−0.649[−02]	0.364[−01]	−0.158[−01]
N III $3p$-$3d$	10 000	0.129[−01]	−0.225[−02]	0.163[−01]	−0.406[−02]
4639.9 Å	20 000	0.205[−01]	−0.427[−02]	0.317[−01]	−0.878[−02]
$C=0.46E+21$	30 000	0.252[−01]	−0.570[−02]	0.403[−01]	−0.123[−01]
	50 000	0.288[−01]	−0.737[−02]	0.520[−01]	−0.166[−01]
	100 000	0.327[−01]	−0.929[−02]	0.617[−01]	−0.230[−01]
	150 000	0.350[−01]	−0.104[−01]	0.665[−01]	−0.256[−01]
Perturbers are:		N II		N III	
N III $3s$-$3p$	10 000	0.753[−02]	−0.127[−02]	0.963[−02]	−0.231[−02]
4100.5 Å	20 000	0.118[−01]	−0.240[−02]	0.183[−01]	−0.495[−02]
$C=0.36E+21$	30 000	0.143[−01]	−0.319[−02]	0.231[−01]	−0.692[−02]
	50 000	0.162[−01]	−0.410[−02]	0.296[−01]	−0.927[−02]
	100 000	0.184[−01]	−0.516[−02]	0.348[−01]	−0.127[−01]
	150 000	0.197[−01]	−0.576[−02]	0.374[−01]	−0.142[−01]
N III $3p$-$3d$	100 000	0.160[−01]	−0.220[−02]	0.214[−01]	−0.402[−02]
4639.9 Å	20 000	0.236[−01]	−0.407[−02]	0.372[−01]	−0.838[−02]
$C=0.46E+21$	30 000	0.274[−01]	−0.520[−02]	0.461[−01]	−0.116[−01]
	50 000	0.303[−01]	−0.675[−02]	0.559[−01]	−0.154[−01]
	100 000	0.340[−01]	−0.832[−02]	0.638[−01]	−0.203[−01]
	150 000	0.358[−01]	−0.921[−02]	0.684[−01]	−0.226[−01]
Perturbers are:		N IV		N V	
N III $3s$-$3p$	10 000	0.103[−01]	−0.305[−02]	0.102[−01]	−0.354[−02]
4100.5 Å	20 000	0.222[−01]	−0.732[−02]	0.251[−01]	−0.952[−02]
$C=0.36E+21$	30 000	0.304[−01]	−0.105[−01]	0.359[−01]	−0.141[−01]
	50 000	0.400[−01]	−0.149[−01]	0.485[−01]	−0.210[−01]
	100 000	0.501[−01]	−0.211[−01]	0.656[−01]	−0.301[−01]
	150 000	0.546[−01]	−0.237[−01]	0.718[−01]	−0.345[−01]
N III $3p$-$3d$	10 000	0.236[−01]	−0.534[−02]	0.239[−01]	−0.620[−02]
4639.9 Å	20 000	0.471[−01]	−0.126[−01]	0.538[−01]	−0.164[−01]

TABLE I. (*Continued*.)

Perturber density=1×10^{17} cm^{-3}					
Perturbers are:		Electrons		Protons	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
$C=0.46E+21$	30 000	0.603[−01]	−0.178[−01]	0.731[−01]	−0.238[−01]
	50 000	0.779[−01]	−0.243[−01]	0.965[−01]	−0.343[−01]
	100 000	0.925[−01]	−0.341[−01]	0.120	−0.490[−01]
	150 000	0.997[−01]	−0.383[−01]	0.130	−0.550[−01]
Perturbers are:		N VI		N VII	
N III $3s$-$3p$	10 000	0.976[−02]	−0.385[−02]	0.962[−02]	−0.416[−02]
4100.5 Å	20 000	0.271[−01]	−0.115[−01]	0.284[−01]	−0.133[−01]
$C=0.36E+21$	30 000	0.399[−01]	−0.177[−01]	0.434[−01]	−0.211[−01]
	50 000	0.568[−01]	−0.268[−01]	0.647[−01]	−0.328[−01]
	100 000	0.802[−01]	−0.393[−01]	0.938[−01]	−0.490[−01]
	150 000	0.882[−01]	−0.463[−01]	0.105	−0.580[−01]
N III $3p$-$3d$	10 000	0.231[−01]	−0.675[−02]	0.230[−01]	−0.730[−02]
4639.9 Å	20 000	0.591[−01]	−0.199[−01]	0.631[−01]	−0.230[−01]
$C=0.46E+21$	30 000	0.838[−01]	−0.298[−01]	0.920[−01]	−0.357[−01]
	50 000	0.112	−0.442[−01]	0.126	−0.543[−01]
	100 000	0.147	−0.644[−01]	0.174	−0.803[−01]
	150 000	0.161	−0.737[−01]	0.191	−0.924[−01]
Perturbers are:		Electrons		Protons	
O IV $3s$-$3p$	10 000	0.299	0.188[−01]	0.407[−03]	0.288[−04]
3066.4 Å	20 000	0.198	0.171[−01]	0.107[−02]	0.648[−04]
$C=0.28E+21$	30 000	0.155	0.129[−01]	0.173[−02]	0.100[−03]
	50 000	0.121	0.104[−01]	0.276[−02]	0.170[−03]
	100 000	0.903[−01]	0.803[−02]	0.416[−02]	0.322[−03]
	150 000	0.776[−01]	0.650[−02]	0.501[−02]	0.433[−03]
O IV $3p$-$3d$	10 000	0.278	0.174[−01]	0.910[−03]	0.222[−03]
3410.9 Å	20 000	0.177	0.147[−01]	0.230[−02]	0.499[−03]
$C=0.34E+21$	30 000	0.144	0.110[−01]	0.356[−02]	0.762[−03]
	50 000	0.112	0.871[−02]	0.542[−02]	0.122[−02]
	100 000	0.824[−01]	0.737[−02]	0.782[−02]	0.199[−02]
	150 000	0.701[−01]	0.643[−02]	0.896[−02]	0.240[−02]
Perturbers are:		He III		O III	
O IV $3s$-$3p$	10 000	0.722[−03]	0.475[−04]	0.112[−02]	0.475[−04]
3066.4 Å	20 000	0.199[−02]	0.121[−03]	0.289[−02]	0.121[−03]
$C=0.28E+21$	30 000	0.325[−02]	0.193[−03]	0.442[−02]	0.193[−03]
	50 000	0.528[−02]	0.334[−03]	0.663[−02]	0.331[−03]
	100 000	0.810[−02]	0.643[−03]	0.944[−02]	0.620[−03]
	150 000	0.982[−02]	0.875[−03]	0.107[−01]	0.831[−03]
O IV $3p$-$3d$	10 000	0.162[−02]	0.367[−03]	0.247[−02]	0.367[−03]
3410.9 Å	20 000	0.429[−02]	0.933[−03]	0.602[−02]	0.930[−03]
$C=0.34E+21$	30 000	0.674[−02]	0.147[−02]	0.880[−02]	0.145[−02]
	50 000	0.104[−01]	0.241[−02]	0.124[−01]	0.231[−02]
	100 000	0.152[−01]	0.401[−02]	0.171[−01]	0.364[−02]
	150 000	0.177[−01]	0.487[−02]	0.186[−01]	0.445[−02]
Perturbers are:		O IV		O V	
O IV $3s$-$3p$	10 000	0.104[−02]	0.573[−04]	0.977[−03]	0.645[−04]
3066.4 Å	20 000	0.309[−02]	0.171[−03]	0.317[−02]	0.231[−03]
$C=0.28E+21$	30 000	0.504[−02]	0.279[−03]	0.540[−02]	0.359[−03]
	50 000	0.814[−02]	0.493[−03]	0.924[−02]	0.645[−03]
	100 000	0.124[−01]	0.959[−03]	0.150[−01]	0.130[−02]
	150 000	0.149[−01]	0.130[−02]	0.184[−01]	0.179[−02]
O IV $3p$-$3d$	10 000	0.232[−02]	0.442[−03]	0.219[−02]	0.498[−03]
3410.9 Å	20 000	0.664[−02]	0.131[−02]	0.693[−02]	0.164[−02]

TABLE I. *(Continued.)*

Perturber density $=1\times10^{17}$ cm^{-3}					
Perturbers are:		Electrons		Protons	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
$C=0.34E+21$	30 000	0.104[−01]	0.212[−02]	0.114[−01]	0.274[−02]
	50 000	0.160[−01]	0.355[−02]	0.185[−01]	0.471[−02]
	100 000	0.232[−01]	0.593[−02]	0.281[−01]	0.830[−02]
	150 000	0.268[−01]	0.724[−02]	0.340[−01]	0.101[−01]
Perturbers are:		O VI		C III	
O IV $3s$-$3p$	10 000	0.915[−03]	0.675[−04]	0.104[−02]	0.475[−04]
3066.4 Å	20 000	0.318[−02]	0.249[−03]	0.272[−02]	0.121[−03]
$C=0.28E+21$	30 000	0.561[−02]	0.434[−03]	0.421[−02]	0.193[−03]
	50 000	0.100[−01]	0.793[−03]	0.641[−02]	0.332[−03]
	100 000	0.174[−01]	0.162[−02]	0.923[−02]	0.625[−03]
	150 000	0.214[−01]	0.229[−02]	0.106[−01]	0.839[−03]
O IV $3p$-$3d$	10 000	0.206[−02]	0.521[−03]	0.231[−02]	0.367[−03]
3410.9 Å	20 000	0.703[−02]	0.192[−02]	0.571[−02]	0.931[−03]
$C=0.34E+21$	30 000	0.120[−01]	0.333[−02]	0.844[−02]	0.145[−02]
	50 000	0.204[−01]	0.586[−02]	0.121[−01]	0.233[−02]
	100 000	0.327[−01]	0.105[−01]	0.169[−01]	0.371[−02]
	150 000	0.403[−01]	0.133[−01]	0.185[−01]	0.454[−02]
Perturbers are:		C IV		C V	
O IV $3s$-$3p$	10 000	0.963[−03]	0.573[−04]	0.906[−03]	0.645[−04]
3066.4 Å	20 000	0.290[−02]	0.171[−03]	0.296[−02]	0.213[−03]
$C=0.28E+21$	30 000	0.477[−02]	0.279[−03]	0.508[−02]	0.359[−03]
	50 000	0.781[−02]	0.494[−03]	0.883[−02]	0.645[−03]
	100 000	0.120[−01]	0.963[−03]	0.146[−01]	0.130[−02]
	150 000	0.146[−01]	0.132[−02]	0.180[−01]	0.181[−02]
O IV 3p-3d	10 000	0.215[−02]	0.442[−03]	0.204[−02]	0.498[−03]
3410.9 Å	20 000	0.625[−02]	0.131[−02]	0.649[−02]	0.164[−02]
$C=0.34E+21$	30 000	0.990[−02]	0.212[−02]	0.108[−01]	0.275[−02]
	50 000	0.154[−01]	0.357[−02]	0.177[−01]	0.473[−02]
	100 000	0.227[−01]	0.602[−02]	0.274[−01]	0.839[−02]
	150 000	0.265[−01]	0.733[−02]	0.334[−01]	0.103[−01]
Perturbers are:		Electrons		Protons	
F V $3s$-$3p$	10 000	0.124	0.151[−01]	0.685[−04]	−0.756[−04]
2455.0 Å	30 000	0.658[−01]	−0.536[−05]	0.353[−03]	−0.277[−03]
$C=0.22E+21$	50 000	0.514[−01]	−0.840[−03]	0.684[−03]	−0.464[−03]
	100 000	0.375[−01]	−0.863[−03]	0.135[−02]	−0.817[−03]
	200 000	0.283[−01]	−0.102[−02]	0.207[−02]	−0.120[−02]
	300 000	0.243[−01]	−0.106[−02]	0.250[−02]	−0.147[−02]
F V $3p$-$3d$	10 000	0.129	−0.773[−02]	0.145[−03]	−0.830[−04]
2701.6 Å	30 000	0.758[−01]	−0.140[−02]	0.716[−03]	−0.304[−03]
$C=0.27E+21$	50 000	0.594[−01]	−0.914[−03]	0.131[−02]	−0.511[−03]
	100 000	0.433[−01]	−0.686[−03]	0.237[−02]	−0.908[−03]
	200 000	0.324[−01]	−0.101[−02]	0.342[−02]	−0.135[−02]
	300 000	0.279[−01]	−0.859[−03]	0.390[−02]	−0.165[−02]
Perturbers are:		He II		He III	
F V $3s$-$3p$	10 000	0.127[−03]	−0.756[−04]	0.118[−03]	−0.115[−03]
2455.0 Å	30 000	0.596[−03]	−0.275[−03]	0.661[−03]	−0.524[−03]
$C=0.22E+21$	50 000	0.102[−02]	−0.450[−03]	0.130[−02]	−0.905[−03]
	100 000	0.169[−02]	−0.759[−03]	0.262[−02]	−0.163[−02]
	200 000	0.236[−02]	−0.107[−02]	0.406[−02]	−0.244[−02]
	300 000	0.258[−02]	−0.125[−02]	0.495[−02]	−0.299[−02]
F V $3p$-$3d$	10 000	0.268[−03]	−0.830[−04]	0.250[−03]	−0.126[−03]

TABLE I. (*Continued*.)

Perturber density=1×10^{17} cm^{-3}					
Perturbers are:		Electrons		Protons	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
2701.6 Å	30 000	0.117[-02]	−0.302[−03]	0.134[−02]	−0.576[−03]
$C=0.27E+21$	50 000	0.189[−02]	−0.497[−03]	0.250[−02]	−0.997[−03]
	100 000	0.290[−02]	−0.845[−03]	0.462[−02]	−0.182[−02]
	200 000	0.381[−02]	−0.120[−02]	0.672[−02]	−0.274[−02]
	300 000	0.413[−02]	−0.141[−02]	0.776[−02]	−0.334[−02]
Perturbers are:		F III		F IV	
F V $3s$-$3p$	10 000	0.199[−03]	−0.115[−03]	0.179[−03]	−0.135[−03]
2455.0 Å	30 000	0.104[−02]	−0.521[−03]	0.110[−02]	−0.749[−03]
$C=0.22E+21$	50 000	0.186[−02]	−0.883[−03]	0.213[−02]	−0.131[−02]
	100 000	0.321[−02]	−0.154[−02]	0.416[−02]	−0.240[−02]
	200 000	0.459[−02]	−0.221[−02]	0.630[−02]	−0.357[−02]
	300 000	0.510[−02]	−0.262[−02]	0.753[−02]	−0.435[−02]
F V $3p$-$3d$	10 000	0.420[−03]	−0.126[−03]	0.380[−03]	−0.148[−03]
2701.6 å	30 000	0.206[−02]	−0.573[−03]	0.223[−02]	−0.823[−03]
$C=0.27E+21$	50 000	0.346[−02]	−0.976[−03]	0.406[−02]	−0.145[−02]
	100 000	0.550[−02]	−0.171[−02]	0.725[−02]	−0.267[−02]
	200 000	0.748[−02]	−0.248[−02]	0.104[−01]	−0.400[−02]
	300 000	0.811[−02]	−0.296[−02]	0.117[−01]	−0.489[−02]
Perturbers are:		F V		F VI	
F V $3s$-$3p$	10 000	0.163[−03]	−0.141[−03]	0.137[−03]	−0.131[−03]
2455.0 Å	30 000	0.113[−02]	−0.956[−03]	0.113[−02]	−0.114[−02]
$C=0.22E+21$	50 000	0.229[−02]	−0.173[−02]	0.238[−02]	−0.212[−02]
	100 000	0.481[−02]	−0.327[−02]	0.536[−02]	−0.417[−02]
	200 000	0.771[−02]	−0.507[−02]	0.911[−02]	−0.662[−02]
	300 000	0.972[−02]	−0.617[−02]	0.116[−01]	−0.811[−02]
F V $3p$-$3d$	10 000	0.345[−03]	−0.155[−03]	0.290[−03]	−0.144[−03]
2701.6 Å	30 000	0.230[−02]	−0.105[−02]	0.233[−02]	−0.125[−02]
$C=0.27E+21$	50 000	0.442[−02]	−0.191[−02]	0.466[−02]	−0.233[−02]
	100 000	0.856[−02]	−0.364[−02]	0.954[−02]	−0.463[−02]
	200 000	0.128[−01]	−0.569[−02]	0.149[−01]	−0.745[−02]
	300 000	0.152[−01]	−0.692[−02]	0.184[−01]	−0.911[−02]
Perturbers are:		F VII		F VIII	
F V $3s$-$3p$	100 000	0.100[−03]	−0.109[−03]	0.922[−04]	−0.106[−03]
2455.0 Å	30 000	0.113[−02]	−0.131[−02]	0.113[−02]	−0.145[−02]
$C=0.22E+21$	50 000	0.245[−02]	−0.250[−02]	0.250[−02]	−0.287[−02]
	100 000	0.585[−02]	−0.507[−02]	0.626[−02]	−0.590[−02]
	200 000	0.105[−01]	−0.827[−02]	0.119[−01]	−0.993[−02]
	300 000	0.135[−01]	−0.101[−01]	0.153[−01]	−0.121[−01]
F V $3p$-$3d$	10 000	0.212[−03]	−0.120[−03]	0.195[−03]	−0.117[−03]
2701.6 Å	30 000	0.234[−02]	−0.143[−02]	0.233[−02]	−0.159[−02]
$C=0.27E+21$	50 000	0.482[−02]	−0.276[−02]	0.494[−02]	−0.315[−02]
	100 000	0.104[−01]	−0.561[−02]	0.111[−01]	−0.653[−02]
	200 000	0.169[−01]	−0.926[−02]	0.190[−01]	−0.111[−01]
	300 000	0.212[−01]	−0.113[−01]	0.239[−01]	−0.135[−01]
Perturbers are:		S III		S IV	
F V $3s$-$3p$	10 000	0.222[−03]	−0.115[−03]	0.201[−03]	−0.135[−03]
2455.0 Å	30 000	0.114[−02]	−0.520[−03]	0.122[−02]	−0.748[−03]
$C=0.22E+21$	50 000	0.199[−02]	−0.878[−03]	0.230[−02]	−0.131[−02]
	100 000	0.332[−02]	−0.152[−02]	0.437[−02]	−0.237[−02]
	200 000	0.468[−02]	−0.216[−02]	0.646[−02]	−0.350[−02]
	300 000	0.514[−02]	−0.254[−02]	0.757[−02]	−0.423[−02]

TABLE I. (*Continued*.)

Perturber density=1×10^{17} cm^{-3}					
Perturbers are:		Electrons		Protons	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
F V $3p$-$3d$	10 000	0.469[−03]	−0.126[−03]	0.425[−03]	−0.148[−03]
2701.6 Å	30 000	0.225[−02]	−0.572[−03]	0.245[−02]	−0.823[−03]
$C=0.27E+21$	50 000	0.368[−02]	−0.970[−03]	0.437[−02]	−0.144[−02]
	100 000	0.570[−02]	−0.169[−02]	0.754[−02]	−0.263[−02]
	200 000	0.758[−02]	−0.242[−02]	0.107[−01]	−0.391[−02]
	300 000	0.822[−02]	−0.286[−02]	0.118[−01]	−0.476[−02]
Perturbers are:		S V		S VI	
F V $3s$-$3p$	10 000	0.182[−03]	−0.141[−03]	0.153[−03]	−0.131[−03]
2455.0 Å	30 000	0.125[−02]	−0.956[−03]	0.126[−02]	−0.114[−02]
$C=022E+21$	50 000	0.249[−02]	−0.172[−02]	0.261[−02]	−0.212[−02]
	100 000	0.510[−02]	−0.322[−02]	0.568[−02]	−0.411[−02]
	200 000	0.799[−02]	−0.493[−02]	0.936[−02]	−0.645[−02]
	300 000	0.985[−02]	−0.603[−02]	0.119[−01]	−0.789[−02]
F V $3p$-$3d$	10 000	0.386[−03]	−0.155[−03]	0.325[−03]	−0.144[−03]
2701.6 Å	30 000	0.254[−02]	−0.105[−02]	0.259[−02]	−0.125[−02]
$C=0.27E+21$	50 000	0.480[−02]	−0.190[−02]	0.508[−02]	−0.233[−02]
	100 000	0.903[−02]	−0.359[−02]	0.101[−01]	−0.457[−02]
	200 000	0.133[−01]	−0.554[−02]	0.155[−01]	−0.725[−02]
	300 000	0.154[−01]	−0.675[−02]	0.188[−01]	−0.888[−02]
Perturbers are:		S VII		S VIII	
F V $3s$-$3p$	10 000	0.112[−03]	−0.109[−03]	0.103[−03]	−0.106[−03]
2455.0 Å	30 000	0.126[−02]	−0.131[−02]	0.126[−02]	−0.145[−02]
$C=0.22E+21$	50 000	0.270[−02]	−0.250[−02]	0.276[−02]	−0.286[−02]
	100 000	0.621[−02]	−0.501[−02]	0.667[−02]	−0.585[−02]
	200 000	0.108[−01]	−0.807[−02]	0.122[−01]	−0.972[−02]
	300 000	0.138[−01]	−0.989[−02]	0.156[−01]	−0.119[−01]
F V $3p$-$3d$	10 000	0.238[−03]	−0.120[−03]	0.219[−03]	−0.117[−03]
2701.6 Å	30 000	0.260[−02]	−0.143[−02]	0.260[−02]	−0.159[−02]
$C=0.27E+21$	50 000	0.529[−02]	−0.275[−02]	0.543[−02]	−0.315[−02]
	100 000	0.110[−01]	−0.556[−02]	0.118[−01]	−0.648[−02]
	200 000	0.175[−01]	−0.906[−02]	0.196[−01]	−0.109[−01]
	300 000	0.217[−01]	−0.111[−01]	0.245[−01]	−0.133[−01]

shift along the S sequence ($4s'$-$4p'$ transition Cl II and Ar III) is detected [6]. This shift behavior was explained by the irregular change of the perturbing energy levels distribution around the upper level of the transition along the sequence. In this case simple theory [10] predicted the sign of the shift [6].

A general problem in the experimental studies along isoelectronic sequences is scaling of the data to the same temperature. Namely, experimental results for low ionization stages obtained at lower temperatures have to be compared with results for higher ionization stages measured at much higher temperatures. To perform a sensible comparison of the data along the sequence it is necessary to scale all experimental results to the same temperature. In cases when width or shift dependence upon temperature is not known this procedure may introduce an uncertainty in the comparison. Therefore the emphasis of this work is concentrated for several reasons on the temperature dependence of the Stark broadening parameters. Both experimental and theoretical investigations will be an extension of our study of $3s$-$3p$ and $3p$-$3d$ transitions of O IV [3] to N III and F V and it will be related to the recent study of the same transitions in another experiment performed with a different plasma source, diagnosed with another diagnostic technique [8].

II. THEORY

By using the semiclassical-perturbation formalism [11,12] we have calculated Stark broadening parameters for N III, O IV, and F V $3s^2S$-$3p(^1S)^2P^0$ and $3p^2P^0$-$3d(^1S)^2D$ multiplets. Besides electron impact line widths and shifts, Stark broadening parameters due to all relevant ion perturbers have been calculated as well. The corresponding data when perturbers are N II–N VI are calculated for N III multiplets and O III–O VI for O IV multiplets. Since in the case of the considered O IV transitions, several transitions between atomic energy levels with different parent terms may influence significantly, particularly on the shift values, the calculations with the inclusions of $2s2p(^3P^0)3p^2S$, $2s2p(^1P^0)3p^2S$, $2s2p(^3P^0)3p^2P$, $2s2p(^1P^0)3p^2P$, $2s2p(^3P^0)3p^2D$, $2s2p(^1P^0)3p^2D$, and $2p^2(^1D)3s^2D$ perturbing $2s^2(^1S)3p^2P^0$; transitions $2s2p(^3P^0)3s^2P^0$ and

$2s2p(^1P^0)3d^2P^0$ perturbing $2s^2(^1S)3d^2D$ and $2s2p(^1P^0)3s^2P^0$ perturbing $2s^2(^1S)3s^2S$ transitions have been performed here.

In order to assure the consistency of the data set, all oscillator strengths (and not only those for added transitions with different parent terms) have been taken from the TOP base (the complete package of the opacity project (OP) data with the database management system is usually referred to as TOP base) [13,14]. In order to compare experimental results for O IV lines from another experiment [8] performed in CO_2, the contribution of the C III–C V perturbers to the width of O IV multiplets are calculated as well. If one compares Stark widths and shifts for O IV calculated with the Coulomb oscillator strengths and oscillator strengths from the TOP base, one obtains for the $3s$-$3p$ multiplet at an electron density of 10^{17} cm^{-3} and $T=100\,000$ K, $w=0.0741$ Å and $d=-0.002\,40$ Å with Coulomb oscillator strengths and $w=0.0741$ Å and $d=-0.002\,33$ Å with TOP base oscillator strengths. For the $3p$-$3d$ multiplet one obtains $w=0.0784$ Å and $d=-0.002\,22$ Å and $w=0.0716$ Å and $d=-0.000\,955$ Å, respectively. If one adds the above mentioned transitions with different parent terms $w=0.0903$ Å and $d=+0.008\,03$ Å for the $3s$-$3p$ multiplet and $w=0.0824$ Å and $d=+0.007\,37$ Å for the $3p$-$3d$ multiplet. One can see that the influence of the perturbing levels with different parent terms is more significant than the differences between Coulomb and TOP base oscillator strengths. Since the measurements of F V Stark widths were performed in the mixture of SF_6 with He and in [8] SF_6 with hydrogen, Stark widths and shifts when S III–S VII and F III–F VII are perturbers have been calculated also. A summary of the formalism used for these calculations is given in [15].

Energy levels needed for calculations have been taken from [16]. For all radiators except O IV oscillator strengths were calculated by using the method by Bates and Damgaard [17,18]. We have been using the method described in Ref. [19] for higher energy levels. Our results are shown in Table I for a perturbers density of 10^{17} cm^{-3} and temperatures $T=10\,000$–$150\,000$ K for N III, O IV, and F V. We also specify a parameter C [15] which, when divided by the corresponding electron-impact full width at half maximum (FWHM), gives an estimate for the maximum perturbers density for which the line may be treated as isolated. For each value given in Table I the collision volume V multiplied by the perturbers density N is much less than one and therefore the binary approximation is valid. Since V is proportional to the cube of the typical emitter-perturber distance $\rho_{\rm typ}^3$, and $\rho_{\rm typ}^3$ may be estimated from the width, representing the width as proportional to the perturber density N, the average velocity v, and the average total cross section $\sigma_{\rm typ}$ ($\sigma_{\rm typ}=\pi\rho_{\rm typ}^2$), this is a good estimate of the validity of the impact approximation [15]. When the impact approximation is not valid, the ion-broadening contribution may be estimated by using quasistatic estimations [1,20]. In the significant parameter region in between where neither of these two approximations is valid, a unified type theory should be used. For example, in Ref. [21] simple analytical forms for such cases are given. The accuracy of the results obtained decreases when broadening by ion interaction becomes important. At high densities, the results are no longer linear with density due to the Debye screening. This effect is more important for the shifts than for the widths.

III. EXPERIMENT

The experimental apparatus and procedure are described in [3] so only minimum details will be given here. The light source was a low pressure pulsed arc with a quartz discharge tube 10 mm internal diameter. The distance between aluminum electrodes was 161 mm, and 3 mm diameter holes were located at the center of both electrodes to allow end-on plasma observations. A 30 mm diaphragm placed in front of the focusing mirror ensures that light comes from the narrow cone about the arc axis. All plasma observations are performed with 1 m monochromator with inverse linear dispersion 8.33 Å/mm in the first order of the diffraction grating, equipped with the photomultiplier tube and a stepping motor. The discharge was driven by a 15.2 μF low inductance capacitor charged to 3 kV (nitrogen experiment: peak current $I_p=14.8$ kA, critically damped current pulse duration $\tau=7.7$ μs, pressure of the gas mixture $p=3$ torr, continuous flow of the gas mixture, composition: 2.0% of N_2 in He) and to 4.8 kV (fluorine experiment: $I_p=20.5$ kA, $\tau=8.3$ μs, $p=0.8$ torr, continuous flow of the mixture 1.4% of SF_6 in He) and fired by an ignitron. The stepping motor and oscilloscope are controlled by a personal computer, which was also used for data acquisition. Recordings of spectral line shapes were performed shot by shot. At each wavelength position of the monochromator time evolution and decay of the plasma radiation were recorded by the digital oscilloscope. Four such signals were averaged at each wavelength. To construct the line profiles these averaged signals at different wavelengths and at various times of the plasma existence were used to construct line profiles. Spectral line profiles were recorded with instrumental half widths of 0.168 Å and 0.192 Å in nitrogen and fluorine experiments, respectively. To determine the Stark half width from the measured profile, a standard deconvolution procedure for the Lorentzian (Stark) and Gaussian (instrumental+Doppler) profiles [22] was used.

For the line-shift measurements we used line profiles at the different times of the plasma existence [23]. For this technique of shift measurements it is necessary to know plasma parameters (electron density and temperature) at the times when both profiles are recorded.

For the electron-density measurements we used, as in our oxygen experiment [3], the width of the He II P_α 4686 Å line [24]. Our main concern in the electron-density measurements was a possible presence of self-absorption of the P_α line which may distort the line profile. This would result in erroneous reading of the line width which would introduce an error in the electron-density measurements. In order to determine the optical thickness of the investigated lines we have introduced in the discharge an additional movable electrode [3,25]. By placing the movable electrode (10 mm thick) at two different positions and by recording the line profiles from two plasma lengths, it is possible to determine $\kappa_\lambda l$, where κ_λ is the spectral line absorption coefficient and l is the plasma length along the direction of observation. Since the measured $\kappa_\lambda l$ for the He II P_α line was always smaller than one it was possible to recover the line profile [26]. Great care was also taken to find the optimum conditions with the least self-absorption of the investigated lines. This was

TABLE II. Transition probabilities for the spectral lines used for the electron temperature measurements.

Ion	Wavelength (Å)	Transition	A (10^8 s^{-1})	Ref.
N III	4097.33	$3s^2S_{1/2}$-$3p^2P^0_{3/2}$	0.853	[28]
	4103.43	$3s^2S_{1/2}$-$3p^2P^0_{1/2}$	0.844	[28]
	4634.16	$3p^2P^0_{1/2}$-$3d^2D_{3/2}$	0.721	[28]
	4640.64	$3p^2P^0_{3/2}$-$3d^2D_{5/2}$	0.864	[28]
N IV	4057.80	$3p^1P^0_1$-$3d^1D_2$	0.662	[44]
F IV	2451.58	$3p^3D_2$-$3d^3F^0_3$	2.39	[45]
	2820.74	$3s^3P^0_1$-$3p^3D_2$	1.11	[45]
	2823.80	$3s^3P^0_0$-$3p^3D_1$	0.823	[45]
	2826.13	$3s^3P^0_2$-$3p^3D_3$	1.48	[45]
F V	2450.66	$3s^2S_{1/2}$-$3p^2P^0_{3/2}$	1.74	[28]
	2703.96	$3p^2P^0_{3/2}$-$3d^2D_{5/2}$	1.30	[28]

achieved by careful examination of the N III and F V line shapes as a function of the experimental conditions (total gas pressure, gas mixture composition, and condenser bank energy), and by checking the optical depth of the strongest lines by measuring the intensity ratios within multiplets and comparing them with theoretical predictions based on the L-S coupling (see, e.g., Ref. [27]). The ratios of N_2 and SF_6 in the mixture with helium were determined after a number of experiments in which these gases were diluted gradually until line intensities within investigated multiplets agree within 3% with the values derived from transition probabilities [28].

The axial electron temperatures were determined in the nitrogen-helium mixture from (a) the Boltzmann plot of the relative intensities of N III 4097.33, 4103.43, 4634.16, and 4640.64 Å lines and (b) from relative intensities of two lines 4097.33 and 4057.80 Å belonging to two successive ionization stages of nitrogen, N III and N IV, respectively. In the SF_6-helium mixture electron temperatures are determined (a) from a Boltzmann plot of F IV 2451.58, 2820.74, 2823.80, and 2826.13 Å lines and (b) from the relative intensities of the 2451.58, and 2450.66 Å lines belonging to F IV and F V, respectively. Transition probabilities and data sources for these measurements are given in Table II. The spectral response of the photomultiplier-monochromator system was calibrated against a standard coiled-coil quartz iodine lamp.

TABLE III. Experimental electron densities N_e and temperatures T_I and T_B derived from the relative intensities of the lines of successive ionization stages and from the Boltzmann plots of relative line intensities, respectively. Estimated uncertainties are given also.

Ion	t (μs)	N_e (10^{17} cm^{-3})	T_I (K)	R_B (K)
N III	1.5	1.38±15%	55 300	33 000±10%
	2.0	1.71±14%	59 300	36 100±10%
	2.5	2.52±14%	64 800	44 300±10%
	3.0	2.64±14%	70 500	39 600±10%
	6.0	1.11±15%	54 700	37 900±10%
F V	1.0	2.54±15%	89 900	71 200±12%

IV. RESULTS AND DISCUSSION

The experimental results for the electron densities and temperatures at the axis of the discharge at various times of the current pulse through the discharge tube are given in Table III together with estimated uncertainties. Since we have been studying Stark broadening parameters dependence upon temperature T_e we made an attempt to determine T_e as accurately as possible using two independent methods. Unfortunately, to apply a very sensitive method of the relative line intensities from two successive ionization stages one requires much higher plasma electron densities [see the local thermodynamic equilibrium (LTE) condition in Eq. (6.55) of Ref. [29]] than were available in our experiment, see Table III. Nevertheless both sets of electron temperatures are given in Table III. For obvious reasons only electron temperatures derived from the Boltzmann plots of the N III and F IV relative line intensities are given with estimated errors, see Table III, and they are used in further discussions. Here it should be pointed out that the possible presence of plasma inhomogeneity may influence electron temperature measurements considerably, namely, if the plasma is inhomogeneous the different ions will radiate primarily from different temperature regions and this can yield large errors in the temperature determination. In order to test the homogeneity of the observed plasma cone electron temperatures were determined with the different apertures of the optical system; observations were performed with a 3 cm and a 10 cm diaphragm in front the focusing mirror. This corresponds to the change of the diameter of the base of the observed plasma cone from 3.6 mm to 7.9 mm (internal diameter of the discharge tube is 10 mm). Within an experimental scatter of the temperature measurements in the time of interest no difference in T_e is detected.

The experimental results for the Stark widths (FWHM), of N III and F V lines are given in Table IV together with the estimated errors. Table IV also contains spectroscopic data for the investigated lines and comparisons with the semiclassical theoretical results obtained by using the semiclassical perturbation approach [11,12] with the code used in a number of papers by M. S. Dimitrijević and S. Sahal-Bréchot (see, e.g., Refs. [30–34]) denoted here as W_{DSB} (electron +ion impact widths, see Table I). Comparison is also made in the same table with theoretical results calculated after

TABLE IV. Experimental Stark widths w_m (FWHM) of investigated N III and F V lines from the $3s^2S$-$3p(^1S)^2P^0$ and the $3p^2P^0$-$3d(^1S)^2D$ multiplets are compared in this table with theoretical widths: semiclassical electron impact, w^e_{DSB}, electron+ion impact, w^{ei}_{DSB}, simplified semiclassical approach after Griem [Eq. (526) of Ref. [1]], w_G, and modified semiempirical formula after Dimitrijević and Konjević [35]. Theoretical widths w^e_{DSB} and w^{ei}_{DSB} are calculated from the data in Table I.

Ion	Transition	λ (Å)	N_e (10^{17} cm^{-3})	T_e (K)	w_m (Å)	w_m/W^e_{DSB}	w_m/w^{ei}_{DSB}	$w_m/_G$	w_m/w_{DK}
N III	$3s^2S_{1/2}$-$3p^2P^0{}_{3/2}$	4097.33	1.38±15%	33 000	0.34_5±7%	0.92	0.89	1.02	1.36
			1.71±14%	36 100	0.42_3±7%	0.93	0.91	1.05	1.40
			2.52±14%	44 300	0.55_7±6%	0.91	0.88	1.01	1.39
			2.64±14%	39 600	0.58_7±6%	0.88	0.85	0.98	1.33
			1.11±15%	37 900	0.26_2±6%	0.92	0.88	1.02	1.38
	$3s^2S_{1/2}$-$3p^2P^0{}_{1/2}$	4103.43	1.38±15%	33 000	0.34_3±7%	0.92	0.89	1.02	1.36
			1.71±14%	36 100	0.40_0±7%	0.90	0.87	1.00	1.32
			2.52±14%	44 300	0.55_7±5%	0.91	0.88	1.01	1.39
			2.64±14%	39 600	0.58_7±5%	0.88	0.85	0.98	1.33
			1.11±15%	37 900	0.27_9±8%	0.98	0.94	1.09	1.46
	$3p^2P^0{}_{1/2}$-$3d^2D_{3/2}$	4634.16	1.38±15%	33 000	0.47_0±7%	1.00	0.97	1.02	1.49
			1.71±14%	36 100	0.55_3±7%	0.97	0.94	0.99	1.46
			2.52±14%	44 300	0.76_6±6%	1.00	0.96	1.00	1.51
			2.64±14%	39 600	0.79_5±6%	0.95	0.91	0.96	1.44
			1.11±15%	37 900	0.35_2±8%	0.98	0.94	0.99	1.49
	$3p^2P^0{}_{3/2}$-$3d^2D_{5/2}$	4640.64	1.38±15%	33 000	0.443±7%	0.95	0.91	0.96	1.40
			1.71±14%	36 100	0.52_6±7%	0.94	0.90	0.95	1.41
			2.52±14%	44 300	0.74_6±5%	0.97	0.93	0.96	1.47
			2.64±14%	39 600	0.79_5±5%	0.95	0.91	0.96	1.44
			1.11±15%	37 900	0.35_2±8%	0.98	0.94	0.99	1.49
F V	$3s^2S_{1/2}$-$3p^2P^0{}_{3/2}$	2450.66	2.54±14%	71 200	0.11_6±5%	1.04	0.99	1.49	1.76
	$3p^2P^0{}_{3/2}$-$3d^2D_{5/2}$	2703.96	2.54±14%	71 200	0.13_4±5%	1.04	0.99	1.54	2.02

Griem [Eq. (526) in Ref. [1]] W_G, and results obtained after Dimitrijević and Konjević [35] W_{DK}. In order to evaluate the contribution of ion impact widths it was necessary to compute plasma composition data for the conditions of the width measurements (electron density and temperature). Here, to simplify calculations we assumed the LTE for our plasma conditions ($N_e > 10^{17}$ cm^{-3}) and the plasma composition data was evaluated as described for the LTE conditions in [29]. The assumption of the LTE conditions is obviously very crude (see two sets of results for electron temperatures in Table III). Its use may be justified by the fact that (a) the expected contribution of all ions in the plasma to the line width or shift may not exceed 10% of the electron width, see Table I, and (b) the difference in the contribution of various ions to the linewidths and shifts is so small (see Table I) that small differences in the computed concentrations of various ions in our experimental conditions is of marginal importance for the final result. For the computation of plasma composition data the energy levels necessary for evaluation of the partition functions are taken from [16,43]. Knowing the concentration of each type of the ion in the plasma, it is trivial (by the help of Table I) to estimate the ion contribution to the plasma broadened linewidth. This estimation is simplified by the fact that electron and ion impact widths have a Lorentzian shape, so the width of the profile represents the sum of the electron and all ion profiles.

The experimental shifts are given in Table V in the form $\Delta d_m/\Delta N_e$, so the estimated error also includes the uncertainty in the electron-density measurements. Since shifts are measured as a difference of two line profiles determined at two different times of the plasma existence corresponding plasma conditions N_e, T are also given in Table V. The experimental Stark shifts are compared with *our semiclassical results* (electrons and electrons+ions, see Table I) Δd_{DSB}, evaluated as for the widths. Since it is difficult to estimate plasma composition data in another experiment in order to estimate the contribution of ions, N III Stark shifts measured by Purić *et al.* [40] are compared in Table V only with our electron impact shifts.

To facilitate comparison between various experiments and theories all available results for studied N III and F V line widths are given in graphical form in Figs. 1–4. In these figures experimental widths are compared with (a) our semiclassical electron impact widths, (b) semiclassical electron impact widths calculated after Griem in [36], given only in Fig. 1, (c) simplified semiclassical results calculated here after Griem [Eq. (526) in Ref. [1]], and (d) modified semiempirical formula evaluated here after Dimitrijević and Konjević [35]. In addition, for our experimental conditions and for those in Ref. [8] plasma composition is evaluated and comparison with the semiclassical widths (electrons+ions) is performed.

Figure 1 shows N III for the $3s^2S$-$3p^2P^0$ multiplet. The large spread of the experimental data produces a very poor mutual consistency. Experimental results from Ref. [38] show large variations of linewidths within the multiplet which is usually an indication of the presence of self-absorption during line shape measurements (see also [36]). The large spread of the experimental widths in [39] may also be partially caused by the optical depth problem. If one takes

TABLE V. Experimental Stark shifts Δd_m determined as a wavelength shift between two lines profiles, compared with the corresponding theoretical shifts: electron impact, Δd^e_{DSB}, and electron+ion impact Δd^{ei}_{DSB}. Results for N III lines were calculated using Coulomb oscillator strengths while the results for O IV lines were obtained with TOP base oscillator strengths [13], [14] with transitions with different parent terms included (see Sec. II).

Ion	Transition	λ_{tab} (Å)	N_{e1} (10^{17} cm^{-3})	T_1 (K)	N_{e2} (10^{17} cm^{-3})	T_2 (K)	Δd_m (Å)	$\Delta d_m/\Delta d^e_{DSB}$	$\Delta d_m/\Delta d^{ei}_{DSB}$	Ref.
N III	$3s^2S_{1/2}$-$3p^2P^0_{3/2}$	4097.33	1.38	33 000	2.52	44 300	−0.04	5.6	7.4	[a]
	$3s^2S_{1/2}$-$3p^2P^0_{3/2}$	4097.33	∼0	∼0	1.78	50 000	−0.041	3.7	4.1	[40]
	$3s^2S_{1/2}$-$3p^2P^0_{1/2}$	4103.43	1.38	33 000	2.52	44 300	−0.04	5.6	7.4	[a]
	$3s^2S_{1/2}$-$3p^2P^0_{1/2}$	4103.43	∼0	∼0	1.78	50 000	−0.041	3.7	4.1	[40]
	$3p^2P^0_{1/2}$-$3d^2D_{3/2}$	4634.16	1.38	33 000	2.52	44 300	−0.04	5.4	8.3	[a]
	$3p^2P^0_{3/2}$-$3d^2D_{5/2}$	4640.64	1.38	33 000	2.52	44 300	−0.03	4.1	8.2	[a]
O IV	$3s^2S_{1/2}$-$3p^2P^0_{3/2}$	3063.43	2.06	62 600	5.07	93 600	0.03	1.4		[a]
	$3s^2S_{1/2}$-$3p^2P^0_{1/2}$	3071.60	2.06	62 600	5.07	93 600	0.03	1.4		[a]
	$3p^2P^0_{1/2}$-$3d^2D_{3/2}$	3403.60	2.06	62 600	5.07	93 600	0.03	1.5		[a]
	$3p^2P^0_{3/2}$-$3d^2D_{5/2}$	3411.76	2.06	62 600	5.07	93 600	0.03	1.5		[a]

[a]This work.

into account estimated experimental errors in Refs. [8], [37], and [39], all these results are in agreement with the present experiment. Spread of the experimental data, however, is rather large to make quantitative conclusions about the agreement with various theoretical approaches. Nevertheless, the best agreement is found with the semiclassical electron impact widths and the simple semiclassical formula [Eq. (526) of Ref. [1]].

Figure 2 shows N III, for the $3p^{2p0}-3d^2D$ multiplet. Comparison between the experimental results and theories is even more unclear. Three sets of experimental data [8], [37], and [39] are in good agreement with the modified semiempirical formula [35]. The present experiment, as in the preceding case, agrees best with our electron impact widths from Table I, and the simple formula [Eq. (526) in Ref. [1]].

Figure 3 shows F V, for the $3s^2S$-$3p^2P^0$ multiplet. Our experimental width is in very good agreement with the semiclassical data and lies between electron impact widths and

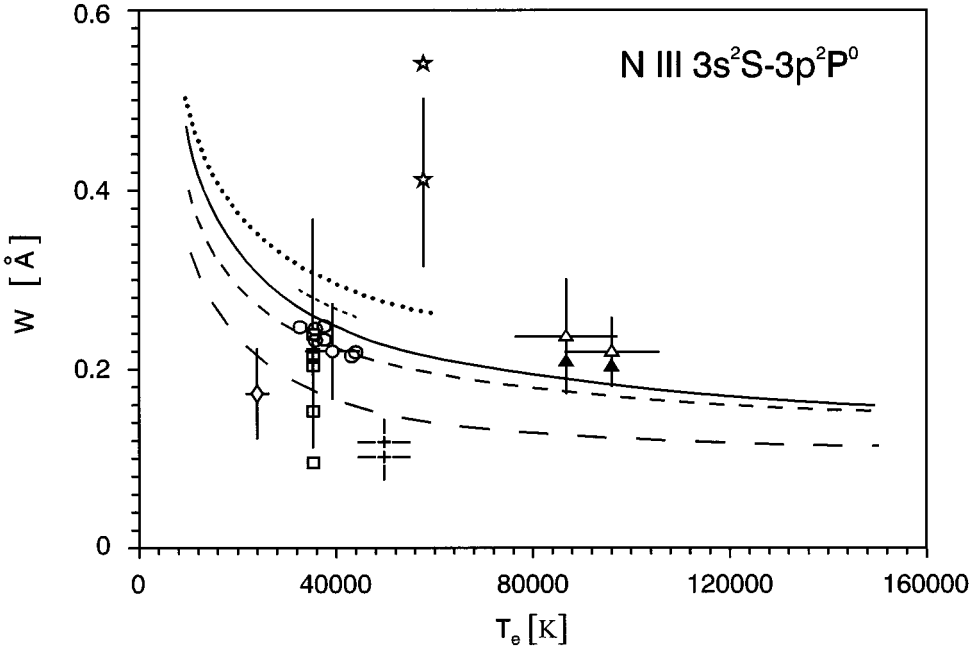

FIG. 1. Full Stark widths (normalized to an electron density of 10^{17} cm^{-3}) for the N III $3s^2S-3p^2P^0$ multiplet vs electron temperature. Theory: —, semiclassical, electron impact widths (see Table I); - - - - -, semiclassical, electron+ion impact widths (see Table I) evaluated only for the experimental conditions of this experiment; for the conditions of Ref. [8] theoretical electron+ion impact widths evaluated from Table I are denoted with Δ; ⋯, semiclassical, electron impact widths (after Griem [36]); – – –, simplified semiclassical approximation [after Griem, Eq. (526) of Ref. [1]]; and — — —, modified semiempirical formula (after Dimitrijević and Konjević [35]). Experiment: ○, this work, ◇, Popović, Platiša, and Konjević [31]; ☆, Källne, Jones, and Barnard [38]; □, Purcell and Barnard [39]; +, Purić, Srećković, Djeniže, and Platiša [40]; and △, Glenzer, Hey, and Kunze [8]. Estimated uncertainties of the experimental data are given whenever available in the original papers. Closed symbols denote theoretical widths (electrons+ions), open symbols denote experimental widths.

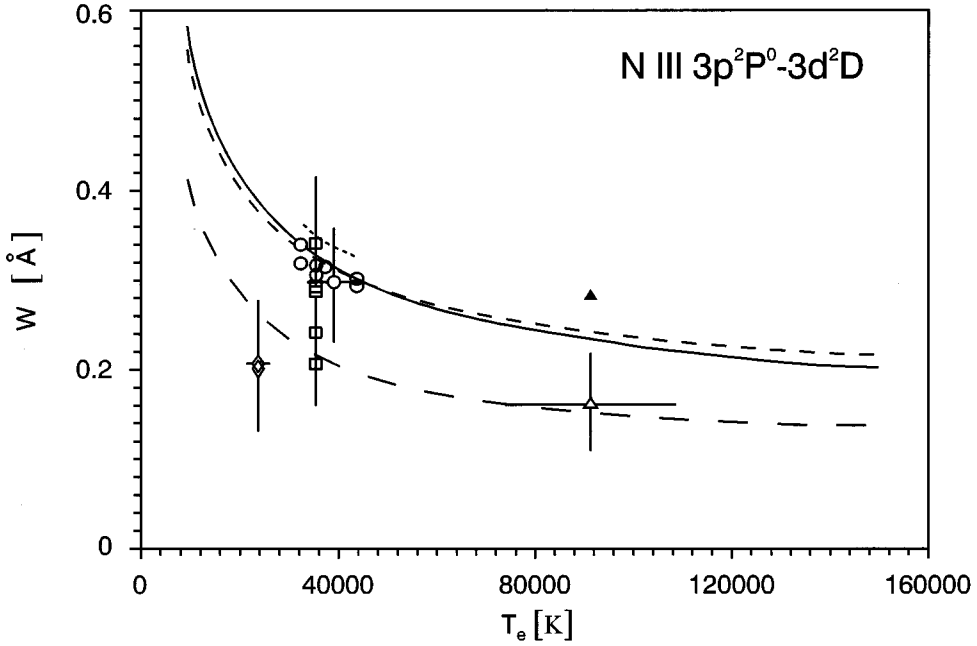

FIG. 2. Same as in Fig. 1 but for the N III $3p^2P^0$-$3d^2D$ multiplet.

electron+ion impact widths derived from data in Table I. The high temperature result of Glenzer, Heg, and Kunze [8], however, is much larger than all other theoretical results.

Figure 4 shows F V, for the $3p^2P^0$-$3d^2D$ multiplet. Both experimental results, this work and Ref. [8], are in very good agreement with our semiclassical data in Table I. On the basis of this result one may conclude that the semiclassical theory describes well the temperature dependence of the Stark widths. Unfortunately this conclusion may not be extended with such confidence to the other investigated multiplets.

Comparison of the N III experimental shifts shows reasonable agreement with our semiclassical results in spite of the fact that ratios of measured over theoretical values range from 1.8 up to 3.3 (see Table V). Measured shifts are very small in our experimental conditions and in this case accurate shift measurements are very difficult to perform. On the other side, theoretical results have a very large uncertainty

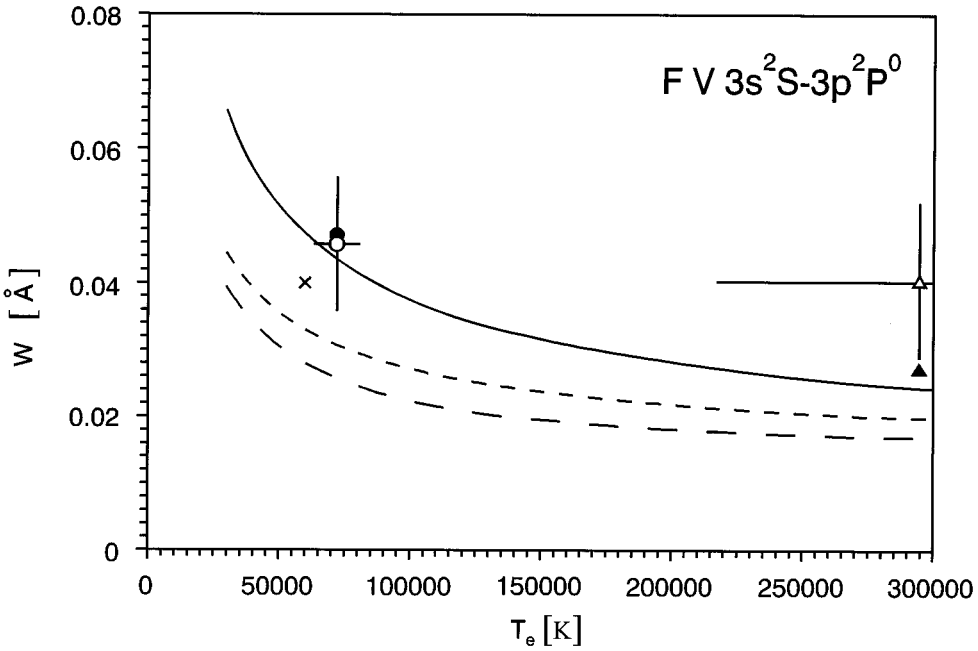

FIG. 3. Same as in Fig. 1 but for the *FV* $3s^2S$-$3p^2P^0$ multiplet; in addition, the predicted value *X*, derived from the regularity trend [47], is included.

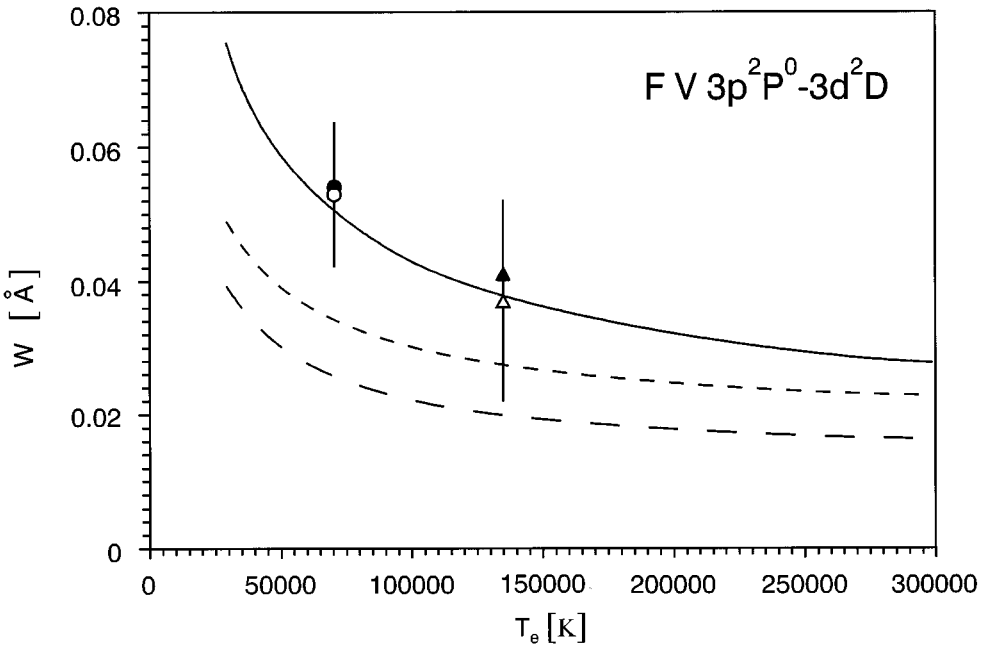

FIG. 4. Same as in Fig. 3 but for the $FV\ 3p^2P^0$-$3d^2D$ multiplet.

whenever shifts are small in comparison with widths as is the case with investigated N III and O IV lines, see Table I. Nevertheless, the results for N III lines of Purić *et al.* [40] agree better with our semiclassical results, see Table V. The agreement between theory and experiment for O IV lines is very good. Here we draw attention to the fact that, contrary to the blueshift of N III lines, O IV lines have a redshift, so good agreement with theoretical predictions is very encouraging. Once more we would like to stress that the use of perturbing energy levels with different parent terms in addition to those from allowed dipole transitions in our semiclassical calculations changed the direction of the shift of the O IV lines from blue to red (see Sec. II). Furthermore, from the comparison of the data in Table V one may conclude that the use of the theoretical ion impact shifts in addition to electron impact shift considerably improves the agreement between theory and experiment for both N III and O IV lines.

Finally, we made a comparison of the Stark widths along the isoelectronic sequence for both investigated multiplets, see Fig. 5. To perform this comparison it was necessary to normalize all experimental and theoretical results to the same temperature. Here we selected an electron temperature of 87 000 K (7.5 eV) which represent a medium value between the low and high temperature data and it was used for the same purpose in Ref. [8]. Temperature dependencies of our electron impact widths, see Table I and Table II in Ref. [3], are taken to normalize higher or lower temperature results. For clarity in comparison along the isoelectronic sequence only two sets of the most comprehensive results are used, this experiment together with Refs. [3] and [8], see Fig. 5. The relative position of the other experimental results can be determined from Figs. 1 and 2 and Figs. 2 and 3 of Ref. [3]. In Fig. 5 the theoretical dependencies of the Stark widths upon Z along the boron sequence are also introduced. Comparison of the experimental and theoretical data in Fig. 5 shows the following.

(a) The $3s^2S$-$3p^2P^0$ multiplet: with the exception of the F V experimental Stark width measured at a high temperature, 300 000 K [8] all other, lower temperature results agree, within the estimated uncertainties, with our semiclassical theoretical predictions. All simplified theoretical approaches show larger decrease of the Stark widths upon Z.

(b) The $3p^2P^0$-$3d^2D$ multiplet: with the exception of the N III Stark width from [8] all other experimental results agree with the semiclassical prediction. Although the simplified theoretical approach [Eq. (526), [1]] agrees best with experiments, the dependence upon Z is not correctly described as it is for the other simplified approaches [35] and [46].

It is common for the comparisons along the sequence for the widths of both multiplets that the agreement between our semiclassical results and experiment for the O IV lines improves if one takes into account the influence of the perturbing levels with the different parent terms.

V. CONCLUSIONS

The results of the semiclassical theoretical calculations for the Stark widths and shifts of N III and F V $3s^2S$-$3p^2P^0$ and $3p^2P^0$-$3d^2D$ multiplets have been reported. In addition to the electron impact widths and shifts, ion widths and shifts due to collisions with all ions of interest for our experimental conditions and those of Ref. [8] are calculated as well. Furthermore, for O IV lines, in addition to the data presented in [3], obtained with the LS coupling oscillator strengths, calculations by using the TOP base oscillator strengths (with and without inclusion of transitions with different parent terms) [13,14] and measured atomic energy levels [16] have been performed for the electronic and ionic perturbers. As-

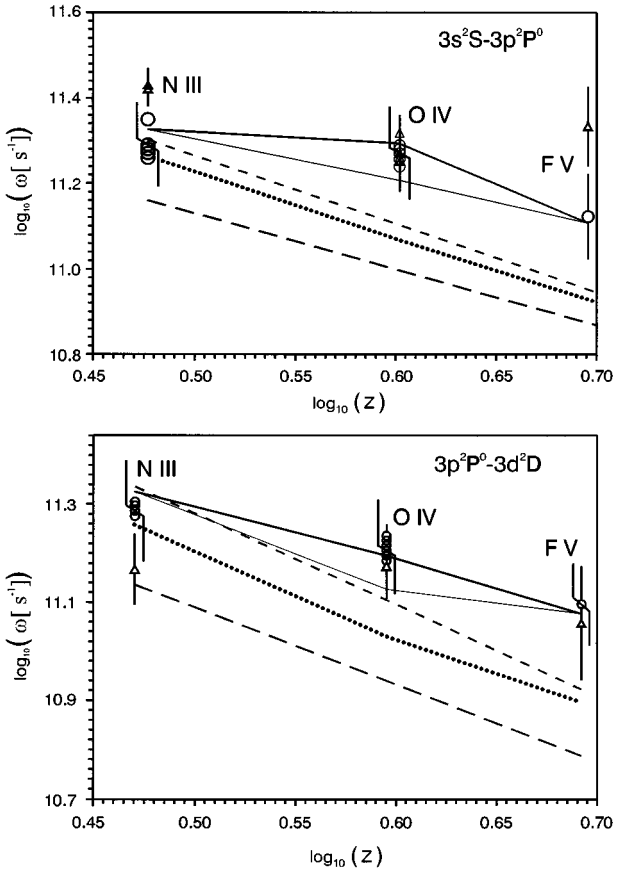

FIG. 5. Stark widths of the *B*-like spectral lines (in angular frequency units) as a function of $\log_{10}Z$. Experimental data are scaled linearly to a value of the electron density of 10^{17} cm^{-3} and to a value of the electron temperature 87 000 K (7.5 eV), Theoretical data are calculated for these values. Experimental results: △, Glenzer, Hey, and Kunze [8] and ○, this work. Error flags are calculated uncertainties including the error in the determination of the full width at half maximum and of the electron density measurements. Theoretical results: —, electron+ion impact widths, data for O IV lines with transitions with a different parent term (from Table I); —, electron+ion impact widths, data for O IV lines with transitions with a different parent term; ---, simple semiclassical, after Griem [Eq. (526) Ref. [1]]; – – –, modified semiempirical formula, after Dimitrijević and Konjević [35]; ⋯, classical-path approximation, after Hey and Breger [46] as calculated in Ref. [8].

suming plasma LTE conditions, plasma composition data are evaluated and, in conjunction with the results for the theoretical Stark broadening data, electron and ion impact widths and shifts are calculated. Experimental Stark widths of N III and F V lines and Stark shifts of N III and O IV lines of the same multiplets are measured in the plasma of a low pressure pulsed arc. Plasma electron density is determined from the width of He II P_α line while the electron temperatures are measured from the Boltzmann plot of the relative intensities of N III and F IV lines. Our experimental Stark widths are in agreement with most of the other experiments. The temperature dependence in the impact limit is characterized by two asymptotic regions and a rather narrow intermediate region. Basically they correspond to the elastic and inelastic collision regime. For neutral lines, the asymptotic analysis is presented, for example, in Refs. [41, 42]. For ions, however, such analysis is more complicated since the Stark broadening functions (A,a,B,b, see Ref. [1]) depend on two arguments and not on one as for neutrals. Consequently, an experimental investigation of the temperature dependence for ions is of higher interest. The temperature dependence of the experimental widths are best described with our semiclassical electron impact results, see Figs. 1–4. The high temperature result for the F V line of Ref. [8], see Fig. 3, represents an exception which cannot be explained within the uncertainty of the experiment and theory. Although we can conclude that all the simple formulas are in agreement with the experiments within their estimated uncertainties, which is typically about ±50%, Griem's simplified theoretical approach [Eq. (526) of Ref. [1]] agrees best with the experimental results, see Figs. 1–4, and Figs. 2 and 3 in Ref. [3].

Comparisons of the experimental widths along the isoelectronic sequence of boron in Fig. 5 show the best agreement with our semiclassical electron impact widths. Two exceptions are the $3p^2P^0$-$3d(^1S)^2D$ line of N III and, in particular, the high temperature result for the $3s^2S$-$3p(^1S)^2P^0$ line of F V, both results are from Ref. [8]. The inclusion of the oscillator strengths of the transitions with the different parent terms in the calculation of the widths of O IV lines improves the agreement between the theory and experiment. Although the simple formulas are in reasonable agreement with the experiments, none of them correctly describes $3p$-$3d$ Stark width dependence upon Z along the sequence, see Fig. 5.

Both measured experimental and calculated theoretical shifts for N III and O IV lines are very small and therefore their intercomparison under the present plasma conditions has a large uncertainty. Thus the agreement between semiclassical theory and this experiment can be considered satisfactory for N III lines, see Table V. The results for N III lines from another experiment [40] are in better agreement with our theory. For O IV lines, however, the experimental shifts have an opposite sign from the theoretically predicted ones [3]. An attempt has been made here to locate the cause of this discrepancy. It has been found that inclusion of ten transitions with different parent term improves the agreement between theory and experiment and correctly predicts a sign of the shift of the observed O IV lines.

Comparison of the data in Table V suggests that the ion impact shifts contribute considerably to the total theoretical shift of N III and O IV lines and its inclusion in the estimation of the total shift (electrons+ions) on the basis of the present experiment improves the agreement with the experiment. We cannot draw the same conclusion for the ion contribution to the Stark widths.

ACKNOWLEDGMENTS

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[1] H. R. Griem, *Spectral Line Broadening by Plasmas* (Academic, New York, 1974).
[2] N. Konjević and W. L. Wiese, J. Phys. Chem. Ref. Data **19**, 1307 (1990).
[3] B. Blagojević, M. V. Popović, N. Konjević, and M. Dimitrijević, Phys. Rev. E **50**, 2986 (1994).
[4] W. L. Wiese and N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **28**, 185 (1982).
[5] F. Böttcher, P. Breger, J. D. Hey, and H.-J. Kunze, Phys. Rev. A **38**, 2690 (1988).
[6] R. Kobilarov and N. Konjević, Phys. Rev. A **41**, 6023 (1990).
[7] S. Glenzer, N. I. Uzelac, and H.-J. Kunze, Phys. Rev. A **45**, 8795 (1992).
[8] S. Glenzer, J. D. Hey, and H.-J. Kunze, J. Phys. B **27**, 413 (1994).
[9] W. L. Wiese and N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **47**, 185 (1992).
[10] M. S. Dimitrijević and V. Kršljanin, Astron. Astrophys. **165**, 269 (1986).
[11] S. Sahal-Bréchot, Astron. Astrophys. **1**, 91 (1969).
[12] S. Sahal-Bréchot, Astron. Astrophys. **2**, 322 (1969).
[13] K. Butler, C. Mendoza, and C. J. Zeippen, J. Phys. B **26**, 4409 (1993).
[14] W. Cunto, C. Mendoza, F. Ochsenbein, and C. J. Zeippen, Astron. Astrophys. **275**, L5 (1993).
[15] M. S. Dimitrijević, S. Sahal-Bréchot, and V. Bommier, Astron. Astrophys. Suppl. Ser. **89**, 581 (1991).
[16] S. Bashkin and J. J. Stoner, Jr., *Atomic Energy Levels and Grotrian Diagrams* (North-Holland, Amsterdam, 1975), Vol. 1.
[17] D. R. Bates and A. Damgaard, Trans. R. Soc. London, Ser. A **242**, 101 (1949).
[18] G. K. Oertel and L. P. Shomo, Astrophys. J. Suppl. Ser. **16**, 175 (1968).
[19] H. Van Regemorter, Hoang Binh Dy, and M. Prud'homme, J. Phys. B **12**, 1073 (1979).
[20] S. Sahal-Bréchot, Astron. Astrophys. **245**, 322 (1991).
[21] A. J. Barnard, J. Cooper, and E. W. Smith, J. Quant. Spectrosc. Radiat. Transfer **14**, 1025 (1974).
[22] J. T. Davies and J. M. Vaughan, Astrophys. J. **137**, 1302 (1963).
[23] J. Purić and N. Konjević, Z. Phys. **249**, 440 (1972).
[24] T. L. Pittman and C. Fleurier, in *Proceedings of the Sixth International Conference on Spectral Line Shapes*, Boulder, 1982 (de Gruyter, Berlin, 1983).
[25] R. Kobilarov, N. Konjević, and M. V. Popović, Phys. Rev. A **40**, 3871 (1989).
[26] W. L. Wiese, in *Plasma Diagnostic Techniques*, edited by R. M. Huddleston and S. L. Leonard (Academic, New York, 1965).
[27] N. Konjević and W. L. Wiese, J. Phys. Chem. Ref. Data **5**, 259 (1976).
[28] S. Glenzer, H.-J. Kunze, J. Musielok, Y.-K. Kim, and W. L. Wiese, Phys. Rev. A **49**, 221 (1994).
[29] H. R. Griem, *Plasma Spectroscopy* (McGraw-Hill, New York, 1964).
[30] M. S. Dimitrijević and S. Sahal-Bréchot, Phys. Scr. (to be published).
[31] M. S. Dimitrijević, S. Sahal-Bréchot and V. Bommier, Astron. Astrophys. Suppl. Ser. **89**, 581 (1991).
[32] M. S. Dimitrijević, S. Sahal-Bréchot and V. Bommier, Astron. Astrophys. Suppl. Ser. **89**, 591 (1991).
[33] M. S. Dimitrijević and S. Sahal-Bréchot, Astron. Astophys. Suppl. Ser. **93**, 359 (1992).
[34] M. S. Dimitrijević and S. Sahal-Bréchot, Astron. Astrophys. Suppl. Ser. **95**, 109 (1992).
[35] M. S. Dimitrijević and N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **24**, 451 (1980).
[36] M. S. Dimitrijević and N. Konjević, J. Quant. Spectrosc. Radiat. Transfer **25**, 387 (1981).
[37] M. V. Popović, M. Platiša, and N. Konjević, Astron. Astrophys. **41**, 463 (1975).
[38] E. Källne, L. A. Jones, and A. J. Barnard, J. Quant. Spectrosc. Radiat. Transfer **22**, 589 (1979); E. Källne and L. A. Jones *ibid*. **25**, 393 (1981).
[39] S. T. Purcell and A. J. Barnard, J. Quant. Spectrosc. Radiat. Transfer **32**, 205 (1984).
[40] J. Purić, A. Srećković, S. Djeniže, and M. Platiša, Phys. Rev. A **36**, 3957 (1987).
[41] S. A. Freudestein and J. Cooper, Astrophys. J. **224**, 1079 (1978).
[42] M. S. Dimitrijević and N. Konjević, Astron. Astrophys. **163**, 297 (1986).
[43] W. C. Martin, R. Zalubas, and A. Musgrove, J. Phys. Chem. Ref. Data **19**, 821 (1990).
[44] J. A. Tully, M. J. Seaton, and K. A. Berrington, J. Phys. B **23**, 3811 (1990).
[45] D. Luo and A. K. Pradham, J. Phys. B **22**, 3377 (1989).
[46] J. D. Hey and Breger, J. Quant. Spectrosc. Radiat. Transfer **24**, 349 (1980); **24**, 427 (1980); and J. D. Hey, S. Afr. J. Phys. **5**, 111 (1982).
[47] J. Purić, S. Djeniže, J. Labat, M. Platiša, A. Srećković, and M. Ćuk, Z. Phys. D **10**, 431 (1988).

Experimental and calculated Stark widths within the Kr I spectrum

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On the basis of the precisely recorded 20 neutral krypton (Kr I) line shapes (in the $5s$-$5p$ and $5s$-$6p$ transitions), we have obtained the basic plasma parameters, i.e., electron temperature (T) and electron density (N) using our line deconvolution procedure in a plasma created in a linear, low-pressure, pulsed arc discharge operated in krypton. The mentioned plasma parameters have also been measured using independent experimental diagnostics techniques. Agreement has been found among the two sets of the obtained parameters. This recommends our deconvolution procedure for plasma diagnostical purposes, especially in astrophysics where direct measurements of the main plasma parameters (T and N) are not possible. On the basis of the observed asymmetry of the Stark broadened line profile, we have obtained not only its ion broadening parameter (A) which is caused by influence of the ion-microfield over the line broadening mechanism but also the influence of the ion-dynamic effect (D) over the line shape. The separate electron (W_e) and ion (W_i) contributions to the total Stark width, which have not been measured so far, have also been obtained. Stark widths are calculated using the semiclassical perturbation formalism for electrons, protons, and helium ions as perturbers.

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I. INTRODUCTION

Due to the development of space born astronomical techniques and devices such as Goddard high resolution spectrograph on the Hubble space telescope the spectral lines of trace elements, such as krypton, are observed and the corresponding atomic data are of increasing interest. Krypton has been detected in the spectra of the interstellar medium [1,2], which represents the material from which the young early type stars (as, e.g., Ap and Bp type stars where Stark broadening data are of interest) are formed [3]. On the basis of the recent investigation of the planetary nebula spectra [4] it was found that krypton is one of the most abundant elements in the cosmos with $Z>32$. Moreover, krypton is present in many light sources and lasers as the working gas. If the Stark broadening is the principal pressure broadening mechanism in plasmas (with 10^{21}–10^{25} m^{-3} electron density), it is possible to obtain from Stark width values other basic plasma parameters as, e.g., electron temperature (T) and density (N). Consequently, the knowledge of the Stark width of the krypton spectral lines is of interest for plasma diagnostical purposes.

Seven experimental works [5–11] are devoted to the neutral krypton (Kr I) Stark width investigation. In experiments performed up to now the symmetrical Voigt or Lorentz line profiles were used for deconvolution procedure giving *a priori* overvalued Stark width values (W_e) generated by electrons without any possibility to estimate the ion component (W_i) generated by Kr II ions (or other ions) [12–14] in the total Stark width (W_t).

Our W_e and W_i values, presented here for 20 Kr I lines, are separated from measured total Stark width using the line deconvolution procedure described in Refs. [15,16] which have already been applied for some He I [17,18] and Ne I [19] lines. On the basis of the observed line profile asymmetry we have obtained the role of the quasistatic ion (A) and ion-dynamic effect (D) in the line broadening mechanism. To the knowledge of the authors no experimental W_t, W_i, and D values and no theoretical W_e and A values exist.

Using the semiclassical perturbation formalism (SCPF) (updated several times) [20–25], as the first, we have calculated W_e values for 11 Kr I lines and W_i values, also, generated by protons and helium ions which are the main components in the astrophysical plasmas.

The basic plasma parameters, i.e., electron temperature (T^D) and electron density (N^D) have also been obtained by using our line deconvolution procedure. To the knowledge of the authors, our T and N values are data results obtained directly from the line profile, using deconvolution procedure. Plasma parameters have also been measured (T^{expt} and N^{expt}) using independent, well-known, experimental diagnostical techniques. Very good agreement was found among the two sets of the obtained parameters (T^D and T^{expt}; and N^D and N^{expt}). This recommends our deconvolution procedure for plasma diagnostical purposes, especially in astrophysics where direct measurements of the main plasma parameters (T and N) are not possible.

II. EXPERIMENT

The modified version of the linear low-pressure pulsed arc [26,27] has been used as a plasma source. A pulsed discharge was performed in a quartz discharge tube of 5-mm inner diameter and plasma length of 7.2 cm. The tube has end-on quartz window. On the opposite side of the electrodes the

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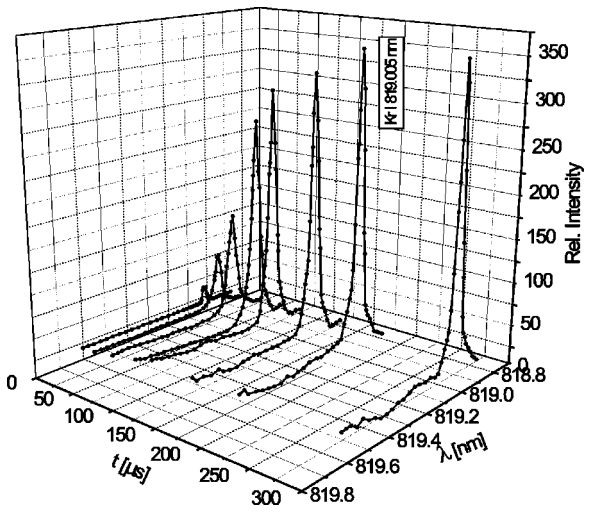

FIG. 1. Temporal evolution of the 819.005-nm Kr I spectral line profile during the plasma decay.

glass tube was expanded in order to reduce erosion of the glass wall and also sputtering of the electrode material onto the quartz windows. The working gas was pure krypton at 130 Pa filling pressure in flowing regime. Spectroscopic observation of isolated spectral lines has been made end-on along the axis of the discharge tube. A capacitor of 14 μF was charged up to 1.5 kV. The line profiles were recorded using a shot-by-shot technique with a photomultiplier (EMI 9789 QB and EMI 9659B) and a grating spectrograph (Zeiss PGS-2, reciprocal linear dispersion 0.73 nm/mm in first order) system. The instrumental full width at half maximum-(FWHM) of 8 pm was determined by using the narrow spectral lines emitted by the hollow cathode discharge. The recorded profiles of these lines are Gaussian in shape within 8% accuracy within the range of the investigated spectral line wavelengths. The spectrograph exit slit (10 μm) with the calibrated photomultiplier was micrometrically traversed along the spectral plane in small wavelength steps (7.3 pm). The averaged photomultiplier signal (five shots at the same spectral range) was digitized using an oscilloscope, interfaced to a computer. A sample output, as example, is shown in Fig. 1.

The absence of self-absorption was checked by using the technique described in Ref. [28]. Diagnostical methods and used procedures have been described, in detail, in our earlier work [27]. Thus, electron temperature (T^{expt}) decay is obtained by using the Saha equation applied for Kr II and Kr I line intensity ratios. Electron density (N^{expt}) decay is obtained using laser interferometry technique. Temporal evolutions of T^{expt} and N^{expt} are presented in Fig. 2, together with averaged T^{D} and N^{D} values obtained using line deconvolution procedure (see Sec. IV).

III. THEORETICAL BACKGROUND

The total line Stark FWHM (full width at a half intensity maximum, W_{t}) is given as

$$W_{\mathrm{t}} = W_{\mathrm{e}} + W_{\mathrm{i}}, \tag{1}$$

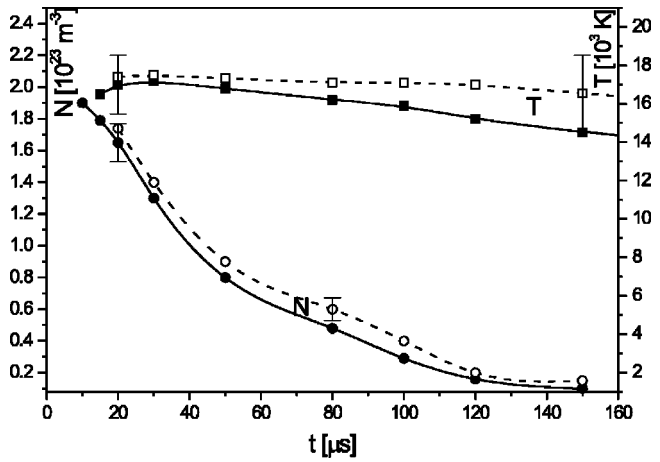

FIG. 2. Electron temperature (T) and density (N) decays. Full lines represent measured data using independent experimental techniques. Dashed lines represent averaged (within 20 Kr I lines) plasma parameters obtained using our line deconvolution procedure. Error bars represent estimated accuracies of the measurements ($\pm 11\%$ and $\pm 7\%$ for T and N, respectively) and deconvolutions ($\pm 12\%$).

where W_{e} and W_{i} are the electron and ion contributions, respectively. For a nonhydrogenic, isolated neutral atom line the ion broadening is not negligible and the line profiles are described by an asymmetric K function [see Eq. (6) in Sec. IV and in Ref. [15]]. The total Stark width (W_{t}) [29–31] may be calculated from the equation

$$W_{\mathrm{t}} \approx W_{\mathrm{e}}[1 + 1.75AD(1 - 0.75R)], \tag{2}$$

where

$$R = \sqrt[6]{\frac{36\pi e^6 N}{(kT)^3}} \tag{3}$$

is the ratio of the mean ion separation to the Debye length. N and T represent electron density and temperature, respectively. A is the quasistatic ion broadening parameter [see Eq. (224) in Ref. [29]] and D is a coefficient of the ion-dynamic contribution with the established criterion

$$D = \frac{1.36}{1.75(1-0.75R)} B^{-1/3} \quad \text{for} \quad B < \left(\frac{1.36}{1.75(1-0.75R)} \right)^3;$$

or

$$D = 1 \quad \text{for} \quad B \geqslant \left(\frac{1.36}{1.75(1-0.75R)} \right)^3, \tag{4}$$

where

$$B = A^{1/3} \frac{4.03 \times 10^{-7} W_{\mathrm{e}}(\mathrm{nm})}{[\lambda\ (\mathrm{nm})]^2} [N(\mathrm{m}^{-3})]^{2/3} \sqrt{\frac{\mu}{T_g\,(K)}} < 1 \tag{5}$$

is the factor with atom-ion perturber reduced mass μ (in amu) and gas temperature T_g. When $D = 1$ the influence of

the ion-dynamic effect is negligible and the line shape is treated using the quasistatic ion approximation. From Eqs. (1)–(6) it is possible to obtain the plasma parameters (N and T) and the line broadening characteristics (W_t, W_e, W_i, A, and D). One can see that the ion contribution, expressed in terms of the A and D parameters directly determines the ion width (W_i) component in the total Stark width [Eqs. (1) and (2)].

IV. NUMERICAL PROCEDURE FOR DECONVOLUTION

The proposed functions for various line shapes [Eq. (6)] is of the integral form and include several parameters. Some of these parameters can be determined in separate experiments, but not all of them. Furthermore, it is impossible to find an analytical solution for the integrals and methods of numerical integration to be applied. This procedure, combined with the simultaneous fitting of several free parameters, causes the deconvolution to be an extremely difficult task and requires a number of computer supported mathematical techniques. Particular problems are the questions of convergence and reliability of deconvolution procedure, which are tightly connected with the quality of experimental data,

$$K(\lambda)=K_o+K_{\max}\int_{-\infty}^{\infty}\exp(-t^2),$$

$$\left[\int_0^{\infty}\frac{H_R(\beta)}{1+\left(2\dfrac{\lambda-\lambda_o-(W_G/2\sqrt{ln2})t}{W_e}-\alpha\beta^2\right)^2}d\beta\right]dt. \tag{6}$$

Here K_o is the baseline (offset) and $K_{\max}$ is the maximum of intensity (intensity for $\lambda=\lambda_o$) [15]. $H_R(\beta)$ is an electric microfield strength distribution function of normalized field strength $\beta=F/F_o$, where F_o is the Holtsmark field strength. A ($\alpha=A^{4/3}$) is the static ion broadening parameter as a measure of the relative importance of ion and electron broadenings. R is the ratio of the mean distance between the ions to the Debye radius, i.e., the Debye shielding parameter and W_e is the electron width (FWHM) in the $j_{A,R}$ profile [see Eq. (7)].

For the purpose of deconvolution iteration process we need to know the value of K function as a function of λ for every group of parameters ($K_{\max}$, λ_o, W_e, W_G, R, A). The function $K(\lambda)$ is in integral form and we have to solve a triple integral in each step of iteration process of varying the above group of parameters. The first integral in the K function is the microfield strength distribution function $H_R(\beta)$, the second one is the $j_{A,R}(\lambda)$ function [Eq. (7)], and the third is the convolution integral of a Gaussian and a plasma broadened spectral line profile $j_{A,R}(\lambda)$, denoted by $K(\lambda)$ [Eq. (6)]. All these integrals have no analytic solution and must be solved using the numerical integration,

$$j_{A,R}(\lambda)=j_o+j_{max}\int_0^{\infty}\frac{H_R(\beta)}{1+\left(2\dfrac{\lambda-\lambda_o}{W_e}-\alpha\beta^2\right)^2}d\beta. \tag{7}$$

The most difficult integral to deal with is the microfield strength distribution function, because this is a multidimensional integral. A straightforward manner would be the estimates of multidimensional integral by Monte Carlo method of integration. The number of random samples of points must be large in order to achieve satisfactory accuracy. That would lead to increased processor time [16].

The second integral in Eq. (6) is the $j_{A,R}(\lambda)$ and it is evaluated by summation method. The third integral is evaluated by the Gauss-Hermite method with $\exp(-t^2)$ as a weight function. In this way the number of terms in the numerical sum is reduced in comparison with the summation methods. It must be noted that in cases where ($W_G>0.5W_e$) in Eq. (6) which are frequent physical situations in astrophysical plasmas [32], this method of integration is not applicable. Then, the integration must be done by classical summation methods, which greatly slow down the iteration process, but these methods are the only correct ones, in this matter. The W_G is defined with Eq. (8) [i.e., Eq. (2.3) in Ref. [15]],

$$W_G=2\sqrt{\frac{2(\ln 2)kT}{m}}\frac{\lambda_o}{c}. \tag{8}$$

Here, T is the emitter equivalent kinetic temperature, m is its mass, and k and c are the Boltzmann constant and the velocity of light, respectively.

In general, the base line K_o in Eq. (6) is a function of wavelength. In many cases it is nearly constant, or linear function. We have included in our procedure the fitting of background by a cubic polynomial, as an independent step, in order to prepare experimental data for the main deconvolution procedure.

In this way Eq. (6) be solved, and now it can start with the fitting procedure itself. For Eq. (6), the fitting procedure will give the values for W_G, W_e, λ_o, R, A, and $K_{\max}$.

We use the standard manner of defining the best fit: the sum of the squares of the deviations (chi-square) of the theoretical function from their experimental points is at its minimum. In other words, we look for the global minimum of the chi-square function which is a hypersurface of n dimensions in a hyperspace of $n+1$ dimensions, where n is equal to a number of parameters for appropriate theoretical function. n is equal to six for the ''K'' profile.

The necessary condition for the minimum of chi-square sum is that the partial derivatives of the function are equal to zero. Therefore, in the case of K function we have a system of six nonlinear homogeneous equations with six parameters. We look for the numerical solutions of these systems by using the well-known Newton's method of successive approximations [15].

The seeking for the numerical solution of this problem by employing the computer is accompanied by a number of numerical difficulties. The Newton's method requires successive solving of the inverse Jacobi matrices of the system of

TABLE I. The Kr I line broadening characteristics. Our measured: total Stark FWHM ($W_t^{expt.}$ in pm within ±12% accuracy), electron Stark width ($W_e^{expt.}$ in pm within ±12% accuracy), ion (Kr II + Kr III) Stark width ($W_i^{expt.}$ in pm within ±12% accuracy), static ion broadening parameter ($A^{expt.}$, dimensionless within ±15% accuracy), and ion-dynamic coefficient ($D^{expt.}$, dimensionless within ±20% accuracy) at measured electron temperature ($T^{expt.}$) and electron density ($N^{expt.}$). $W_e^{theor.}$ denote our calculated electron Stark widths (see Table II). "Ref." represents experimental values given in this work (Tw) and those used from other authors: SKS, Ref. [11]; EMZ, Ref. [5]; KM, Ref. [10]; BHN, Ref. [6]; LAM, Ref. [9]; VS, Ref. [7]; UK, Ref. [8]. Transitions and wavelengths are taken from Refs. [14,38]. The asterisk denotes Stark widths calculated by us on the basis of the given $W_e^{expt.}$ and $A^{expt.}$ values at plasma parameters presented in Ref. [11] using Eqs. (1)–(3).

Transition	Multiplet	λ (nm)	$T^{expt.}$ (10^4 K)	$N^{expt.}$ (10^{22}m^{-3})	$W_t^{expt.}$ (pm)	$W_e^{expt.}$ (pm)	$W_i^{expt.}$ (pm)	$A^{expt.}$	$D^{expt.}$	Ref.	$W_e^{theor.}$ (pm)	$W_e^{expt.}/W_e^{theor.}$
$5s$-$5p$	$[3/2]_1^o-[1/2]_o$	758.741	1.7	16.5	177.5	164.4	13.1	0.074	1.46	Tw	255.8	0.64
			1.0	1.0	11.3*	10.1	1.2*	0.049		SKS	13.8	0.73
			1.3	1.0		14.6				EMZ	14.7	0.99
	$[3/2]_2^o-[3/2]_2$	760.154	1.7	16.5	157.6	146.4	11.2	0.071	1.53	Tw	196.4	0.80
			1.0	1.0	9.7*	8.6	1.1*	0.047		SKS	10.3	0.84
			1.3	1.0		16.0				EMZ	10.9	1.47
	$[3/2]_2^o-[3/2]_1$	769.454	1.7	16.5	130.8	121.8	9.0	0.068	1.65	Tw	191.4	0.64
			1.0	1.0	8.9*	8.0	0.9*	0.045		SKS	9.9	0.80
	$[3/2]_1^o-[3/2]_2$	819.005	1.7	16.5	172.8	160.7	12.1	0.070	1.56	Tw	226.0	0.71
			1.0	1.0	10.8*	9.6	1.2*	0.046		SKS	11.8	0.82
			1.3	1.0		14.8				EMZ	12.6	1.17
	$[3/2]_1^o-[3/2]_1$	829.811	1.7	16.5	165.5	154.2	11.3	0.068	1.60	Tw	217.8	0.71
			1.0	1.0	10.5*	9.4	1.1*	0.045		SKS	11.4	0.82
			1.3	1.0		14.7				EMZ	12.3	1.20
	$[3/2]_2^o-[5/2]_3$	811.290	1.7	16.5	169.7	157.6	12.1	0.071	1.56	Tw	193.0	0.82
			1.0	1.0	11.1*	9.9	1.2*	0.047		SKS	10.1	0.98
			1.3	1.0		13.3				EMZ	10.8	1.23
	$[3/2]_2^o-[5/2]_2$	810.436	1.7	16.5	189.2	175.2	14.0	0.074	1.50	Tw	194.7	0.90
			1.0	1.0	12.7*	11.3	1.4*	0.049		SKS	10.1	1.12
$5s$-$5p'$	$[3/2]_2^o-[1/2]_1$	557.029	1.7	16.5	156.9	145.8	11.1	0.070	1.25	Tw		
			1.0	10.0		96.0				KM		
			1.2	1.0		6.3				BHN		
			1.1	10.0		86.0				LAM		
	$[3/2]_2^o-[3/2]_2$	556.222	1.7	16.5	137.3	127.6	9.7	0.070	1.30	Tw		
			1.2	1.0		5.6				BHN		
	$[3/2]_1^o-[3/2]_2$	587.091	1.7	16.5	140.0	130.0	10.0	0.071	1.34	Tw		
			1.0	10.0		122.0				KM		
			1.2	1.0		5.8				BHN		
			1.7	158.0		900.0				VS		
			1.3	102.0		680.0				UK		
$5s'$-$5p'$	$[1/2]_1^o-[1/2]_1$	828.105	1.7	16.5	170.5	158.5	12.0	0.070	1.58	Tw		
	$[1/2]_1^o-[1/2]_o$	768.525	1.7	16.5	154.3	143.1	11.2	0.073	1.55	Tw		
			1.0	1.0	10.5*	9.4	1.1*	0.048		SKS		
			1.3	1.0		179.0				EMZ		
	$[1/2]_o^o-[1/2]_1$	785.482	1.7	16.5	161.0	149.8	11.2	0.069	1.56	Tw		
			1.0	1.0	10.1*	9.0	1.1*	0.046		SKS		
			1.3	1.0		154.0				EMZ		
	$[1/2]_1^o-[3/2]_2$	826.324	1.7	16.5	170.0	157.9	12.1	0.071	1.58	Tw		
			1.0	1.0	11.8*	10.6	1.2*	0.047		SKS		
	$[1/2]_o^o-[3/2]_1$	805.95	1.7	16.5	149.1	139.1	10.0	0.066	1.63	Tw		
			1.0	1.0	9.3*	8.4	0.9*	0.044		SKS		
			1.3	1.0		109.0				EMZ		

TABLE I. (*Continued*).

Transition	Multiplet	λ (nm)	$T^{\text{expt.}}$ (10^4 K)	$N^{\text{expt.}}$ (10^{22}m^{-3})	$W_t^{\text{expt.}}$ (pm)	$W_e^{\text{expt.}}$ (pm)	$W_i^{\text{expt.}}$ (pm)	$A^{\text{expt.}}$	$D^{\text{expt.}}$	Ref.	$W_e^{\text{theor.}}$ (pm)	$W_e^{\text{expt.}}/W_e^{\text{theor.}}$
$5s$-$6p$	$[3/2]_2^o-[1/2]_1$	436.264	1.7	16.5	342.8	325.2	17.6	0.050	1	Tw	389.4	0.84
	$[3/2]_2^o-[3/2]_2$	427.397	1.7	16.5	448.8	423.7	25.1	0.055	1	Tw	392.7	1.08
			1.1	10.0		275.0				LAM	223.0	1.23
	$[3/2]_1^o-[3/2]_1$	446.369	1.7	16.5	367.2	348.3	18.9	0.050	1	Tw	414.2	0.84
			1.1	10.0		263.0				LAM	234.0	1.12
	$[3/2]_2^o-[5/2]_3$	431.958	1.7	16.5	345.9	328.0	17.9	0.050	1	Tw	381.2	0.86
			1.2	1.0		27.0				BHN	21.8	1.24
$5s'$-$6p'$	$[1/2]_1^o-[1/2]_o$	435.136	1.7	16.5	495.6	469.9	25.7	0.051	1	Tw		

equations for each step, which are error prone due to the errors of rounding. Moreover, the numerical partial derivatives in Jacobi matrix itself are sources of errors of rounding. These errors of rounding destabilize the convergence of solution of the system, although the all-mathematical conditions are fulfilled. The algorithm may be stabilized by reducing the iteration procedure to independent parameters only, by neglecting the nondiagonal elements of Jacobi matrix. By this simplification the errors of rounding in inverse Jacobi matrix calculation decrease. Further stabilization of iterative process may be achieved by weighing the nondiagonal elements of inverse Jacobi matrix by real numbers in the domain (0, 1]. These modifications of Newton's method do not spoil the conditions of convergence and uniqueness of mathematical solution, but affect somewhat the speed of convergence. In this way we have contrived to give numerical solutions for fitting functions with more than three free parameters, which is difficult for nonpolynomial fits.

This sophisticated deconvolution method, which allows direct determining of all six parameters by fitting theor.etical K-profile [Eq. (6)], on experimental data, requires sufficient number of experimental points per line, and small statistical errors. The upper limits of numerical conditionality of this method are minimum twenty experimental points per line [the border of line is $(-3/2W_e+\lambda_o<\lambda<+3/5W_e+\lambda_o)$, where W_e is electron FWHM], and maximal statistical indeterminacy in intensity is 5% at every experimental point. Poor experimental measurements weaken the conditionality of the system of equations, and lead to nonapplicability of this method. This has been concluded by testing the sensitivity of the algorithm by generating random statistical noise with Gaussian distribution in every point involved in theor.etical profiles.

V. METHOD OF CALCULATION

The description of the semiclassical perturbation formalism is given in Refs. [20–25,33]. Within this formalism, Stark full-width (W) at the intensity half maximum (FWHM) and shift (d) of an isolated spectral line, may be expressed as [20,21]

$$W=N\int vf(v)dv\left(\sum_{i'\neq i}\sigma_{ii'}(v)+\sum_{f'\neq f}\sigma_{ff'}(v)+\sigma_{el}\right),$$

$$d=N\int vf(v)dv\int_{R_3}^{R_D}2\pi\rho d\rho\sin 2\phi_p, \tag{9}$$

where N is the electron density, $f(v)$ the Maxwellian velocity distribution function for electrons, ρ denotes the impact parameter of the incoming electron, i and f denote the initial and final atomic energy levels, and i', f' their corresponding perturbing levels. The inelastic cross section $\sigma_{j,j'}(v)$ can be expressed by an integral over the impact parameter of the transition probability $P_{jj'}(\rho,v)$ as

$$\sum_{j'\neq j}\sigma_{jj'}(v)=\frac{1}{2}\pi R_1^2+\int_{R_1}^{R_D}\sum_{j\neq j'}P_{jj'}(\rho,v),j=i,f \tag{10}$$

and the elastic cross section is given by

$$\sigma_{el}=2\pi R_2^2+\int_{R_2}^{R_D}8\pi\rho d\rho\sin^2\delta,$$

$$\delta=(\phi_p^2+\phi_q^2)^{1/2}. \tag{11}$$

The phase shifts ϕ_p and ϕ_q due, respectively, to the polarization potential (r^{-4}) and to the quadrupolar potential (r^{-3}), are given in Sec. 3 of Chap. 2 in Ref. [20]. R_D is the Debye radius. All the cutoffs R_1, R_2, R_3 are described in Sec. 1 of Chap. 3 in Ref. [21].

For electrons hyperbolic paths due to the attractive Coulomb force were used, while for perturbing ions the paths are different since the force is repulsive. The formulas for the ion-impact widths and shifts are analogous to Eqs. (9)–(11). The difference in calculation of the corresponding transition probabilities and phase shifts as a function of the impact parameter in Eqs. (10) and (11) is in the ion perturber trajectories which are influenced by the repulsive Coulomb force instead of an attractive one as for electrons.

Energy levels have been taken from Ref. [34]. Oscillator strengths have been calculated by using the method of Bates and Damgaard [35,36]. For higher levels, the method described in Ref. [37] has been used. It is not possible to perform semiclassical calculation in an adequate way for experi-

TABLE II. Calculated Kr I Stark FWHM ($W^{\text{theor.}}$ in pm) for electrons (a), protons (b), and helium ions (c) as perturbers for various temperatures (T) at 10^{22} m^{-3} perturber density.

λ (nm)		T (10^3 K)					
		2.5	5.0	10.0	20.0	30.0	50.0
758.741	a	10.6	12.2	13.8	16.4	18.1	21.0
	b	4.10	4.25	4.42	4.63	4.78	4.99
	c	3.89	4.01	4.12	4.26	4.36	4.50
760.154	a	8.22	9.12	10.3	12.6	14.4	17.2
	b	3.51	3.60	3.69	3.81	3.90	4.02
	c	3.40	3.47	3.53	3.61	3.66	3.74
769.454	a	7.91	8.76	9.88	12.2	13.9	16.8
	b	3.50	3.57	3.66	3.76	3.83	3.94
	c	3.40	3.46	3.52	3.58	3.63	3.70
819.005	a	9.38	10.4	11.8	14.6	16.8	20.2
	b	4.06	4.15	4.26	4.39	4.49	4.62
	c	3.94	4.01	4.08	4.17	4.22	4.31
829.811	a	9.04	9.98	11.4	14.1	16.3	19.8
	b	4.05	4.14	4.23	4.34	4.42	4.54
	c	3.95	4.02	4.08	4.15	4.20	4.27
811.290	a	8.26	8.94	10.1	12.5	14.6	17.8
	b	3.59	3.66	3.74	3.84	3.90	4.00
	c	3.50	3.56	3.61	3.67	3.71	3.78
810.436	a	8.25	8.93	10.1	12.5	14.6	17.8
	b	3.59	3.66	3.74	3.83	3.90	4.00
	c	3.50	3.56	3.61	3.67	3.71	3.77
436.264	a	17.5	19.6	21.7	24.3	26.2	28.6
	b			6.17	6.58	6.86	7.27
	c					6.06	6.32
427.397	a	17.3	19.9	22.0	24.5	26.1	28.6
	b			6.42	6.84	7.12	7.54
	c						6.55
446.369	a	18.1	20.7	23.1	25.8	27.6	30.4
	b			6.83	7.25	7.54	7.96
	c						6.96
431.958	a	16.7	19.0	21.2	23.9	25.8	28.6
	b			6.17	6.54	6.79	7.16
	c						6.31

mental spectral lines originating from transitions involving $5p'[1/2]$, $5p'[3/2]$, $6p'[1/2]$, and $6p'[3/2]$ energy levels, since experimental data for $nd'[1/2]$ energy levels are missing. The expected accuracy of the semiclassical perturbation approach is $\pm 30\%$. However, due to the complexity of krypton spectrum and missing atomic energy levels, we expect that the accuracy of calculated Stark widths is $\pm 40\%$ for transitions from $5p$ levels and even $\pm 45\%$ from transitions involving $6p$ levels.

VI. RESULTS AND DISCUSSION

Our experimentally obtained $W_t^{\text{expt.}}$, $W_e^{\text{expt.}}$, $W_i^{\text{expt.}}$, $A^{\text{expt.}}$, and $D^{\text{expt.}}$ data are presented in Table I.

Calculated Stark FWHM values ($W^{\text{theor.}}$) generated by electrons, protons and helium ions for eleven Kr I lines in the $5s$-$5p$ and $5s$-$6p$ transitions using SCPF are presented in Table II.

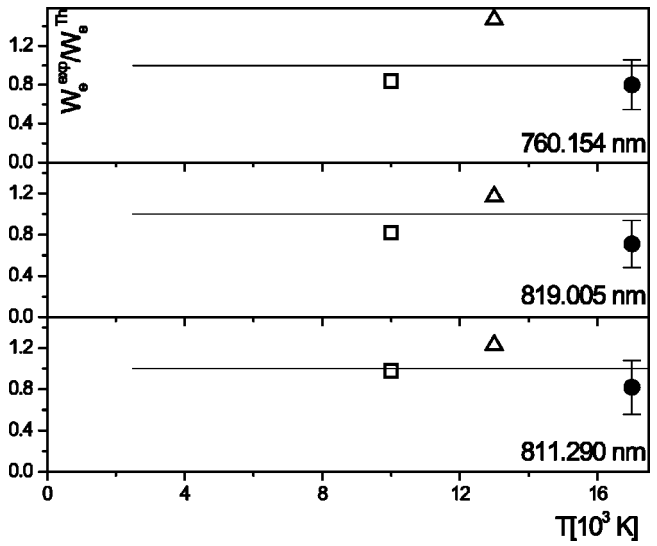

FIG. 3. Ratios of the experimental $W_e^{\text{expt.}}$ and our calculated $W_e^{\text{theor.}}$ electron Stark widths vs electron temperature for the most investigated Kr I spectral lines belonging to the $5s$-$5p$ transition. ●, our experimental results and those of other authors: □, Ref. [11] and △, Ref. [5]. Error bars ($\pm 30\%$) include the uncertainties of the width ($\pm 12\%$), electron density ($\pm 7\%$), and temperature ($\pm 11\%$) measurements.

The measured $N^{\text{expt.}}$ and $T^{\text{expt.}}$ decays are presented in Fig. 2, together with the averaged (within 20 Kr I lines) N^{D} and T^{D} values obtained using the line profile deconvolution procedure for Kr I lines. One can conclude that the agreement among $N^{\text{expt.}}$ and N^{D} values is very good (within 7% on average). This fact confirms homogeneity of investigated plasma in the linear part of our light source (see Fig. 1 in Ref. [26]). In the case of the electron density, the situation is similar. The agreement among the two sets of the electron temperature decays ($T^{\text{expt.}}$ and T^{D}) is between the experimental accuracy of $\pm 11\%$ and uncertainties ($\pm 12\%$) of the results obtained by deconvolution procedure.

Existing experimental Stark width values ($W_e^{\text{expt.}}$) are compared to our measured and calculated ($W_e^{\text{theor.}}$) data (see Table I and Fig. 3).

The EMZ [5] and LAM [9] $W_e^{\text{expt.}}$ values lie above our calculated ones for about 25% and 17%, respectively.

Our $W_e^{\text{expt.}}/W_e^{\text{theor.}}$ is 0.82 (on average) except 758.741-nm and 769.454-nm lines for which 0.64 was found. The agreement between our measured and calculated (W_e) values is better for the lines in highly lying ($5s$-$6p$) transition.

$W_e^{\text{expt.}}$ values from Ref. [11] agree well with our calculated ones. Thus, the ratio $W_e^{\text{expt.}}/W_e^{\text{theor.}}$ for values from Ref. [11] is 0.86 (averaged within seven lines).

In the case of the most investigated 587.091-nm Kr I line, the comparison among experimental values is not possible due to various plasma parameters at which they are determined.

We have found that the ion contribution (Kr II + Kr III) to the total ($W_t^{\text{expt.}}$) Stark width is about 8% for the $5s$-$5p$

transitions and about 5% for the $5s$-$6p$ transitions.

It turns out that the ratio between our $W_i^{\text{expt.}}$ values and those from Ref. [11] is constant ($10\pm24\,\%$) for 11 Kr I lines. Furthermore, this ratio has approximately the same value as the ratio between the factors of N/T in the two experiments ($9.7\pm18\,\%$).

We have found that the Stark widths ($W^{\text{theor.}}$) generated by protons and helium ions are mutually close and are two or four times smaller than the widths generated by electrons and practically independent of T up to 50 000 K (see Table II).

Our $A^{\text{expt.}}$ values can be separated into two groups. In the first group are the higher A values (from 0.067 up to 0.074) corresponding to the lines in the $5s$-$5p$ transitions. The second group comprises the lower A values (from 0.050 up to 0.055) corresponding to the lines in the higher lying $5s$-$6p$ transitions.

It turns out that our $A^{\text{expt.}}$ values show small internal scatter within the mentioned groups. They lie within $\pm7\%$ of the mean value. A similar behavior is also shown by A values from Ref. [11] in the $5s$-$5p$ transitions. Their scatter is $\pm6\%$.

The normalized A values obtained in Ref. [11] (taking the $N^{1/4}$ normalization factor from Ref. [29]) are about 34% higher than ours. But, taking into account the difference between electron temperatures (10 000 K and 17 000 K) in the two experiments, this discrepancy is really lower than 34% and can be estimated to be 20%. Thus, one can conclude that tolerable agreement exists among our A values and those from Ref. [11].

It should be pointed out that our A values in the Kr I $5s$-$6p$ transitions are the unique data in this field. We have found that the ion-dynamic effect plays a significant role in the Kr I line broadening (at our plasma conditions) and multiplies the quasistatic ion effect by about 1.5 times (on average) in the case of the $5s$-$5p$ transition.

VII. CONCLUSION

We have found evident influence of the quasistatic ion and ion-dynamic effects on the investigated Kr I spectral line shapes. Moreover, since conditions of validity of the impact and quasistatic approximation differ in Refs. [20,21] and in Ref. [29], experimental determinations of ion broadening contribution are of interest for their elaboration. It is shown that the line deconvolution procedure, described by Ref. [15], applied to Kr I line profiles, gives convenient plasma parameters (N and T, confirmed experimentally) at about 17 000 K electron temperature and 1.65×10^{23} m^{-3} electron density. We recommend this method for plasma diagnostical and modeling purposes.

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[1] J.A. Cardelli, B.D. Savage, and D.C. Ebbets, Astrophys. J. **383**, L23 (1991).
[2] D. S. Leckrone, G. M. Wahlgren, S. G. Johansson, and S. J. Adelman, in *Peculiar versus Normal Phenomena in A-type and Related Stars,* International Astronomical Union Colloquium No. 138, Trieste, 1992, edited by M. M. Dworetsky, F. Castelli, and R. Faraggiana (Astronomical Society of the Pacific, San Francisco, 1993).
[3] D.S. Leckrone *et al.*, ASP Conf. Ser. **44**, 42 (1993).
[4] H.L. Dinerstein, Astrophys. J. **550**, L223 (2001).
[5] W.E. Ernst, B.H. Müller, and T. Zaengel, Physica C **93**, 414 (1978).
[6] T. Brandt, V. Helbig, and K. Nick, in *Proceedings of ICSLS, 1981*, edited by B. Wende (W. de Gruyter, Berlin, 1981), p. 265.
[7] Y. Vitel and M. Skowronek, J. Phys. B **20**, 6493 (1987).
[8] N.I. Uzelac and N. Konjević, J. Phys. B **22**, 2517 (1989).
[9] A. Lesage, D. Abadie, and M.H. Miller, Phys. Rev. A **40**, 1367 (1989).
[10] P. Klein and D. Meiners, J. Quant. Spectrosc. Radiat. Transf. **17**, 197 (1977).
[11] D. Schinköth, M. Kock, and E. Schultz-Gulde, J. Quant. Spectrosc. Radiat. Transf. **64**, 635 (2000).
[12] A. Lesage and J. R. Fuhr (unpublished).
[13] N. Konjević *et al.*, J. Phys. Chem. Ref. Data **31**, 819 (2002).
[14] NIST (2002), Atomic Spectra Data Base Lines, http://physics.nist.gov .
[15] V. Milosavljević and G. Poparić, Phys. Rev. E **63**, 036404 (2001).
[16] V. Milosavljević, Ph.D. thesis, University of Belgrade, Faculty of Physics, Belgrade, 2001 (unpublished).
[17] V. Milosavljević and S. Djeniže, Astron. Astrophys. **393**, 721 (2002).
[18] V. Milosavljević and S. Djeniže, New Astron. **7/8**, 543 (2002).
[19] V. Milosavljević and S. Djeniže, Phys. Lett. A **305/1-2**, 70 (2002).
[20] S. Sahal-Bréchot, Astron. Astrophys. **1**, 91 (1969).
[21] S. Sahal-Bréchot, Astron. Astrophys. **2**, 322 (1969).
[22] S. Sahal-Bréchot, Astron. Astrophys. **35**, 321 (1974).
[23] M.S. Dimitrijević and S. Sahal-Bréchot, J. Quant. Spectrosc. Radiat. Transf. **31**, 301 (1984).
[24] M.S. Dimitrijević and S. Sahal-Bréchot, Phys. Rev. A **31**, 316 (1985).
[25] M.S. Dimitrijević, S. Sahal-Bréchot, and V. Bommier, Astron. Astrophys., Suppl. Ser. **89**, 581 (1991).
[26] S. Djeniže, V. Milosavljević, and A. Srećković, J. Quant. Spectrosc. Radiat. Transf. **59**, 71 (1998).
[27] V. Milosavljević *et al.*, Phys. Rev. E **62**, 4137 (2000).
[28] S. Djeniže and S. Bukvić, Astron. Astrophys. **365**, 252 (2001).
[29] H. R. Griem, *Spectral Line Broadening by Plasmas* (Academic Press, New York, 1974).

[30] A.J. Barnard, J. Cooper, and E.W. Smith, J. Quant. Spectrosc. Radiat. Transf. **14**, 1025 (1974).
[31] D.E. Kelleher, J. Quant. Spectrosc. Radiat. Transf. **25**, 191 (1981).
[32] L.Č. Popović, M.S. Dimitrijević, and D. Tankosić, Astron. Astrophys., Suppl. Ser. **139**, 617 (1999).
[33] C. Fleurier, S. Sahal-Bréchot, and J. Chapelle, J. Quant. Spectrosc. Radiat. Transf. **17**, 595 (1977).
[34] J. Sugar and A. Musgrove, J. Phys. Chem. Ref. Data **20**, 859 (1991).
[35] D.R. Bates and A. Damgaard, Philos. Trans. R. Soc. London, Ser. A **242**, 101 (1949).
[36] H. VanRegemorter, Dy. HoangBinh, and M. Prud'homme, J. Phys. B **12**, 1053 (1979).
[37] G.K. Oertel and L.P. Shomo, Astrophys. J., Suppl. Ser. **16**, 175 (1968).
[38] R. A. Striganov and N. S. Sventickij, *Tablicy Spektral'nykh linij* (Atomizdat, Moskva, 1966).

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Stark broadening of visible Ar I spectral lines

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Abstract
Stark broadening parameters (width and shift) of six Ar I spectral lines: 522.1, 549.6, 518.6, 560.7, 603.2 and 696.5 nm, corresponding to the transitions $3p^5nd \rightarrow 3p^54p$ for $n = 7$–5 and $4p' \rightarrow 4s$ have been calculated on the basis of the impact theory within the semi-classical perturbation approach. The case of the quasistatic ions has also been examined. The conditions of use of the presented results have been discussed. The considered lines are in the optical part of the spectrum and are of interest for laboratory research, particularly surface wave sustained discharges, and astrophysical purposes. The obtained results are compared with published experimental results and values calculated by other authors. The influence of the used coupling (j-L or LS) and oscillator strengths (The Opacity Project (TOP) database or Coulomb approximation) has also been considered.

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1. Introduction

Stark broadening of spectral lines is important for the diagnostics and modelling of laboratory plasmas, and for many purposes in astrophysics. In spite of numerous efforts to obtain the atomic parameters entering the calculation of spectral line intensities and profiles, a number of these important parameters are still missing. Plasma-broadened and shifted spectral line profiles have been used for a number of years, as the basis of a non-interfering plasma diagnostic technique (see e.g. [1] and references therein). This technique needing Stark broadening data became, in some cases, the most sensitive and often the only possible plasma diagnostic tool.

Broadening of spectral lines emitted in surface wave sustained discharges (SWDs) is poorly discussed in experimental and theoretical studies. The plasma parameters of SWDs, experimentally investigated from 1 Torr to atmospheric pressure are presented in [2–12].

According to the recent experimental investigations of an argon SWD at atmospheric pressure [10, 11], the two Ar I lines 522.1 and 549.6 nm seem to be good data sources for determination of the electron density. The axial variation of the normalized (to its highest value) Lorentzian width of the 522.1 and 549.6 nm argon lines compared to that of the H_β line confirms that the former lines are sensitive to the electron density variation and the Stark effect contributes significantly to their Lorentzian broadening. This is in agreement with the general considerations regarding the structure of the atomic energy levels. It has been shown [13, 14] that one should expect a gradual increase in the Stark widths of the lines belonging to a spectral series with increasing the principal quantum number (n^*) of the upper state.

On the other hand, with the development of space-born spectroscopy, the importance of atomic data, including the Stark broadening parameters, for trace elements like argon, increases. For example argon is found in RS CVn binary σ^2 Coronae Borealis [15], and 'Chandra's' x-ray spectra of young supernovae 1998S and 2003bg revealed argon overabundance [16]. Recently, argon lines have been observed in the optical spectrum of the Be star Hen 2-90 [17], as well as in planetary nebulae and H II regions in the two dwarf irregular galaxies Sextans A and B [18]. Also argon abundance has been determined from spectral lines, e.g. for LSE 78, an extreme helium star [19], for the similar star BD-9°4395 [20], for DY Cen [21] and γ Peg [22], as well as for the Sun [23]. Consequently, Stark line broadening parameters for neutral and ionized argon are of interest for the

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modelling and investigation of astrophysical plasmas. We note here that lines within the optical spectral range are particularly significant.

In this paper, results of the semi-classical perturbation ([24, 25] (updates of the theory in [14] and [26])) calculations of Stark widths and shifts for six visible argon lines are presented. Three of them have not been calculated before. Obtained results are compared with the published experimental and theoretical Stark broadening parameters [1, 27–53]. Moreover, the influence of j-L and LS coupling schemes and oscillator strength is considered.

2. Theory

Within the semi-classical perturbation formalism [24, 25] (also [14, 26], as well as references therein), the full–half width (W) and the shift (d) of an isolated line originating from the transition between the initial level i and the final level f is expressed as:

$$W = 2n_{\mathrm{e}} \int_0^\infty v f\,(v)\mathrm{d}v \left[\sum_{\mathrm{i}'\neq\mathrm{i}} \sigma_{\mathrm{ii}'}\,(v) + \sum_{\mathrm{f}'\neq\mathrm{f}} \sigma_{\mathrm{ff}'}\,(v) + \sigma_{\mathrm{el}} \right], \quad (1)$$

$$d = \int_0^\infty v f\,(v)\mathrm{d}v \int_{R_3}^{R_\mathrm{d}} 2\pi\rho\mathrm{d}\rho \sin 2\varphi_{\mathrm{p}}, \quad (2)$$

where i′ and f′ are perturbing levels, n_{e} and v are the electron density and the velocity of perturbers respectively, and $f(v)$ is the Maxwellian distribution of electron velocities.

The inelastic cross-sections $\sigma'_{\mathrm{i_{ii}}}(v)$ (respectively $\sigma'_{\mathrm{ff}}(v)$) can be expressed by an integration of the transition probability $P_{\mathrm{ii}'}$ over the impact parameter:

$$\sum_{\mathrm{i}'\neq\mathrm{i}} \sigma_{\mathrm{ii}'}\,(v) = \frac{1}{2}\pi R_1^2 + \int_{R_1}^{R_\mathrm{d}} 2\pi\rho\mathrm{d}\rho \sum_{\mathrm{i}'\neq\mathrm{i}} P_{\mathrm{ii}'}\,(\rho, v) \quad (3)$$

The elastic collision contribution to the width is given by:

$$\sigma_{\mathrm{el}} = 2\pi R_2^2 + \int_{R_2}^{R_\mathrm{d}} 8\pi\rho\,\mathrm{d}\rho \sin^2\delta, \quad (4)$$

$$\delta = \left(\varphi_{\mathrm{p}}^2 + \varphi_{\mathrm{q}}^2\right)^{1/2}. \quad (5)$$

The phase shifts φ_{p} and φ_{q} are due to the polarization and quadrupole potential respectively. The cut-offs parameters R_1, R_2, R_3, the Debye cut-off R_{d} and the symmetrization procedure are described in [24, 25].

The impact approximation is valid when strong collisions are separated in time, or when the duration of collisions is much shorter than the separation time between strong collisions: $n_{\mathrm{e}}\pi\rho_{\mathrm{typ}}^3 \ll 1$, where ρ_{typ} is typical impact parameter for strong collisions.

The resulting profiles are Lorentzian. This condition is well verified for electron collisions for a large range of densities. For ion collisions the impact approximation might fail, especially for high densities or low temperatures. Then it is possible to apply the quasistatic approximation, given by [27]:

$$W_{\mathrm{iq}} = 1.75\times10^{-4} n_{\mathrm{e}}^{1/4} A \left[1 - 0.068\, n_{\mathrm{e}}^{1/6} T^{-1/2}\right] W_{\mathrm{e}} \quad (6)$$

$$d_{\mathrm{iq}} = 10^{-4} n_{\mathrm{e}}^{1/4} A \left[1 - 0.068 n_{\mathrm{e}}^{1/6} T^{-1/2}\right] W_{\mathrm{e}} \quad (7)$$

W_{e} is the impact contribution of electrons to the total width, T is in Kelvin and n_{e} in cm^{-3}. A is the quasistatic parameter, defined by Griem in [27] (see also [26]) as follows:

$$A = \left(\frac{eF_0^2}{\hbar W_{\mathrm{e}}} |\alpha_{\mathrm{i}} - \alpha_{\mathrm{f}}|\right)^{3/4} \quad (8)$$

$F_0 = 2\pi\,(4/15)^{2/3}\, e n_{\mathrm{e}}^{2/3}$ is the normal field strength. The polarizability of the initial level α_{i} (resp. α_{f} is the polarizability of the final level) is expressed as:

$$\alpha_i = 4a_0^3 \sum_{\mathrm{i}'\neq\mathrm{i}} f_{\mathrm{ii}'} \left(\frac{I_{\mathrm{H}}}{\Delta E_{\mathrm{ii}'}}\right)^2 \quad (9)$$

a_0 is the Bohr radius, $f_{\mathrm{ii}'}$ is the oscillator strength and I_{H} is the ionization energy of hydrogen.

3. Application to some visible neutral Ar lines

3.1. Atomic data

To study the influence of the values of oscillator strengths (which enter in the expressions for the semi-classical cross-sections and the A parameter) on the Stark broadening parameters, different sources of atomic data have been used. The calculations were performed for particular lines within multiplets (spin–orbital interaction is included).

In table 1, wavelengths of the studied argon lines, the corresponding transitions in j-L and LS coupling, and perturbing levels i′ and f′ are presented.

The most appropriate j-L coupling scheme for argon atoms has been used. The values of the energy levels have been taken from National Institute of Standards and Technology (NIST) catalogue [54]. However, there are no required oscillator strengths for transitions between higher energy levels there. Except for Ar I 696.5 nm, the studied spectral lines belong to the transitions, which initial levels are intermediate Rydberg levels. For the nearest perturbing levels the oscillator strengths are also missing from Kurucz's catalogue [55]. For this reason, the oscillator strengths (j-L coupling) have been calculated within the Bates and Damgaard approximation.

3.2. Results and discussion

3.2.1. Calculations. The calculations have been made for a set of temperatures 2.5–5.0 × 10^4 K at a perturber density of 10^{14} cm^{-3}. The results are presented in table 2 for the six studied argon lines. The calculated Stark widths (full–half widths at half intensity maximum) W and shifts d for collisions with electrons ($W_{\mathrm{e}} + d_{\mathrm{e}}$), Ar$^+$ ions ($W_{\mathrm{i}} + d_{\mathrm{i}}$), protons ($W_{\mathrm{p}} + d_{\mathrm{p}}$) and the quasistatic parameter A are given. Also, the values of various validity criteria, analysed in [56], are included.

Table 1. Basic data on the considered Ar I spectral lines. Here, λ nm denotes wavelength, i and f are initial and final level of the transition (within the frame of j-L and LS coupling), i′ and f′ are the corresponding perturbing levels.

(nm)	Transition (i – f)	i′ levels	f′ levels
522.1	$3p^5 7d$–$4p$ $^2[7/2]^\circ_4$- $^2[5/2]_3$ $^3F^\circ_4$- $^3D_3$	5f, 6f, 7f, 8f, 9f, 5p, 6p, 7p, 8p, 9p	4s, 5s, 6s, 3d, 4d, 5d, 6d
549.6	$3p^5 6d$–$4p$ $^2[7/2]^\circ_4$- $^2[5/2]_3$ $^3F^\circ_4$- $^3D_3$	4f, 5f, 6f, 7f, 4p, 5p, 6p, 7p	4s, 5s, 6s, 3d, 4d, 5d, 6d
518.8	$3p^5 5d'$–$4p$ $^2[3/2]^\circ_2$- $^2[1/2]_1$	4f, 5f, 6f, 7f, 4p, 5p, 6p, 7p	4s, 5s, 6s, 3d, 4d, 5d, 6d
603.2	$3p^5 5d$–$4p$ $^2[7/2]^\circ_4$- $^2[5/2]_3$ $^3F^\circ_4$- $^3D_3$	4f, 5f, 6f, 7f, 4p, 5p, 6p, 7p	4s, 5s, 6s, 3d, 4d, 5d, 6d
560.7	$3p^5 5d$–$4p$ $^2[1/2]^\circ_1$- $^2[1/2]_1$	4f, 5f, 6f, 7f, 4p, 5p, 6p, 7p	4s, 5s, 6s, 3d, 4d, 5d, 6d
696.5	$3p^5 4p'$–$4s$ $^2[1/2]_1$- $^2[3/2]^\circ_2$	4s, 5s, 6s 3d, 4d, 5d, 6d	3p, 4p, 5p, 6p

C_1 is the impact approximation validity criterion (C_1 should be much less than one we use here less than or equal to 0.1).

$$C_2 = \frac{W_{\text{inel}}}{W_{\text{el}}}$$

is the ratio of the contribution of inelastic collisions versus elastic ones for the width.

C_3 is the criterion for the 'one state' approximation validity.

C_4 is the ratio of the contribution of strong collisions to the total impact width and thus gives a validity criterion for the perturbation theory approximation.

C_5 is the criterion for the isolated line approximation, defined in [14, 57].

$$C_5 = \frac{W}{(\Delta E_{\text{ii}'})_{\min}},$$

where W is the total width, $W = W_e + W_i$ for laboratory plasma and $W = W_e + W_p$ for astrophysical plasma. $(\Delta E_{\text{ii}'})_{\min}$ is the energy distance between the upper level and the nearest perturbing level.

3.2.2. Validity criterions of impact approximation. The impact approximation is valid for electron and proton collisions in all considered cases, since the corresponding values of C_1 are very small compared to unity for all transitions and temperatures at the density of interest. Concerning Ar ion collisions, the impact approximation is valid for Ar I 518.8, 603.2, 560.7 and 696.5 nm within the whole temperature range. For Ar I 522.1 nm the impact approximation is not valid for all temperatures, so that the quasistatic approximation should be applied. For Ar I 549.6 nm the impact approximation is valid for temperature values above 10 000 K.

3.2.3. Isolated lines. The line is isolated if $C_5 < 1$, so that, according to [14, 57], energy levels broadened by collisions do not overlap. All lines studied in this paper are isolated within the whole range of temperatures for the considered density.

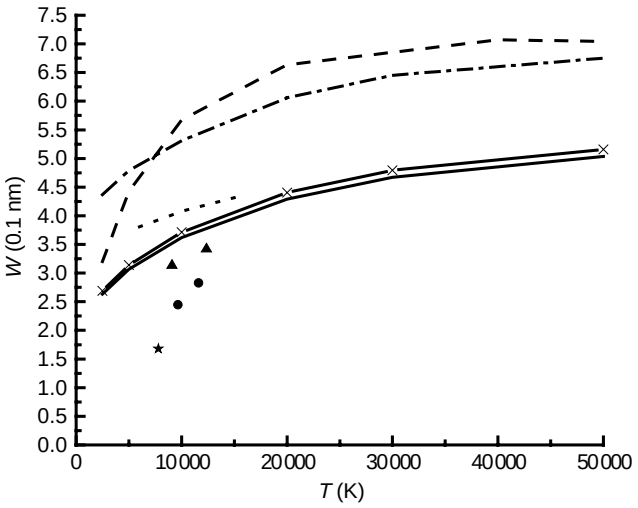

Figure 1. Stark full widths at half maximum of Ar I 549.6 nm versus temperature. Theoretical and experimental values are normalized to the electron density of 10^{16} cm^{-3}. The legend for symbols used is in table 3 (— for impact ions, –×– for quasistatic ions).

The values of C_3 criterion for electron perturbers show that the 'one state approximation' is valid, because the lower level contribution is negligible ($C_3 \gg 1$), except the Ar I 696.5 nm, where $5 > C_3 > 2$ at temperatures over 10 000 K. Consequently, except for the Ar I 696.5 nm, it is possible to continue to use the isolated line approximation in the "one state case" for the lines studied here since the contribution of collisions with the upper level is entirely dominant (98–99% of inelastic collisions).

The contribution of inelastic collisions of ionized argon and proton perturbers are entirely negligible, so that the corresponding values are omitted in table 2.

The validity condition of the perturbation theory is given by the ratio C_4, which represents the relative contribution of strong collisions to the total impact width. This contribution (≈30–50%) is practically the same for the electron and ionized argon collisions for all line transitions. The contribution of strong collisions to proton-impact widths is negligible so the corresponding values are omitted in table 2.

3.2.4. Comparison with other theoretical and experimental results. In figures 1–8 the calculations (Tw) for the Stark broadening parameters of studied spectral lines in pure argon gas are compared with those published by Griem in [27, 28] with the experimental widths and shifts, which in the critical reviews ([1], references therein and updates up to 2005) were estimated to have accuracy A or B. For lines where there are no results in [27], corresponding data from [28, 53] were used. The oscillator strengths entering in Griem's calculations were obtained for multiplet transition in j-L coupling using the Bates and Damgaard approximation.

In order to check the obtained results for Stark broadening parameters, previous results [58–60] were added. The data for energy levels and oscillator strengths from Kurucz's catalogue [55] are used in [58, 59]. The missing values of oscillator strengths for the transitions between initial level and nearest perturbing levels were taken from TOP base catalogue [61, 62] where the transitions of neutral argon are

Table 2. Stark broadening parameters for Ar I lines for a perturber (electrons, argon ions and protons) density of 10^{14}cm^{-3} and temperatures from 2500 up to 50000 K. The width (FWHM) W and shift d values are given in Angströms. The validity criteria and parameters $C_1 - C_5$, according to subsection 3.2. are included.

Perturbers are:		Electrons		Ionized argon		Protons	
Transition	T (10^3K)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)
7d $^2[7/2]_4$–4p $^2[5/2]_3$522.1 nm	2.5	0.385E – 01	0.215E – 01	–	–	0.106E – 01	0.523E – 02
	5	0.474E – 01	0.217E – 01	–	–	0.110E – 01	0.605E – 02
	10	0.588E – 01	0.198E – 01	0.997E – 02	0.410E – 02	0.114E – 01	0.692E – 02
	20	0.718E – 01	0.146E – 01	0.102E – 01	0.469E – 02	0.120E – 01	0.786E – 02
	30	0.785E – 01	0.118E – 01	0.104E – 01	0.506E – 02	0.125E – 01	0.846E – 02
	50	0.843E – 01	0.898E – 02	0.106E – 01	0.555E – 02	0.130E – 01	0.925E – 02
	T (10^3 K)	C_1	C_2	A	C_1	C_1	
	2.5	0.249E – 02	0.928	0.617E – 01	0.813E + 00	0.983E – 01	
	5	0.202E – 02	1.756	0.528E – 01	0.501E + 00	0.618E – 01	
	10	0.166E – 02	3.251	0.449E – 01	0.307E + 00	0.392E – 01	
	20	0.133E – 02	5.041	0.387E – 01	0.189E + 00	0.252E – 01	
	30	0.112E – 02	6.006	0.362E – 01	0.142E + 00	0.195E – 01	
	50	0.853E – 03	7.142	0.343E – 01	0.100E + 00	0.143E – 01	
C_5	T (10^3 K)	C_3	C_4	C_3	C_4	C_3	C_4
0.446E – 02	2.5	239	0.579		0.489		
0.531E – 02	5	343	0.537		0.490		
0.638E – 02	10	371	0.485		0.493		
0.762E – 02	20	318	0.423		0.500		
0.828E – 02	30	280	0.381		0.506		
0.886E – 02	50	239	0.331		0.512		
Transition	T (10^3 K)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)
6d $^2[7/2]_4$–4p $^2[5/2]_3$ 549.6 nm	2.5	0.209E – 01	0.126E – 01	0.544E – 02	0.185E – 02	0.604E – 02	0.318E – 02
	5	0.251E – 01	0.134E – 01	0.555E – 02	0.215E – 02	0.629E – 02	0.365E – 02
	10	0.305E – 01	0.126E – 01	0.567E – 02	0.247E – 02	0.659E – 02	0.415E – 02
	20	0.371E – 01	0.964E – 02	0.580E – 02	0.281E – 02	0.696E – 02	0.470E – 02
	30	0.408E – 01	0.808E – 02	0.590E – 02	0.303E – 02	0.721E – 02	0.504E – 02
	50	0.443E – 01	0.638E – 02	0.605E – 02	0.332E – 02	0.756E – 02	0.551E – 02
	T (10^3 K)	C_1	C_2	A	C_1	C_1	
	2.5	0.855E – 03	0.724	0.522E – 01	0.300	0.365E – 01	
	5	0.667E – 03	1.386	0.456E – 01	0.184	0.230E – 01	
	10	0.531E – 03	2.612	0.394E – 01	0.113	0.147E – 01	
	20	0.424E – 03	4.286	0.340E – 01	0.695E – 01	0.948E – 02	
	30	0.361E – 03	5.235	0.317E – 01	0.526E – 01	0.737E – 02	
	50	0.278E – 03	6.340	0.298E – 01	0.372E – 01	0.540E – 02	
C_5	T (10^3 K)	C_3	C_4	C_3	C_4	C_3	C_4
0.142E – 02	2.5	101	0.583		0.488		
0.165E – 02	5	148	0.541		0.491		
0.194E – 02	10	164	0.493		0.497		
0.231E – 02	20	143	0.437		0.506		
0.252E – 02	30	128	0.396		0.511		
0.272E – 02	50	111	0.345		0.517		
Transition	T (10^3 K)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)
5d′ $^2[3/2]_2$–4p′ $^2[5/2]_1$ 518.8 nm	2.5	0.695E – 02	0.373E – 02	0.235E – 02	0.560E – 03	0.245E – 02	0.946E – 03
	5	0.845E – 02	0.404E – 02	0.237E – 02	0.641E – 03	0.249E – 02	0.107E – 02
	10	0.104E – 01	0.395E – 02	0.239E – 02	0.729E – 03	0.255E – 02	0.122E – 02
	20	0.127E – 01	0.343E – 02	0.241E – 02	0.826E – 03	0.262E – 02	0.137E – 02
	30	0.141E – 01	0.301E – 02	0.242E – 02	0.886E – 03	0.267E – 02	0.147E – 02
	50	0.155E – 01	0.247E – 02	0.245E – 02	0.966E – 03	0.274E – 02	0.160E – 02

Table 2. Continued

Perturbers are:		Electrons		Ionized argon		Protons	
Transition	T (10^3K)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)
	T (10^3 K)	C_1	C_2	A	C_1	C_1	
	2.5	0.194E – 03	0.685	0.310E – 01	0.101E – 00	0.112E – 01	
	5	0.155E – 03	1.176	0.268E – 01	0.609E – 01	0.682E – 02	
	10	0.126E – 03	2.063	0.229E – 01	0.366E – 01	0.420E – 02	
	20	0.101E – 03	3.373	0.197E – 01	0.221E – 01	0.260E – 02	
	30	0.873E – 04	4.124	0.182E – 01	0.165E – 01	0.198E – 02	
	50	0.688E – 04	4.956	0.169E – 01	0.114E – 01	0.140E – 02	
C_5	T (10^3 K)	C_3	C_4	C_3	C_4	C_3	C_4
0.291E – 03	2.5	31.27	0.598	–	0.472	–	–
0.338E – 04	5	48.08	0.559	–	0.473	–	–
0.401E – 03	10	58.55	0.510	–	0.477	–	–
0.475E – 03	20	55.87	0.454	–	0.479	–	–
0.519E – 03	30	51.66	0.417	–	0.482	–	–
0.566E – 03	50	45.96	0.366	–	0.488	–	–
Transition	T (10^3 K)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)
5d $^2[7/2]_4$ – 4p $^2[5/2]_3$ 603.2 nm	2.5	0.108E – 01	0.706E – 02	0.292E – 02	0.106E – 02	0.326E – 02	0.179E – 02
	5	0.126E – 01	0.768E – 02	0.297E – 02	0.122E – 02	0.340E – 02	0.204E – 02
	10	0.149E – 01	0.738E – 02	0.304E – 02	0.138E – 02	0.357E – 02	0.232E – 02
	20	0.179E – 01	0.586E – 02	0.312E – 02	0.157E – 02	0.378E – 02	0.261E – 02
	30	0.198E – 01	0.515E – 02	0.317E – 02	0.169E – 02	0.392E – 02	0.280E – 02
	50	0.217E – 01	0.418E – 02	0.326E – 02	0.184E – 02	0.412E – 02	0.306E – 02
	T (10^3 K)	C_1	C_2	A	C_1	C_1	
	2.5	0.240E – 03	0.556	0.411E – 01	0.893E – 01	0.109E – 01	
	5	0.179E – 03	1.054	0.367E – 01	0.545E – 01	0.692E – 02	
	10	0.137E – 03	2.047	0.324E – 01	0.335E – 01	0.443E – 02	
	20	0.108E – 03	3.571	0.282E – 01	0.207E – 01	0.287E – 02	
	30	0.922E – 04	4.479	0.261E – 01	0.157E – 01	0.223E – 02	
	50	0.722E – 04	5.512	0.244E – 01	0.111E – 01	0.164E – 02	
C_5	T (10^3 K)	C_3	C_4	C_3	C_4	C_3	C_4
0.364E – 03	2.5	36.381	0.591	–	0.488	–	–
0.413E – 03	5	53.770	0.548	–	0.499	–	–
0.478E – 03	10	61.005	0.501	–	0.501	–	–
0.562E – 03	20	54.769	0.450	–	0.509	–	–
0.616E – 03	30	49.458	0.411	–	0.515	–	–
0.666E – 03	50	43.709	0.362	–	0.521	–	–
Transition	T (10^3 K)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)
5d $^2[1/2]_1$ – 4p $^2[1/2]_1$ 560.7 nm	2.5	0.810E – 02	−0.897E – 3	0.271E – 02	−0.403E – 3	0.275E – 02	−0.677E – 3
	5	0.109E – 01	−0.375E – 3	0.272E – 02	−0.459E – 3	0.276E – 02	−0.768E – 3
	10	0.145E – 01	0.667E – 04	0.273E – 02	−0.521E – 3	0.278E – 02	−0.866E – 3
	20	0.185E – 01	0.170E – 03	0.274E – 02	−0.588E – 3	0.281E – 02	−0.976E – 3
	30	0.207E – 01	0.221E – 03	0.274E – 02	−0.630E – 3	0.283E – 02	−0.105E – 2
	50	0.229E – 01	0.385E – 03	0.275E – 02	−0.688E – 3	0.286E – 02	−0.114E – 2
	T (10^3 K)	C_1	C_2	A	C_1	C_1	
	2.5	0.194E – 03	1.715	0.178E – 01	0.994E – 01	0.105E – 01	
	5	0.179E – 03	2.622	0.142E – 01	0.595E – 01	0.631E – 02	
	10	0.164E – 03	3.989	0.115E – 01	0.355E – 01	0.379E – 02	
	20	0.141E – 03	5.647	0.956E – 02	0.212E – 01	0.229E – 02	
	30	0.123E – 03	6.470	0.878E – 02	0.157E – 01	0.170E – 02	
	50	0.976E – 04	7.303	0.814E – 02	0.107E – 01	0.118E – 02	

Table 2. Continued

Perturbers are:	Electrons			Ionized argon		Protons	
Transition	T (10^3K)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)
C_5	T (10^3 K)	C_3	C_4	C_3	C_4	C_3	C_4
0.469E – 03	2.5	48.860	0.576	–	0.467	–	–
0.590E – 03	5	71.582	0.552	–	0.468	–	–
0.747E – 03	10	83.152	0.500	–	0.466	–	–
0.921E – 04	20	76.860	0.441	–	0.469	–	–
0.102E – 02	30	70.199	0.403	–	0.470	–	–
0.111E – 02	50	61.658	0.355	–	0.470	–	–
Transition	T (10^3 K)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)	W (0.1 nm)	d (0.1 nm)
$4p'\,^2[1/2]_1$–$4s\,^2[3/2]_3$ 696.5 nm	2.5	0.526E – 03	0.297E – 03	0.245E – 03	0.476E – 04	0.250E – 03	0.789E – 04
	5	0.563E – 03	0.352E – 03	0.246E – 03	0.536E – 04	0.252E – 03	0.888E – 04
	10	0.637E – 03	0.355E – 03	0.247E – 03	0.603E – 04	0.256E – 03	0.999E – 04
	20	0.805E – 03	0.296E – 03	0.248E – 03	0.678E – 04	0.260E – 03	0.112E – 03
	30	0.949E – 03	0.243E – 03	0.249E – 03	0.725E – 04	0.263E – 03	0.120E – 03
	50	0.117E – 02	0.192E – 03	0.250E – 03	0.790E – 04	0.267E – 03	0.131E – 03
	T (10^3 K)	C_1	C_2	A	C_1	C_1	
	2.5	0.167E-05	0.360	0.102E-01	0.141E-02	0.151E-03	
	5	0.110E-05	0.431	0.973E-02	0.843E-03	0.910E-04	
	10	0.787E-06	0.752	0.888E-02	0.504E-03	0.551E-04	
	20	0.666E-06	1.587	0.744E-02	0.302E-03	0.336E-04	
	30	0.628E-06	2.295	0.658E-02	0.224E-03	0.252E-04	
	50	0.586E-06	3.204	0.563E-02	0.154E-03	0.176E-04	
C_5	T (10^3 K)	C_3	C_4	C_3	C_4	C_3	C_4
0.135E-05	2.5	420	0.627	–	0.468	–	–
0.142E-05	5	19.5	0.594	–	0.469	–	–
0.155E-05	10	5.016	0.567	–	0.470	–	–
0.185E-05	20	2.990	0.518	–	0.472	–	–
0.211E-05	30	2.609	0.507	–	0.474	–	–
0.250E-05	50	2.359	0.467	–	0.476	–	–

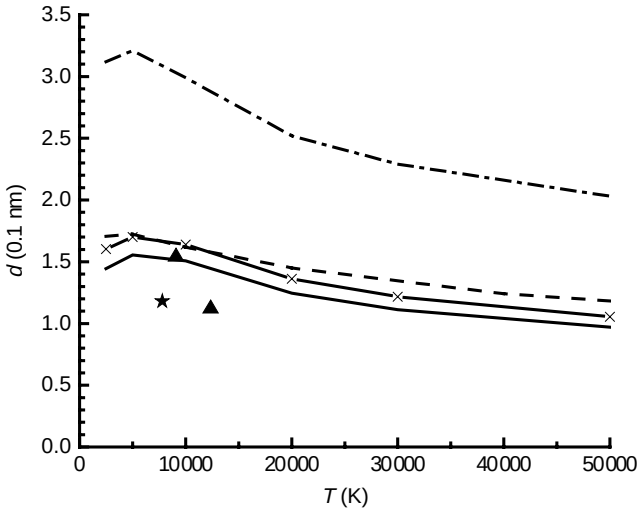

Figure 2. Stark shifts of Ar I 549.6 nm versus temperature. Theoretical and experimental values are normalized to the electron density of 10^{16} cm^{-3}. The legend for symbols used is in table 3 (— for impact ions, –×– for quasistatic ions).

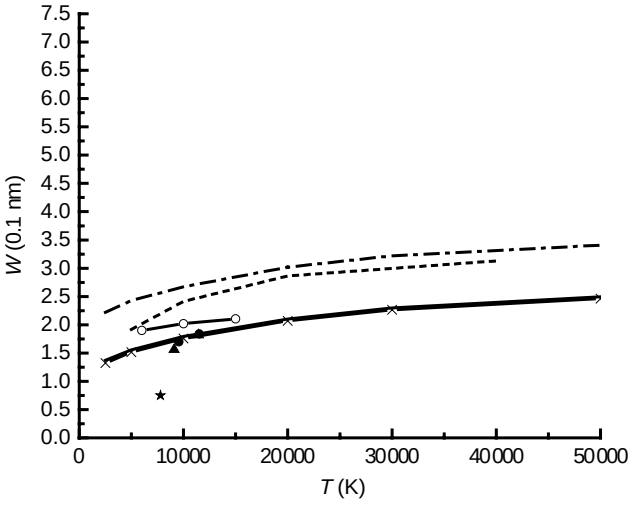

Figure 3. Stark full widths at half maximum of Ar I 603.2 nm versus temperature. Theoretical and experimental values are normalized to the electron density of 10^{16} cm^{-3}. The legend for symbols used is in table 3 (— for impact ions, –×– for quasistatic ions).

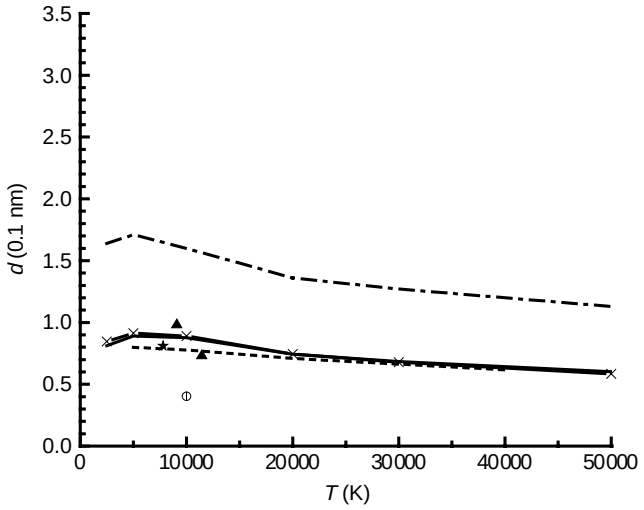

Figure 4. Stark shifts of Ar I 603.2 nm versus temperature (— for impact ions, –×– for quasistatic ions). Theoretical and experimental values are normalized to the electron density of 10^{16} cm^{-3}. The legend for symbols used is in table 3.

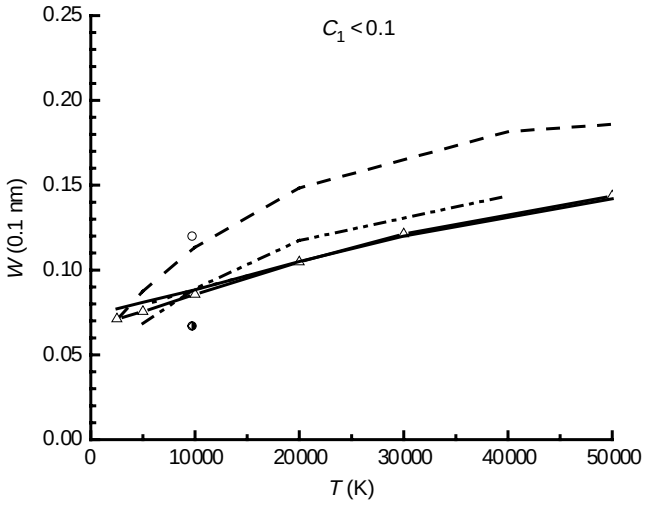

Figure 5. Stark full widths at half maximum of Ar I 696.5 nm versus temperature. Only experimental results with parameter $C_1 < 0.1$ for ions are included. Theoretical and experimental values are normalized to the electron density of 10^{16} cm^{-3}. The legend for symbols used is in table 3.

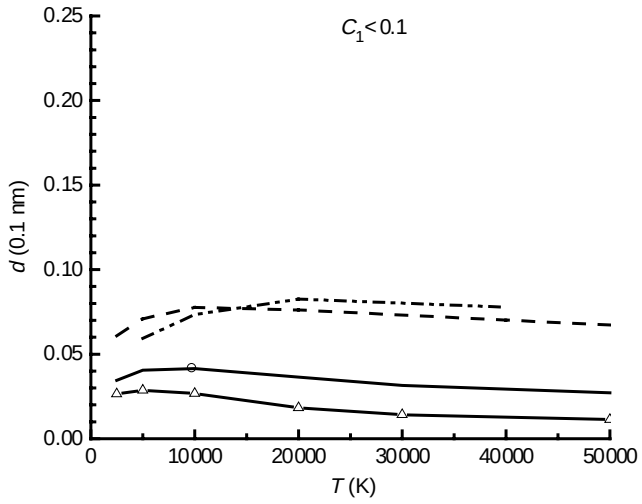

Figure 6. Stark shifts of Ar I 696.5 nm versus temperature. Only experimental results with parameter $C_1 < 0.1$ for ions are included. Theoretical and experimental values are normalized to the electron density of 10^{16} cm^{-3}. The legend for symbols used is in table 3.

treated without spin–orbital interaction (multiplets) in the *LS* coupling scheme. In [60] three of the studied lines (Ar I 522.1, 549.6 and 603.2 nm) were treated within *LS* coupling without spin–orbital interaction, where the energy values and oscillator strength values were taken from TOP base.

In table 3, the measured Stark widths (W_{exp}) and shifts (d_{exp}) along with the corresponding experimental conditions (n_e and T—references [29–52]), the symbols used in the figures and accuracy according to the critical reviews ([1], references therein and updates up to 2005) are presented. Two estimates of uncertainties are listed when they differ for experimental Stark width and shift. The first one refers to the width and the second pertains to the shift. According to the critical reviews ([1], references therein and updates up to 2005) the estimates are given using code letters: A = uncertainties within 15%; $B^+ = 23\%$; $B = 30\%$; $C^+ = 40\%$ and $C = 50\%$. The symbols are included only for spectral lines for which Stark parameters are shown in figures 1–8. Experimental results for Stark broadening parameters which are not included in the critical reviews are also presented in table 3. Theoretical calculations (W_{th} and d_{th}) are performed for $n_e = 1 \times 10^{16}$ cm^{-3}.

There is only one experimental result [35] for the Ar I 522.1 nm spectral line and there are no theoretical data published by other authors. The theoretical values in this work are approximately twice and 1.25 times larger respectively, for the width and the shift, than the experimental ones.

For the Ar I 549.6 and 603.2 nm spectral lines the impact approximation is not valid for ions under all experimental conditions in the literature. The calculated Stark widths and shifts for quasistatic ions were added in figures 1–4. The theoretical results for Stark broadening obtained in (Tw) are closer to the experimental points for these lines. The difference between impact and quasistatic ion broadening is small. For 549.6 nm, one obtains smaller widths and shifts with impact ions (figures 1 and 2). The shift values for 549.6 nm from Griem's theory coincide with quasistatic ones in (Tw) for temperatures up to 20000 K and they are a little larger for higher temperatures. In fact, for 603.2 nm the broadening and shift values in the cases of impact and quasistatic ions obtained in (Tw) are the same (see figures 3 and 4). Shift values from the Sahal-Bréchot theory are a little larger then Griem's calculated ones for temperatures up to 20000 K and they coincide for higher temperatures.

The Ar I 696.5 nm spectral line is one of the most commonly used argon lines for diagnostic purposes. It is well isolated, visible and intense. This explains the great interest in it. This line is usually applied to measure the electron densities over 1×10^{16} cm^{-3}. In figures 5 and 6 the calculations within the frame of impact approximation for electrons and ions (Tw) and Griem's calculations are presented. Only experimental results where n_e and T (see table 3) values correspond to $C_1 < 0.1$ for ions, i.e. where the validity condition for the impact approximation ($C_1 \ll 1$) is well satisfied, are included. The theoretical Stark broadening parameters obtained with Sahal-Bréchot theory

Table 3. Experimental (W_{exp}, d_{dexp}) and theoretical (W_{th}, d_{th}) Stark broadening parameters (width and shift) in Å at $n_e = 10^{16}$ cm^{-3}. The symbol used in figures 1–8 for a particular reference and accuracy, according to the critical review [1] are also given. The symbol (— T_w means present calculations for impact ions; (— × —T_w): present calculations for quasistatic ions. Two estimates of uncertainties are listed when they are different for experimental Stark width and shift. The first one refers to the width and the second pertains to the shift. The estimates are given using code letters: A = uncertainties within 15%; B$^+$ = 23%; B = 30%; C$^+$ = 40%; C = 50%.

λ (nm)	n_e (10^{16} cm^{-3})	T (10^3 K)	W_{th} (0.1 nm)	W_{exp} (0.1 nm)	d_{th} (0.1 nm)	d_{exp} (0.1 nm)	Symbols reference accuracy
522.1	1.0	7.8		3.18		1.9	[35] B
	1.0	10.0	8.16		−4.95		[58]
	1.0	10.0	9.92		5.15		[60]
	1.0	10.0	6.88		2.39		Tw
549.6	1.1–5.3	9.65–11.6		2.7–15.0			● [32] B
	0.63–7.3	9.1–12.35		1.97–25.0		0.97–8.18	▲ [33] B
	1.0	7.8		1.68		1.18	★ [35] B
	1.0	10.0	5.68		1.62		– – – – [28]
	1.0	10.0	4.08		−2.45		····· [58]
	1.0	10.0	5.31		2.99		—·— [60]
	1.0	10.0	3.62		1.51		——Tw
	1.0	10.0	3.71		2.02		—×— Tw
518.8	0.63–4.7	9.1–11.45		1.26–11.0		(−0.10)–0.38	[33] B
	1.0	7.8		1.09		−0.18	[35] B
	1.0	10.0	1.77		−1.14		[59]
	1.0	10.0	1.28		0.47		Tw
603.2	1.0–5.0	9.55–11.5		1.7–9.2			● [32] B
	0.63–4.7	9.1–11.45		0.98–8.55		0.62–3.45	▲ [33] B
	1.0	7.8		0.75		0.81	★ [35] B
	1.6	10.0		2.47		0.644	⦶ [52] C+,B
	1.0	10.0	2.41		0.78		- - - - - [27]
	1.0	10.0	2.02		−1.28		— ○ — [59]
	1.0	10.0	2.67		1.60		— · — [60]
	1.0	10.0	1.79		0.88		——Tw
	1.0	10.0	1.76		1.04		—×—Tw
560.7	0.63–7.3	9.1–12.4		0.77–9.43		0.35–1.8	[33] B
	1.0	7.8		0.72		0.49	[35] B
	1.0	10.0	1.38		−0.74		[59]
	1.0	10.0	1.72		−0.045		Tw
696.5	1.2–6.0	9.7–11.8		0.14–0.63		0.05–0.23	○ [29] B
	4.8–19.6	10.0–20.0		0.40–1.40		0.17–0.67	[30] C
	14.5	13.8		0.80			[31] C
	1.2–7.7	9.7–12.25		0.08–0.66			◑ [34] B
	1.9–14.7	10.2–13.9		0.08–1.07			[36]
	10	12.75		0.8			[37]
	10.0	13.0		0.81		0.50	[38]
	60–62	16.5–17.4		4.40–4.90		1.90–2.10	[39]
	6.0	11.9		0.4			▽ [40] B
	58–91	13.6–14.6		5.8–9.1			[41]
	57–157	15.7–19.0		3.9–7.1			[42]
	20–10	14.0–12.0		1.4–0.8			[43]
	3.3–5.5	13.0–17.0				0.10–0.18	✰ [44] B, B
	12.1–19.7	13.5–24.0		1.18–1.85			[45]
	0.4	11.1		0.0284			[46]
	10.0	13.5–26.5		0.97		0.26	✳ [47] A, A
	3.8	13.0		0.33			◗ [48] B+
	8.0	12.76–18.56		1.07		0.36	□ [49] B+
	57–363	16.8–19.6		3.9–20.9		2.1–9.4	[50]
	6.7–7.1	15.6–16.2		0.519–0.57		0.175–0.199	[51]
	1.0	10.0	0.113		0.078		- - - - [28]
	1.0	10.0	0.089		0.073		– · · – [53]
	1.0	10.0	0.086		0.027		— △ — [48]
	1.0	10.0	0.089		−0.030		····· [58]
	1.0	10.0	0.088		0.042		——Tw
	1.0	10.0	0.067		0.039		—×—Tw

in [48] are also added. The calculations in [48] are performed for multiplet transition in *j*-*L* coupling. There are two experimental data for the width. Stark broadening widths obtained by the Sahal-Bréchot theory [48, 58] and (Tw), but using different data sources, are similar. Griem's widths [53] are near to them while those in [28] are much higher. Concerning the shifts, there is only one experimental value which is better fitted by the present theoretical results (Tw).

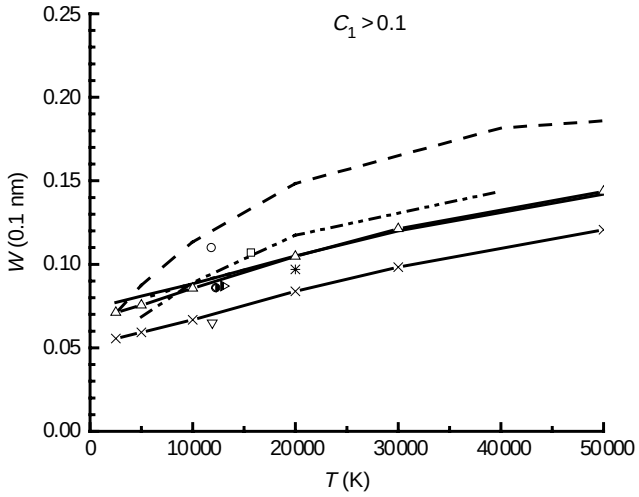

Figure 7. Stark full widths at half maximum of Ar I 696.5 nm versus temperature. Only experimental results with parameter $C_1 > 0.1$ for ions are included. Theoretical and experimental values are normalized to the electron density of 10^{16} cm^{-3}. The legend for symbols used is in table 3 (— for impact ions, –×– for quasistatic ions).

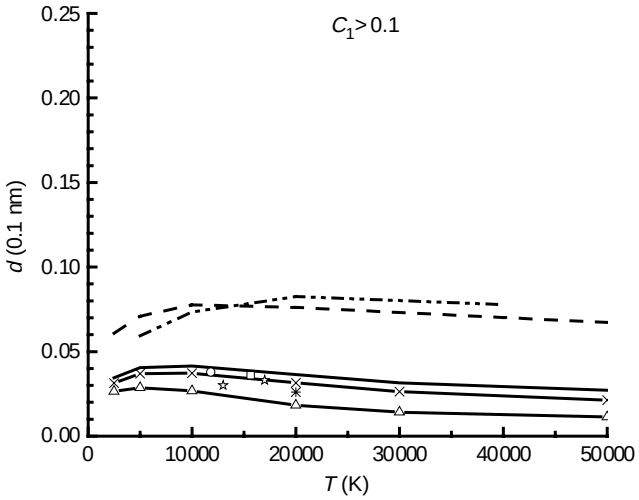

Figure 8. Stark shifts of Ar I 696.5 nm versus temperature. Only experimental results with parameter $C_1 > 0.1$ for ions are included. Theoretical and experimental values are normalized to the electron density of 10^{16}cm^{-3}. The legend for symbols used is in table 3 (— for impact ions, –×– for quasistatic ions).

In figures 7 and 8 the calculations for Stark broadening parameters for Ar I 696.5 nm within quasistatic approximation for ions are included. Only experimental results where n_e and T (see table 3) values correspond to $C_1 > 0.1$, i.e. where $C_1 \ll 1$ condition is not completely fullfilled for ions, are included. The values of C_1 for ions, within the $0.5 > C_1 > 0.1$ range, correspond to the transitional range where neither the impact nor the quasistatic approximation for ions are accurate. For $C_1 > 0.5$, the condition of validity of the impact approximation ($C_1 \ll 1$) is not satisfied even approximately and the quasistatic one should be used. Within the considered C_1 values range, there are six experimental Stark widths (figure 7). Four of them are closer to the theoretical values obtained for impact ions [48] and (Tw). There are five experimental shift values (figure 8). They are fitted better by

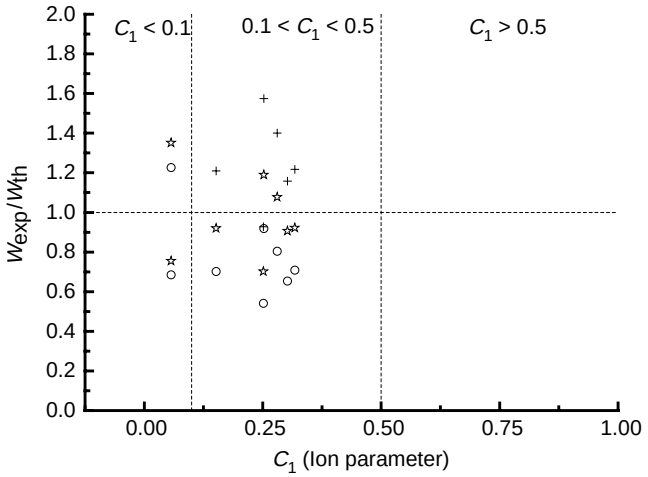

Figure 9. Ratio of experimental and theoretical (○ according to Griem's theory, ✯ according to Sahal-Bréchot theory for impact ions, + according to Sahal-Bréchot theory for quasistatic ions) Stark widths for Ar I 696.5 nm versus the validity criterion of the impact approximation for ions (the impact approximation for ions is valid if the parameter C_1 is small compared to unity).

the theoretical shift values for quasistatic ions in this work. For Ar I 696.5 nm, the theoretical values of both width and shift are smaller in the quasistatic approach for Ar ions than in the case of impact ions.

A comprehensive study of the experimental Stark broadening of Ar I 696.5 nm, published over the period of 30 years was reported in [45] yielding $W = 0.0814$ nm $\pm 5.0\%$, normalized to $n_e = 10^{17}$cm^{-3} and $T = 13\,000$ K. There is a good agreement between this value and the corresponding ones from Sahal-Bréchot theory [48, 58] and (Tw), 0.0857 -0.0884 nm $\pm$ 30%.

In figure 9 the ratios of measured widths and calculated ones (according to Griem's [28] and Sahal-Bréchot theory for impact and quasistatic ions) versus the parameter C_1 for ion perturbers are presented. The values of C_1 correspond to the experimental n_e and T conditions, according to table 3. The majority (six) of experimental widths fall in the transitional range (from impact to quasistatic regime for ion perturbers, $0.5 > C_1 > 0.1$), two in the impact regime $C_1 > 0.1$ and there are no data for $C_1 > 0.5$, when only the quasistatic approximation is applicable. The both theories predict similar values in the impact regime. One can see that on average Griem's theory overestimates the experimental Stark widths in the transitional range. The Sahal-Bréchot theory gives better results in this region. The ratio values for impact ions (Tw) are near to unity in the second region, while those for quasistatic ions (Tw) are underestimated.

It is necessary to mark the disagreement in shift sign of the spectral lines, obtained in [58, 59] and in this work. For the Ar I 522.1, 549.6 and 603.2 nm the shifts in [58, 59] are blue while they are red in [60] and (Tw). All experimental data for these three lines in the literature (table 3) are red shifts. Theoretical values (Tw) are closer to the experimental ones. For Ar I 518.8 nm a blue shift was obtained in [59] while here it is positive (red shift). The reported experimental shifts [33, 35] for this line are blue for temperatures up to 10 000 K. The positive (red) shift was obtained in [33] for higher values of the perturber density and the temperature.

A very good agreement is obtained between theoretical (Tw) and experimental shifts for Ar I 696.5 nm; both are red. Blue shifts are obtained in the whole temperature interval in [58]. Concerning Ar I 560.7 nm spectral line, there is a disagreement between calculated shifts in [59] and (Tw) (both blue), and experimental ones, which are red shifts (table 3). Additionally, it is noted in [25], that the theoretical shift is more sensitive to the input oscillator strength values than the width. The shift can be used as an estimate for the reliability of the f_{ij} values. In general, the disagreement in the shift sign of the calculated [58, 59] and (Tw) should be explained with the usage of two different sources of oscillator strength in [58, 59].

4. Conclusion

Stark broadening parameters (width and shift) of six Ar I spectral lines: 522.1, 549.6, 518.6, 560.7, 603.2 and 696.5 nm, corresponding to the transitions $3p^5nd–3p^54p$ for $n = 7–5$ and $3p^54p'–3p^54s$ have been calculated on the basis of the impact theory within the semi-classical perturbation approach. The case of the quasistatic ions has also been examined. The conditions of the use of the presented results have been discussed. The considered lines are in the optical part of the spectrum.

It is better to use j-L coupling for argon atoms and to include spin–orbital interaction in the calculations of the Stark broadening parameters. It is necessary to employ all allowed transitions between the nearest perturbing energy levels and the initial level of the studied transitions, except the Ar I 696.5 where both (initial and final) levels should be included.

The reported results for the Stark width and shift are closer to the experimental data than Griem's shifts, except the shift values for Ar I 603.2 nm, for which the results calculated here almost coincide with Griem's shift values.

Additionally, there is a necessity for more experimental data for Stark width and shift of Ar I 522.1, 549.6, 518.8, 603.2 and 560.7 nm argon lines to critically check the theoretical results presented here. The analysis of the Stark broadening parameters of Ar I 696.5 nm shows a good agreement between experimental results and theoretical results predicted by the Sahal-Bréchot theory in this work.

An application of Stark broadening calculations of argon spectral lines in the case of SWDs under atmospheric pressure will be published in [53].

Acknowledgments

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References

[1] Konjević N, Lesage A, Fuhr J R and Wiese W L 2002 *J. Phys. Chem. Ref. Data* **31** 820–927
[2] Moisan M and Pelletier J 1992 *Microwave Excited Plasmas* (New York: Elsevier)
[3] Koleva Iv 1998 *Ph.D. Thesis* University of Sofia (Bulgaria)
[4] Sola A, Calzada M D and Gamero A 1995 *J. Phys. D: Appl. Phys.* **28** 1099–110
[5] Calzada M D, Moisan M, Gamero A and Sola A 1996 *J. Appl. Phys.* **80** 46–54
[6] Grozev D, Kirov K, Makasheva K and Sola A 1997 *IEEE Trans. Plasma Sci.* **3** 415–22
[7] Djermanova N, Grozev D, Kirov K, Makasheva K, Shivarova A and Tsvetkov Ts 1999 *J. Appl. Phys.* **86** 737–745
[8] Christov L, Christova M, Gagov V, Koleva I and Shivarova A 1999 *J. Tech. Phys.* **XL** 411
[9] Christova M, Gagov V and Koleva I 2000 *Spectrochim. Acta* Part B **55** 815–22
[10] Christova M and Calzada M D 2000 *Proc. 15th Int. Symp. on Plasma Chemistry (Orleans)* **IV** 1453
[11] Christova M, Castaños-Martinez E, Calzada M D, Kabouzi Y, Luque J M and Moisan M 2004 *Appl. Spectr.* **58** 1032–37
[12] Santiago I, Christova M, Garcia M C and Calzada M D 2004 *European J. Phys. Appl. Phys.* **28** 325–30
[13] Wiese W L and Konjević N 1982 *J. Quant. Spectrosc. Radiat. Transfer* **28** 185
[14] Dimitrijević M S and Sahal-Bréchot S 1984 *J. Quant. Spectrosc. Radiat. Transfer* **31** 301–13
[15] Suh J A, Audard M, Güdel M and Paerels F B S 2005 *Astrophys. J.* **630** 1074–87
[16] Lewin W 2005 Chandra Proposal ID #07500185
[17] Kraus M, Borges F M, De Araújo F X and Lamers H J G L M 2005 *Astron. Astrophys.* **441** 289–302
[18] Kniazev A Yu, Grebel E K, Pustilnik S A, Pramskij A G and Zucker D B 2005 *Astron. J.* **130** 1558–73
[19] Jeffery C S 1993 *Astron. Astrophys.* **279** 188
[20] Jeffery C S and Heber U 1992 *Astron. Astrophys.* **260** 133
[21] Jeffery C S and Heber U 1993 *Astron. Astrophys.* **270** 167
[22] Peters G J 1976 *Astrophys. J. Suppl. Ser.* **30** 551
[23] Anders E and Grevesse N 1989 *Geochim. Cosmochim. Acta* **53** 197
[24] Sahal-Bréchot S 1969 *Astron. Astrophys.* **1** 91
[25] Sahal-Bréchot S 1969 *Astron. Astrophys.* **2** 322
[26] Ben Nessib N, Ben Lakhdar Z and Sahal-Bréchot S 1996 *Phys. Scr.* **54** 608
[27] Griem H R 1974 *Spectral Line Broadening by Plasmas* (New York: Academic)
[28] Griem H R 1964 *Plasma Spectroscopy* (New York: McGraw-Hill)
[29] Popenoe C H and Schumaher Jr J B 1965 *J. Res. Natl. Bur. Stand.* A **69** 495
[30] Evans D and Tankin R S 1967 *Phys. Fluids* **10** 1137–44
[31] Chapelle J, Sy A, Cabannes F and Blandin J 1967 *J. Quant. Spectrosc. Radiat. Transfer* **8** 1201–16
[32] Schulz P and Wende B 1968 *Z. Phys.* **208** 116
[33] Bues I, Haag T and Richter J 1969 *Astron. Astrophys.* **2** 249–50
[34] Tonejc A, Acinger K and Vujnović V 1972 *J. Quant. Spectrosc. Radiat. Transfer* **12** 1305
[35] Ranson P and Chapelle J 1974 *J. Quant. Spectrosc. Radiat. Transfer* **14** 1
[36] Nick K P 1982 *Thesis* University of Kiel
[37] Iglesias E, Guimerans Y, Castell R, Mandelbaum D and Sanchez A 1983 *Acta Cient. Venez.* **34** 84–8
[38] Jones D W, Musiol K and Wiese W L 1983 *Proc. Int. Conf. on Spectral Line Shapes (Berlin)* vol. 2, ed K Burnett and W de Gruyter p 125
[39] Vitel Y and Skowronek M 1987 *J. Phys. B: At. Mol. Opt. Phys.* **20** 6477
[40] Bakshi V and Kearney J R 1989 *J. Quant. Spectrosc. Radiat. Transfer* **42** 405–13
[41] Uzelac N I 1989 *Thesis* University of Belgrade
[42] Siyacoun A 1992 *Thesis* University of Paris IV
[43] Valognes J S, Bardet J P, Flih S A and Vitel Y 1993 *J. Phys. B: At. Mol. Opt. Phys* **26** 4751–68
[44] Djeniže S, Skuljan Lj and Konjević R 1995 *J. Quant. Spectrosc. Radiat. Transfer* **54** 581–7

[45] Pellerin S, Musiol K, Pokrzywka B and Chappelle J 1996 *J. Phys. B: At. Mol. Opt. Phys.* **29** 3911
[46] Kusz J and Mazure D 1997 *Proc. Int. Conf. on Spectral Line Shapes (Berlin)* vol. 9, ed M Zoppi and L Ulivi (New York: AIP) p 323
[47] Aparicio J A, Pérez C, del Val J A, Gigosos M A, De la Rosa M I and Mar S 1998 *J. Phys. B: At. Mol. Opt. Phys.* **31** 4909
[48] Dimitrijević M S, Skuljan Lj and Djeniže S 2002 *Phys. Scr.* **66** 77
[49] Dzierzega K, Bratasz L, Pellerin S, Pokrzywka B and Musiol K 2003 *Phys. Scr.* **67** 52
[50] Valognes J S, Bardet J P, Flih S A and Vitel Y 2004 *J. Quant. Spectrosc. Radiat. Transfer* **87/3–4** 221–41
[51] Milosavljević V, Ellingboe A R and Djeniže S 2006 *Spectrochim. Acta Part* B **61** 81–7
[52] Kasakov A I and Ivanov B A 1981 VINITI Deposited Dc. N2125–81
[53] Griem H R 1962 *Phys. Rev.* **128** 515–23
[54] Online at http://physics.nist.gov/
[55] Kuruczs R L CD-ROM 23
[56] Terzi N, Sahal-Bréchot S and Ben Lakhdar Z 1998 *Astron. Astrophys. Suppl. Ser.* **123** 229–44
[57] Baranger M 1958 *Phys. Rev.* **111** 494
[58] Christova M, Sahal-Bréchot S and Allard N 2004 *Proc. Int. Conf. on Gas Discharge (Toulouse)* **K9**
[59] Christova M, Sahal–Bréchot S, Allard N and Calzada M D 2004 *Proc. Int. Conf. on Spectral Line Shapes (Paris)* 394
[60] Christova M, Dimitrijević M S and Sahal-Bréchot S 2005 *Mem. S.A.It.* **vol 7** 238–41
[61] Cunto W, Mendoza C, Ochsenbein F and Zeippen C J 1993 *Astron. Astrophys.* **275** L5
[62] Zeippen C J 1995 *Phys. Scr.* T **58** 43
[63] Christova M and Christov L (to be published)

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Stark broadening calculations of neutral copper spectral lines and temperature dependence

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Abstract
The aim of this work is to theoretically determine Stark broadening parameters of 5105.54, 5700.24, 5782.13, 3273.96 and 3247.54 Å neutral copper spectral lines. Our results are compared with available experimental and other theoretical data. The results obtained are also used for the continuation of our investigation of the temperature dependence of Stark widths of neutral atom spectral lines in order to improve existing methods for the scaling of Stark broadening parameters with temperature.

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1. Introduction

Neutral copper (CuI) is often used in the electrical industry as an electrode material. Therefore, diagnostic techniques for this element are of particular interest in industrial laboratories.

Numerous efforts to obtain atomic parameters are needed for the calculation of spectral line intensities, profiles and widths, but several such important parameters are still missing. In plasmas, the Stark broadening of spectral lines is important not only for experimental methods but also for theoretical understanding. For example, the visible spectra of the CuI and CuII species, of recent plasma research focus, have been used [1] to determine the electron temperature and density of decaying plasma.

The first attempt to experimentally investigate the Stark broadening of neutral copper lines was made in 1925 by Holtsmark and Trumpy [2], but the first reliable determinations were published in 1987 by Fleurier [3] (in preliminary form by Fleurier and Maulat [4]) and by Neger and Jäger [5]. Theoretical values of the Stark broadening parameters for a number of neutral copper lines were determined using the semiclassical method by Grishina *et al* [6, 7] according to Griem *et al* [8] and by Sibgatullin *et al* [9] and Babina *et al* [10] according to Cooper and Oertel [11], where the 'back reaction' of the perturbed emitter on the perturbing electron is taken into account. In these works, the necessary coordinate operator matrix elements were determined using known experimental oscillator strengths from the critical compilation of Radzig and Smirnov [12]. In two papers [13, 14], the simplified method of Dimitrijević and Konjević [15] was applied: in [13] using the Coulomb approximation for the necessary coordinate operator matrix elements and in [14] using the experimental oscillator strengths from [12]. In a number of papers, the quadratic Stark constant (C_4) (e.g. [16]) was determined. Stark full width at half intensity maximum W can then be obtained using the well-known Lindholm formula [17]:

$$W(s^{-1}) = 11.37 v^{1/3} C_4^{2/3} N, \qquad (1)$$

where v is the mean velocity of electrons and N is the density of perturbers. We use for comparison the estimates from [18] obtained on the basis of regularities and systematic trends.

In the present work, we theoretically determine the full Stark width at half maximum FWHM of five CuI spectral

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lines due to collisions with electrons using the semiclassical perturbation formalism [19, 20]. Obtained results will also be used to study the dependence of Stark broadening parameters on temperature and to check and analyse a simple theoretical estimate of the Stark width temperature dependence, derived by us in a previous article [21] and applied to several neutral helium multiplets.

The principal aim of the previous work [21] was to draw attention (especially for astrophysicists using Stark width values at $T = 10\,000$ K and extrapolating them to other temperatures as $T^{-1/2}$) to the uncertainties of such a method, especially for Stark broadening of neutral atom lines (where cross sections for inelastic collisions have a more pronounced part, increasing with energy), and to propose a better method. Here, the objective is also to test the occasionally used interpolation of Stark widths of neutral atoms using $T^{1/6}$ dependence taken from the low-temperature limit (see e.g. [22, 23]). The results obtained for Stark widths are also compared with available experimental and selected theoretical results.

2. Theory

In the derivation of the expression for Stark broadening parameters by Sahal-Bréchot [19, 20, 24], the optical theorem is used (cf also Baranger [25]) and the line width can then be expressed in terms of elastic and inelastic collision rates. Thus, experience gained in atomic collision theory can be used as a guide in the choice of impact parameters and strong collision terms. Next, dipole, quadrupole and quadratic (the polarization r^{-4} potential) interactions are taken into account.

For transition between levels i and f, the FWHM ($W = 2w$) and the shift d can be put in the form [19, 20, 24]

$$W = 2w = N\int_0^\infty vf(v)\,\mathrm{d}v\left(\sum_{i'\neq i}\sigma_{ii'}(v) + \sum_{f'\neq f}\sigma_{ff'}(v) + \sigma_{\mathrm{el}}\right), \tag{2}$$

$$d = N\int_0^\infty vf\,(v)\,\mathrm{d}v\int_{R_3}^{R_\mathrm{D}} 2\pi\rho\,\mathrm{d}\rho\,\sin 2\phi_p. \tag{3}$$

Here i' and f' are the perturbing levels, N is the density of perturbers, v is the relative velocity and $f(v)$ is the Maxwellian distribution of velocities.

The inelastic cross sections $\sigma_{ii'}(v)$ (resp. $\sigma_{ff'}(v)$) are given by an integration over the impact parameter ρ of the transition probability $P_{ii'}(v, \rho)$ (resp. $P_{ff'}(v, \rho)$) as

$$\sum_{i'\neq i}\sigma_{ii'}\,(v) = \frac{1}{2}\pi R_1^2 + \int_{R_1}^{R_\mathrm{D}} 2\pi\rho\,\mathrm{d}\rho\sum_{i'\neq i}P_{ii'}(\rho, v). \tag{4}$$

The elastic contribution to the width or elastic cross section is given by

$$\sigma_{\mathrm{el}} = 2\pi R_2^2 + \int_{R_2}^{R_\mathrm{D}} 8\pi\rho\,\mathrm{d}\rho\,\sin^2\delta, \tag{5}$$

with

$$\delta = (\phi_\mathrm{p}^2 + \phi_\mathrm{q}^2)^{1/2}. \tag{6}$$

The phase shifts ϕ_p and ϕ_q are respectively due to the polarization and quadrupolar interactions, described in [19, 24, 26].

The cutoffs (R_1, R_2, R_3), as well as the symmetrization procedures in the inelastic cross sections, are described in [20]. R_D is the upper cutoff allowing for Debye shielding. A description of the semiclassical perturbation formalism used here is given in [19, 20, 27].

3. Results and discussion

3.1. Electronic collisional width and shift

Concerning collisions of neutral atoms with electrons, the impact approximation is usually valid for physical conditions of stellar atmospheres and of laboratory experiments. Inelastic collisions play an important role, except at very low temperatures where elastic collisions are dominant.

We have calculated the electron impact line widths and shifts for five lines of neutral copper (CuI), $4s^2\,{}^2D_{5/2}$–$4p\,{}^2P^\mathrm{o}_{3/2}$ (5105.54 Å), $4s^2\,{}^2D_{3/2}$–$4p\,{}^2P^\mathrm{o}_{3/2}$ (5700.24 Å), $4s^2\,{}^2D_{3/2}$–$4p\,{}^2P^\mathrm{o}_{1/2}$ (5782.13 Å), $4s\,{}^2S_{1/2}$–$4p\,{}^2P^\mathrm{o}_{1/2}$ (3273.96 Å) and $4s\,{}^2S_{1/2}$–$4p\,{}^2P^\mathrm{o}_{3/2}$ (3247.54 Å), using the semiclassical perturbation formalism [19, 20, 24].

In order to compare our results with other theoretical results, when only the multiplet value is given, the needed widths W_line, shifts d_line and quasistatic quadratic ion broadening parameters A_line for a particular line within a multiplet are obtained from their multiplet values W, d and A, respectively, using [36, 37]

$$W_\mathrm{line} = \left(\frac{\lambda}{\langle\lambda\rangle}\right)^2 W, \quad d_\mathrm{line} = \left(\frac{\lambda}{\langle\lambda\rangle}\right)^2 d$$

and

$$A_\mathrm{line} = \left(\frac{\lambda}{\langle\lambda\rangle}\right)^{-3/2} A, \tag{7}$$

where W, d, A and $\langle\lambda\rangle$ are values for the multiplet, and W_line, d_line, A_line and λ refer to the line within the multiplet.

In critical reviews of experimental data [28–32] there are three selected experiments [4, 5, 33], but the comparison may be performed for only the 3247.54 Å CuI resonance spectral line with experimental values from [3, 33]. Skuljan *et al* [33] described an experiment where they photoelectrically observed the CuI 3247.54 Å resonance line end on, with a pulsed arc superimposed on a glow discharge at 17 000 K electron temperature in an argon–helium plasma. Copper was evaporated from the electrodes, and it was estimated that there is no self-absorption in the resonance line because of the very low concentration of copper atoms in the argon–helium plasma. A standard deconvolution procedure was used to account for other broadening mechanisms. The other experimental results (5105.54 Å and 5782.13 Å CuI spectral lines) were taken from Fleurier [3].

In our calculations, the energy levels and oscillator strengths were taken from Corliss [34] (also given in the critical compilation of Fu *et al* [35], where they are estimated as the best values for these lines).

As already discussed by Baranger [25, 38–40] and Sahal-Bréchot [19, 20], the impact approximation is

Table 1. Electron impact widths: W_{eK}—results of Konjević and Konjević [13] obtained using the method of Dimitrijević and Konjević [15], W_{eG}—results of Grishina *et al* [6, 7] obtained using the GBKO [8, 23] semiclassical theory, W_{eB}—results of Babina *et al* [10] obtained using the semiclassical theory of Cooper and Ortel [11], W_e—our calculations according to the semiclassical perturbation formalism [19], for CuI lines as a function of temperature T with an electron density of $N_e = 10^{16}$ cm^{-3}.

λ (Å)	T (K)	W_{eK} (Å)	W_{eG} (Å)	W_{eB} (Å)	W_e (Å)
5105.54	$4s^2\ ^2D_{5/2}$–$4p\ ^2P^o_{3/2}$				
	5000	0.014 9	0.0103	0.0085	0.0093
	10000	0.0193	0.0126	0.0099	0.0102
	20 000	0.0238	0.0156	0.0123	0.0105
	30 000	0.0262	0.0177	0.0142	0.0111
5700.24	$4s^2\ ^2D_{3/2}$–$4p\ ^2P^o_{3/2}$				
	5000	0.0186	0.0128	0.0106	0.0114
	10 000	0.0240	0.0157	0.0123	0.0136
	20 000	0.0297	0.0194	0.0153	0.0127
	30 000	0.0327	0.0221	0.0177	0.0143
5782.13	$4s^2\ ^2D_{3/2}$–$4p\ ^2P^o_{1/2}$				
	5000	0.0191	0.0132	0.0109	0.0118
	10 000	0.0247	0.0162	0.0127	0.0131
	20 000	0.0306	0.0200	0.0158	0.0123
	30 000	0.0336	0.0227	0.0182	0.0136
3273.96	$4s\ ^2S_{1/2}$–$4p\ ^2P^o_{1/2}$				
	5000	–	0.003 32	0.002 67	0.003 00
	10 000	–	0.004 33	0.003 04	0.003 21
	20 000	–	0.005 81	0.004 08	0.003 30
	30 000	–	0.006 87	0.005 08	0.003 91
3247.54	$4s\ ^2S_{1/2}$–$4p\ ^2P^o_{3/2}$				
	5000	–	0.003 27	0.002 63	0.003 20
	10 000	–	0.004 26	0.002 99	0.003 01
	17 000	–	0.005 67	0.004 01	0.003 45
	20 000	–	0.005 72	0.004 01	0.003 46
	30 000	–	0.006 76	0.005 00	0.003 98

valid when the average effect of collisions is weak; in other words when strong collisions are separated in time or, equivalently, when the duration of a collision is very small compared to the separation time between strong collisions. The validity criterion for the impact approximation can be written [19] as

$$C_{\text{impact}} = N\pi\rho_{\text{typ}}^3 \ll 1, \tag{8}$$

where ρ_{typ} is a typical impact parameter for strong collisions.

The validity condition of the impact approximation for collisions with electrons is fulfilled for all lines considered here because $C_{\text{impact}} < 6.0 \times 10^{-6} \ll 1$ at $N_e = 10^{16}$ cm^{-3} and will not be displayed in the tables. It is also fulfilled for CuII ions because $C_{\text{impact}} < 2.0 \times 10^{-4} \ll 1$ at $N_e = 10^{16}$ cm^{-3}.

Tables 1 and 2 present the results of our calculations of electronic widths W_e and electronic shift d_e for CuI lines according to the semiclassical perturbation formalism [19, 20] as a function of temperature T for an electron density of $N_e = 10^{16}$ cm^{-3}. For comparison, we selected the theoretical results obtained using the GBKO semiclassical method [8, 23] of Grishina *et al* [6, 7], the results of Babina *et al* [10] obtained using the semiclassical method of Cooper and Ortel [11] and the results of Konjević and Konjević [13] obtained using the method of Dimitrijević and Konjević [15], because they are usually used without experimental oscillator strengths as in [14].

One can see that the semiclassical values for electronic width obtained here are in relatively good agreement with the values obtained using other variants of the semiclassical method [8, 11], especially for lower temperatures, and the agreement becomes worse for higher temperatures. The results of Konjević and Konjević [13] obtained with the approximate method in [15] are higher for 50% at the low-temperature limit and around 2.36 times at $T = 30\,000$ K.

Concerning the shifts we also noticed a relatively good agreement with the semiclassical results of [6, 7, 10] obtained with different variants of the semiclassical method, and a disagreement with the results of [13] obtained using the approximate method of [15].

3.2. Total collisional width and shift

If the impact approximation criterion is satisfied for collisions with ions, the resulting profile is Lorentzian, we are in the impact regime and we add the electronic and ionic contributions to the total width and shift. If not, we are in the quasistatic regime and an ion broadening parameter A is relevant for obtaining the contribution of the ions to the total width and shift. However, it must be noticed that often an intermediate region between the impact and quasistatic approximations is expected for collision with ions. For such conditions the static models employed here can only give an estimate for the ionic contribution to the total width and shift.

For collisions of neutral atoms with ions, the impact approximation is most often valid in the physical conditions of hot stellar atmospheres where the density is low (10^{14} cm^{-3}) and where the ion perturbers are light protons. In laboratory experiments, the density is higher (10^{16}–10^{17} cm^{-3}) and the perturbers are heavier. Thus, the validity condition of the

Table 2. Electron impact shifts: d_{eK}—results of Konjević and Konjević [13] obtained using the approximate method of Dimitrijević and Konjević [15], d_{eG}—results of Grishina *et al* [6, 7] obtained using the GBKO [8, 23] semiclassical theory, d_{eB}—results of Babina *et al* [10] obtained using the semiclassical theory of Cooper and Ortel [11], d_e—our calculations according to the semiclassical perturbation formalism [19], for CuI lines as a function of temperature T with an electron density of $N_e = 10^{16}$ cm^{-3}.

λ (Å)	T (K)	d_{eK} (Å)	d_{eG} (Å)	d_{eB} (Å)	d_e (Å)
5105.54	$4s^2\,^2D_{5/2}$–$4p\,^2P^o_{3/2}$				
	5000	−0.000 27	0.007 99	0.007 83	0.010 10
	10 000	−0.000 82	0.008 83	0.008 86	0.009 81
	20 000	−0.001 18	0.009 29	0.009 47	0.009 06
	30 000	−0.001 36	0.009 25	0.009 44	0.008 43
5700.24	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{3/2}$				
	5000	−0.000 34	0.009 96	0.009 76	0.011 60
	10 000	−0.001 02	0.011 01	0.011 04	0.011 30
	20 000	−0.001 47	0.011 58	0.011 80	0.010 60
	30 000	−0.00170	0.011 53	0.011 77	0.009 86
5782.13	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{1/2}$				
	5000	−0.000 35	0.010 25	0.010 04	0.010 90
	10 000	−0.001 05	0.011 33	0.011 36	0.010 70
	20 000	−0.001 52	0.011 92	0.012 15	0.009 91
	30 000	−0.001 75	0.011 86	0.012 11	0.009 24
3273.96	$4s\,^2S_{1/2}$–$4p\,^2P^o_{1/2}$				
	5 000	–	0.002 37	0.002 28	0.000 99
	10 000	–	0.002 51	0.002 54	0.001 02
	20 000	–	0.002 43	0.002 51	0.001 04
	30 000	–	0.002 27	0.002 34	0.001 03
3247.54	$4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$				
	5000	–	0.002 31	0.002 24	0.001 12
	10 000	–	0.002 47	0.002 50	0.001 15
	20 000	–	0.002 39	0.002 47	0.001 18
	30 000	–	0.002 23	0.002 30	0.001 17

impact approximation has to be checked for each case, but ion dynamics effects are generally not negligible at medium densities (10^{16} cm^{-3}). When the impact approximation is valid for ions, inelastic collisions can be neglected in comparison with elastic collision contribution, and quadrupolar interactions can play an important role for lines arising from low levels so that the polarization term can also be neglected. At high densities (10^{17} cm^{-3} and more), the impact approximation breaks down for ion perturbers and the quasistatic approximation may be used.

The quasistatic profile for quadrupolar interactions was obtained by Sahal-Bréchot, [41]. In this case, the potential has non-spherical symmetry and the correct angular average was taken into account. The resulting profile is Lorentzian for neutral atom–ion interactions. The expression of FWHM is given in [41]. We note that the quadrupolar quasistatic width is always small compared to the width due to electron collisions. One should also notice that the quasistatic profiles for isolated lines provided by Griem [23] are computed with quadratic interaction potential and are asymmetric.

If the quadratic interaction potential is dominant, the quasistatic ionic width and shift are given by Griem [23, 42]:

$$W_{iQ} = 1.75\, A \left[1 - 0.068 N_e^{1/6} T^{-1/2}\right] W_e \qquad (9)$$

and

$$d_{iQ} = 1.00\, A \left[1 - 0.068 N_e^{1/6} T^{-1/2}\right] W_e. \qquad (10)$$

W_e is the impact contribution of electrons to the total width, T is the temperature in kelvin and N_e is the electron density in cm^{-3}.

Equations (9) and (10) are applicable for [23]

$$0.05 \lesssim A \lesssim 0.5, \qquad (11)$$

$$N_e T^{-1/2} \lesssim 4.97 \times 10^5. \qquad (12)$$

For $A < 0.05$, quadrupole interaction should be included and the upper limit $A \approx 0.5$ is imposed by the transition to the linear Stark effect.

The quasistatic quadratic ion broadening parameter A is expressed in [37, 43] as follows:

$$A = \left(\frac{e F_0^2}{\hbar W_e} |\alpha_i - \alpha_f|\right)^{3/4}, \qquad (13)$$

$$F_0 = 2\pi (4/15)^{2/3} e N_e^{2/3}. \qquad (14)$$

F_0 is the normal field strength and α_i is the polarizability of the initial level (resp. α_f is the polarizability of the final level) [23], where

$$\alpha_i = 4a_0^3 \sum_{i' \neq i} f_{ii'} \left(\frac{I_H}{\Delta E_{ii'}}\right)^2. \qquad (15)$$

a_0 is the Bohr radius, I_H is the ionization energy of hydrogen and $\Delta E_{ii'}$ is the difference in energy between the i and i' levels.

We have computed the quasistatic quadratic ion broadening parameter A (see table 3) using the general atomic structure and compared the obtained results with the A-values,

Table 3. Quasistatic quadratic ion broadening parameter: A_K—results of Konjević and Konjević [13], A_G—results of Grishina *et al* [6, 7], A_B—results of Babina *et al* [10], A—present calculations according to the semiclassical perturbation formalism [19], for CuI lines with an electron density of $N_e = 10^{16}$ cm^{-3}.

λ (Å)	T (K)	A_K	A_G	A_B	A
5105.54	$4s^2\,^2D_{5/2}$–$4p\,^2P^o_{3/2}$				
	5000	0.0064	0.0280	0.0323	0.0261
	10 000	0.0051	0.0240	0.0288	0.0243
	20 000	0.0045	0.0204	0.0245	0.0238
	30 000	0.0045	0.0175	0.0219	0.0229
5700.24	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{3/2}$				
	5000	0.0054	0.0237	0.0274	0.0260
	10000	0.0043	0.0203	0.0244	0.0227
	20000	0.0038	0.0173	0.0208	0.0239
	30000	0.0038	0.0148	0.0186	0.0218
5782.13	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{1/2}$				
	5000	0.0053	0.0232	0.0268	0.0239
	10 000	0.0042	0.0199	0.0239	0.0220
	20 000	0.0037	0.0169	0.0203	0.0231
	30 000	0.0037	0.0145	0.0182	0.0215
3273.96	$4s\,^2S_{1/2}$–$4p\,^2P^o_{1/2}$				
	5000	–	0.0232	0.0273	0.0206
	10000	–	0.0190	0.0247	0.0196
	20000	–	0.0152	0.0199	0.0192
	30000	–	0.0134	0.0169	0.0169
3247.54	$4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$				
	5000	–	0.0235	0.0276	0.0219
	10 000	–	0.0192	0.0250	0.0229
	17 000	–	0.0199	0.0226	0.0207
	20 000	–	0.0154	0.0201	0.0206
	30 000	–	0.0136	0.0171	0.0186

calculated by Konjević and Konjević [13], Grishina *et al* [6, 7] and Babina *et al* [10]. We can also note the relative agreement with [6, 7, 10] and the disagreement with [13], which is a consequence of the disagreement of Stark width entering in the determination of A.

In table 4 we show total widths (electron + ion) W_I, where ion contribution is calculated according to the impact approximation [19, 20] for CuII perturbing ions, and W_Q, where ion contribution is calculated according to the quasistatic approximation [23]. Our results are compared with the total widths from [6, 7, 10], where the ion contribution is determined within the quasistatic approximation.

For all temperatures, W_Q are smaller than W_I by 8–9%. The results with ion contribution determined within the impact approximation (W_I) at low temperatures are in slightly better agreement with semiclassical calculations [6, 7] W_{eG} obtained using the GBKO theory [8, 23], whereas the results with ion contribution determined within the quasistatic approximation at low temperatures are in slightly better agreement with semiclassical results [10] W_B obtained using the theory of Cooper and Ortel [11]. At high temperatures, W_I are in slightly better agreement with W_B and W_{eG} than W_Q and are in better agreement with W_B.

In table 5, we compare our calculations of total widths W_I with the ion contribution determined according to the impact approximation [19] with the simplified theoretical estimates of Konjević and Konjević [13] (W_K) and Pichler [16] (W_P) and with the experimental results of Fleurier [3] (W_F), Skuljan *et al* [33] (W_S) and Lakićević [18] (W_L) at different temperatures and densities.

The widths and shifts in Fleurier [3] were measured for several intense lines of CuI and CuII in a plasma, at electron densities ranging from 2×10^{16} to 2×10^{17} cm^{-3} and at temperatures between 5000 and 20 000 K, where a homogeneously copper-seeded plasma was produced.

Skuljan *et al* [33] presented measured Stark width values of the 3247.54 Å CuI resonance spectral line at only 17 000 K temperature in a linear pulsed arc plasma superimposed on the glow discharge positive column plasma in an argon–helium mixture.

From table 5 we note the large disagreement of experimental values with semiclassical theoretical results, indicating that the new measurements will be important.

We also compared our semiclassical determinations of Stark widths with different approximate methods [13, 16, 18].

In Konjević and Konjević [13], the Stark widths and shifts of several CuI multiplets were calculated using the approximate method of Dimitrijević and Konjević [15]. From table 5, we note that this method gives considerably larger Stark widths for CuI lines in comparison with semiclassical results. Also the shift has different sign.

Pichler [16] presented a calculation of the quadratic Stark constant C_4, which, according to the theory of Lindholm [17], is related to Stark width and can be used for the estimation of electron impact Stark widths and shifts. We can see in table 5 that these results are too low in comparison with the semiclassical values.

On the basis of the Stark width and shift dependence on ionization potential from the lower level of the corresponding transition (effective ionization potential), Lakićević [18] estimated the Stark width and shift for the CuI $4s^2\,^2S$–$4p\,^2P^o$ transition for an electron temperature of 20 000 K and an electron density of 10^{17} cm^{-3}. He obtained 0.124 Å for the

Table 4. Total Stark widths (electron + ion): W_G—results of Grishina *et al* [6, 7], W_B—results of Babina *et al* [10], W_I—our calculations using the semiclassical perturbation method (impact approximation for CuII perturbers) [19] and W_Q—our calculations using the impact approximation for electrons and the quasistatic approximation [23] for CuII perturbers, for CuI lines as a function of temperature T with an electron density of $N_e = 10^{16}$ cm^{-3}.

λ (Å)	T (K)	W_G (Å)	W_B (Å)	W_I (Å)	W_Q (Å)
5105.54	$4s^2\,^2D_{5/2}$–$4p\,^2P^o_{3/2}$				
	5000	0.0105	0.0088	0.0104	0.0095
	10 000	0.0131	0.0139	0.0115	0.0105
	20 000	0.0163	0.0129	0.0119	0.0108
	30 000	0.0184	0.0149	0.0126	0.0115
5700.24	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{3/2}$				
	5000	–	–	0.0127	0.0117
	10 000	–	–	0.0151	0.0140
	20 000	–	–	0.0144	0.0131
	30 000	–	–	0.0162	0.0147
5782.13	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{1/2}$				
	5000	–	–	0.0131	0.0121
	10 000	–	–	00146	0.0134
	20 000	–	–	0.0139	0.0127
	30 000	–	–	0.0153	0.0140
3273.96	$4s^2S_{1/2}$–$4p\,^2P^o_{1/2}$				
	5000	0.003 39	0.002 76	0.003 32	0.003 06
	10 000	0.004 47	0.003 17	0.003 56	0.003 29
	20 000	0.006 00	0.004 25	0.003 70	0.003 39
	30 000	0.007 08	0.005 27	0.004 34	0.004 00
3247.54	$4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$				
	5 000	–	–	0.003 55	0.003 27
	10 000	–	–	0.003 40	0.003 09
	20 000	–	–	0.003 89	0.003 56
	30 000	–	–	0.004 44	0.004 09

Table 5. Total Stark widths (electron + ion): experimental results of W_F—Fleurier [3] and W_S—Skuljan *et al* [33]. Theoretical results of W_K—Konjević and Konjević [13], W_P—Pichler *et al* [16], W_L—Lakićević [18] and W_I—our calculations using the semiclassical perturbation method [19] (impact approximation for electrons and ions), for CuI lines at different experimental densities N and temperatures T.

λ (Å)	N_e (cm^{-3})	T_e (K)	W_F (Å)	W_S (Å)	W_K (Å)	W_P (Å)	W_L (Å)	W_I (Å)
5105.54	10^{17}	10 000	0.430	–	0.210	0.026	–	0.115
5700.24	10^{17}	10 000	–	–	0.260	0.032	–	0.151
5782.13	10^{17}	10 000	0.720	–	0.270	0.034	–	0.146
3273.96	10^{17}	20 000	–	–	–	–	0.124	0.037
3247.54	6.6×10^{16}	17 000	–	0.095	–	–	–	0.026

FWHM value and 0.065 Å for the shift. The obtained width value is 3.35 times larger than the semiclassical one.

In table 6, we present the results for the total impact shift d_I obtained using the semiclassical perturbation method (impact approximation for electrons and ions) [19] and the total quasistatic shift d_Q using the approximate formula [42] compared with the results of [6, 7, 10]. We can see that d_Q is smaller than d_I by 7–11% at $T = 5000$ K and by 11–19% at $T = 30\,000$ K which is larger than for the widths. Also, d_I is always in slightly better agreement with semiclassical shifts from [6, 7, 10] than d_Q. For the 5105.54 Å line the agreement of d_I with d_G and d_B is within 1–2%, whereas for 3273.960 Å the agreement is excellent for low temperatures ($\sim 1\%$ at $T = 5000$ K) but increasing temperature increases the disagreement so that at $T = 30\,000$ K the difference is around 30%.

In table 7, we compare our calculations of total shifts d_I using the semiclassical perturbation method [19] (impact approximation for electrons and CuII ions) with those of the experimental results of Fleurier [3] (d_F) and the theoretical results of Konjević and Konjević [13] (d_K) and Lakićević [18] (d_L) at different temperatures and densities.

From table 7, we see that (d_F) is 2.87 times smaller than the semiclassical one for $\lambda = 5105.54$ Å and 2.74 times smaller for $\lambda = 5782$ Å and that d_L is 3.25 times larger than the semiclassical value for 3273.96 Å.

In figure 1, we show two curves presenting the electronic Stark width W_e for the resonance line 3247.54 Å ($4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$) versus temperature T: solid line—our electronic width calculations according to the semiclassical perturbation formalism; dottted line—our electronic width calculations using the low-temperature $T^{1/6}$ scaling extrapolated from $T = 10\,000$ K. We can see that extrapolation with $T^{1/6}$ is much better for neutral atom line Stark width than with $T^{-1/2}$, which was considered in [21]. It is relatively good for the considered line for temperatures

Table 6. Total Stark shifts (electron + ion) for CuI lines as a function of temperature T for an electron density of $N_e = 10^{16}$ cm^{-3}. d_G—results of Grishina *et al* [6, 7], d_B—results of Babina *et al* [10], d_I—our calculations using the semiclassical perturbation formalism [19] and impact approximation for CuII perturbers; d_Q—our calculations using the semiclassical perturbation formalism [19] for electrons and the quasistatic approximation (see equation (10)) for ions.

λ (Å)	T (K)	d_G (Å)	d_B (Å)	d_I (Å)	d_Q (Å)
5105.54	$4s^2\,^2D_{5/2}$–$4p\,^2P^o_{3/2}$				
	5000	0.008 16	0.008 00	0.019 45	0.010 23
	10 000	0.009 12	0.009 16	0.019 17	0.009 98
	20 000	0.009 67	0.009 83	0.018 43	0.009 25
	30 000	0.009 68	0.009 85	0.017 80	0.008 64
5700.24	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{3/2}$				
	5000	–	–	0.022 30	0.011 76
	10 000	–	–	0.022 00	0.011 51
	20 000	–	–	0.021 30	0.010 84
	30 000	–	–	0.020 56	0.010 11
5782.13	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{1/2}$				
	5000	–	–	0.021 00	0.011 06
	10 000	–	–	0.020 80	0.010 90
	20 000	–	–	0.020 01	0.010 13
	30 000	–	–	0.019 34	0.009 48
3273.96	$4s\,^2s_{1/2}$–$4p\,^2P^o_{1/2}$				
	5000	0.002 42	0.002 34	0.001 92	0.001 02
	10 000	0.002 59	0.002 62	0.001 96	0.001 06
	20 000	0.002 54	0.002 60	0.001 98	0.001 09
	30 000	0.002 39	0.002 45	0.001 97	0.001 08
3247.54	$4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$				
	5000	–	–	0.002 18	0.001 16
	10 000	–	–	0.002 22	0.001 20
	20 000	–	–	0.002 25	0.001 24
	30 000	–	–	0.002 24	0.001 23

Table 7. Total Stark shifts (electron + ion) for CuI lines at an electron density N_e of 10^{17} cm^{-3}. Experimental results of Fleurier [3]—d_F and theoretical results of Konjević and Konjević [13]—d_K, Lakićević [18]—d_L and d—our calculations using the semiclassical perturbation method [19] (impact approximation for electrons and CuII ions).

λ (Å)	T (K)	d_F (Å)	d_K (Å)	d_L (Å)	d_I (Å)
5105.54	10 000	0.067	−0.010	–	0.192
5700.24	10 000	–	−0.012	–	0.220
5782.13	10 000	0.076	−0.012	–	0.208
3273.96	20 000	–	–	0.065	0.020

between approximately 8000 and 40 000 K. However, for larger and lower temperatures, it becomes unreliable as well.

The $T^{1/6}$ scaling is obtained from the low-temperature limit of the semiclassical expression for the Stark width. Namely, the electron width can be approximated by [22]

$$W_e = 2\left(\frac{32}{27}\right)^{1/2} N_e \pi \left(\frac{\hbar a_o}{m}\right)\left(\frac{E_H}{kT}\right)^{1/2} R^2_{ii'} f_w(\eta R_{ii'}), \tag{16}$$

where m and N_e are electron mass and electron density, respectively. k is the Boltzmann constant, T the temperature, E_H the hydrogen atom ionization energy and a_0 the Bohr radius, and the function $f_w(\eta_{jj'} R_{jj'})$ is an approximate fit of the expression

$$f_w(\eta R_{ii'}) = \tfrac{1}{2}\left[A^2\left(z^{\min}\right) + B^2\left(z^{\min}\right)\right]^{1/2} + a\left(z^{\min}\right), \tag{17}$$

$$R_{jj'}{}^2 = f_{jj'} \times \frac{\lambda_{jj'}(\text{Å})}{303.7}. \tag{18}$$

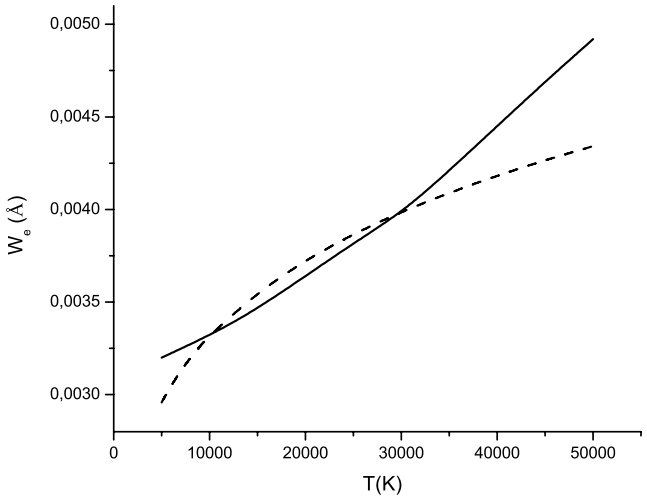

Figure 1. Electronic Stark width for the $4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$ transition of the copper resonance spectral line (3247.54 Å) as a function of temperature T. (Solid line) Our electronic width calculations using the semiclassical perturbation formalism. (Dotted line) Our electronic width calculations using the low-temperature $T^{1/6}$ scaling extrapolated from $T = 10\,000$ K. The electron density is 10^{16}cm^{-3}.

$R^2_{jj'}$ is the dipole matrix element (in units of the Bohr radius a_0^2), $f_{jj'}$ is the oscillator strength for a transition between levels j and j', $\lambda_{jj'}$ as the corresponding wavelength and

$$\eta_{jj'} = \frac{\triangle E_{jj'}}{3kT} = \frac{|E_j - E_{j'}|}{3kT}, \tag{19}$$

Table 8. Critical temperatures T_c for the CuI spectral lines.

λ (Å)	Transition	T_c (kK)
5105.54	$4s^2\,^2D_{5/2}$–$4p\,^2P^o_{3/2}$	292
5700.24	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{3/2}$	370
5782.13	$4s^2\,^2D_{3/2}$–$4p\,^2p^o_{1/2}$	301
3273.96	$4s\,^2S_{1/2}$–$4p\,^2P^o_{1/2}$	398
3247.54	$4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$	361

where E_j and $E_{j'}$ are energies of the corresponding atomic levels.

The Stark broadening functions $a(z^{\min})$, $A(z^{\min})$ and $B(z^{\min})$ can be written in terms of modified Bessel functions (see [23], p 56). $z^{\min}$ is the dimensionless parameter, which depends on the minimal impact parameter $\rho_{\min}$ and the average velocity $\overline{v}$, and is given by

$$z^{\min} = \rho_{\min}\frac{\triangle E_{jj'}}{\hbar\overline{v}}. \tag{20}$$

For low temperatures ($\eta R_{ii'} = \frac{\Delta E_{ii'} R_{ii'}}{kT} \gg 1$),

$$f_w\,(\eta R_{ii'}) \approx 0.487\,(\eta R_{ii'})^{-2/3}\,. \tag{21}$$

Hence the electron width becomes

$$W_e = 2\times 0.487\left(\frac{32}{27}\right)^{1/2} N_e\pi\left(\frac{\hbar a_o}{m}\right)\left(\frac{E_H}{k}\right)^{1/2} \times R_{ii'}^{4/3}\left(\frac{\Delta E_{ii'}}{k}\right)^{-2/3} T^{1/6} \tag{22}$$

or

$$W_e = C\times N_e\,T^{1/6}, \tag{23}$$

where C is a constant depending on the atomic transition.

We also note that if, for neutral emitters, the width increases after a certain temperature T_c, it will start to decrease.

In table 8, we express critical temperatures T_c when the Stark width starts to decrease for all the spectral lines studied here. One can see that they are at very high temperatures where neutral copper lines do not exist; hence for the lower temperatures, of interest for the Stark broadening of CuI, Stark widths of the considered lines always increase with temperature.

4. Conclusion

We have calculated Stark widths and shifts due to collisions with electrons for five lines of neutral copper, using the semiclassical perturbation formalism. We have additionally provided Stark broadening parameters for collisions with copper ions in the impact and quasistatic approximations. The obtained data can be used for laboratory and stellar plasmas diagnostics, investigation and modelling.

These results are compared with other semi-classical and approximate calculations and with experimental data. They agree very well with other semiclassical calculations but all of the theoretical results are in disagreement with experimental findings, indicating the need for a new experimental determination of CuI Stark broadening parameters.

Our results demonstrate that the considered Stark widths increase with temperature for all T values of interest and that the critical temperature when they start to decrease is beyond the temperature range of interest. The temperature trend of Stark widths in this case is not in accordance with $T^{-1/2}$ dependence but with the low-temperature limit $T^{1/6}$ dependence.

References

[1] Djilianova O, Sadowski M J, Skladnik-Sadowska E, Malinowski K, Scholz M, Blagoev A and Paskalev K 2006 *J. Phys.: Conf. Ser.* **44** 175
[2] Holtsmark J and Trumpy B 1925 *Z. Phys.* **31** 803
[3] Fleurier C 1987 *Spectral Line Shapes* **III** 67
[4] Fleurier C and Maulat C 1985 *Proc. 17th Int. Conf. on Phenomena in Ionized Gases (Budapest, 1985)* vol 2 p 981
[5] Neger T and Jäger H 1987 *Z. Nat. forsch.* A **42** 429
[6] Grishina N A, Il'in G G, Salakhov M Kh and Sarandaev E V 1998 *19th SPIG Contributed papers* p 361
[7] Grishina N A, Il'in G G, Salakhov M Kh and Sarandaev E V 1998 *Coherent Optics and Optical Spectroscopy* (Russia: Kazan) p 43
[8] Griem H R, Baranger M, Kolb A C and Oertel G 1962 *Phys. Rev.* **125** 177
[9] Sibgatullin M E, Il'in G G, Salakhov M Kh and Sarandaev E V 2000 *Coherent Optics and Optical Spectroscopy* (Russia: Kazan) p 123
[10] Babina E M, Il'in G G, Konovalova O A, Salakhov M Kh and Sarandaev E V 2003 *Publ. Astron. Obs. Belgrade* **76** 163
[11] Cooper J and Oertel G K 1969 *Phys. Rev.* **180** 286
[12] Radzig A A and Smirnov B M 1986 *Atomic and Ionic Parameters* (Moscow: Energoizdat)
[13] Konjević R and Konjević N 1986 *Fizika* **18** 327
[14] Dimitrijević M S, Il'in G G, Salakhov M Kh and Sarandaev E V 1996 *18th Symp. on Physics of Ionized Gases (Kotor, 1996)* p 283
[15] Dimitrijević M S and Konjević N 1986 *Astron. Astrophys.* **163** 297
[16] Pichler G 1972 *Fizika* **4** 235
[17] Lindholm E 1946 *Ark. Mat. Astron. Fys.* **32** A 1
[18] Lakićević I S 1983 *Astron. Astrophys.* **127** 37
[19] Sahal-Bréchot S 1969 *Astron. Astrophys.* **1** 91
[20] Sahal-Bréchot S 1969 *Astron. Astrophys.* **2** 322
[21] Zmerli B, Ben Nessib N and Dimitrijević M S 2008 *Eur. J. Phys.* D **48** 389
[22] Freudenstein S A and Cooper J 1978 *Astrophys. J.* **224** 1079
[23] Griem H R 1974 *Spectral Line Broadening by Plasmas* (New York: Academic)
[24] Sahal-Bréchot S 1974 *Astron. Astrophys.* **35** 321
[25] Baranger M 1958 *Phys. Rev.* **111** 494
[26] Sahal-Bréchot S and Van Regemorter H 1964 *Ann. Astron.* **27** 432
[27] Dimitrijević M S and Sahal-Bréchot S 1985 *Phys. Rev.* A **31** 316
[28] Lesage A 2009 *New Astron. Rev.* **52** 471
[29] Konjevic N and Roberts J R 1976 *J. Phys. Chem. Ref. Data* **5** 209
[30] Konjevic N, Dimitrijević M S and Wiese W L 1984 *J. Phys. Chem. Ref. Data* **13** 619
[31] Konjevic N and Wiese W L 1990 *J. Phys. Chem. Ref. Data* **19** 1307
[32] Konjevic N, Lesage A, Fuhr J R and Wiese W L 2002 *J. Phys. Chem. Ref. Data* **31** 819
[33] Skuljan Lj, Bukvić S and Djeniže S 1995 *Publ. Obs. Astron. Belgrade* **50** 127
[34] Corliss C H 1970 *J. Res. Nat. Bur. Stand* A **74** 781

[35] Fu K, Jogwich M, Knebel M and Wiesemann K 1995 *At. Data Nuc. Data Tables* **61** 1
[36] Popović L Č, Milovanović N and Dimitrijević M S 2001 *Astron. Astrophys.* **365** 656
[37] Griem H R 1964 *Plasma Spectroscopy* (New York: McGraw-Hill)
[38] Baranger M 1958 *Phys. Rev.* **111** 481
[39] Baranger M 1958 *Phys. Rev.* **112** 855
[40] Baranger M 1962 *Atomic and Molecular Processes* ed D R Bates (New York: Academic)
[41] Sahal-Bréchot S 1991 *Astron. Astrophys.* **245** 322
[42] Griem H R 1962 *Phys. Rev.* **128** 515
[43] Ben Nessib N, Ben Lakhdar Z and Sahal-Bréchot S 1996 *Phys. Scr.* **54** 608

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Stark broadening calculations of neutral copper spectral lines and temperature dependence

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Abstract
The aim of this work is to theoretically determine Stark broadening parameters of 5105.54, 5700.24, 5782.13, 3273.96 and 3247.54 Å neutral copper spectral lines. Our results are compared with available experimental and other theoretical data. The results obtained are also used for the continuation of our investigation of the temperature dependence of Stark widths of neutral atom spectral lines in order to improve existing methods for the scaling of Stark broadening parameters with temperature.

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1. Introduction

Neutral copper (CuI) is often used in the electrical industry as an electrode material. Therefore, diagnostic techniques for this element are of particular interest in industrial laboratories.

Numerous efforts to obtain atomic parameters are needed for the calculation of spectral line intensities, profiles and widths, but several such important parameters are still missing. In plasmas, the Stark broadening of spectral lines is important not only for experimental methods but also for theoretical understanding. For example, the visible spectra of the CuI and CuII species, of recent plasma research focus, have been used [1] to determine the electron temperature and density of decaying plasma.

The first attempt to experimentally investigate the Stark broadening of neutral copper lines was made in 1925 by Holtsmark and Trumpy [2], but the first reliable determinations were published in 1987 by Fleurier [3] (in preliminary form by Fleurier and Maulat [4]) and by Neger and Jäger [5]. Theoretical values of the Stark broadening parameters for a number of neutral copper lines were determined using the semiclassical method by Grishina *et al* [6, 7] according to Griem *et al* [8] and by Sibgatullin *et al* [9] and Babina *et al* [10] according to Cooper and Oertel [11], where the 'back reaction' of the perturbed emitter on the perturbing electron is taken into account. In these works, the necessary coordinate operator matrix elements were determined using known experimental oscillator strengths from the critical compilation of Radzig and Smirnov [12]. In two papers [13, 14], the simplified method of Dimitrijević and Konjević [15] was applied: in [13] using the Coulomb approximation for the necessary coordinate operator matrix elements and in [14] using the experimental oscillator strengths from [12]. In a number of papers, the quadratic Stark constant (C_4) (e.g. [16]) was determined. Stark full width at half intensity maximum W can then be obtained using the well-known Lindholm formula [17]:

$$W(s^{-1}) = 11.37 v^{1/3} C_4^{2/3} N, \qquad (1)$$

where v is the mean velocity of electrons and N is the density of perturbers. We use for comparison the estimates from [18] obtained on the basis of regularities and systematic trends.

In the present work, we theoretically determine the full Stark width at half maximum FWHM of five CuI spectral

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lines due to collisions with electrons using the semiclassical perturbation formalism [19, 20]. Obtained results will also be used to study the dependence of Stark broadening parameters on temperature and to check and analyse a simple theoretical estimate of the Stark width temperature dependence, derived by us in a previous article [21] and applied to several neutral helium multiplets.

The principal aim of the previous work [21] was to draw attention (especially for astrophysicists using Stark width values at $T = 10\,000$ K and extrapolating them to other temperatures as $T^{-1/2}$) to the uncertainties of such a method, especially for Stark broadening of neutral atom lines (where cross sections for inelastic collisions have a more pronounced part, increasing with energy), and to propose a better method. Here, the objective is also to test the occasionally used interpolation of Stark widths of neutral atoms using $T^{1/6}$ dependence taken from the low-temperature limit (see e.g. [22, 23]). The results obtained for Stark widths are also compared with available experimental and selected theoretical results.

2. Theory

In the derivation of the expression for Stark broadening parameters by Sahal-Bréchot [19, 20, 24], the optical theorem is used (cf also Baranger [25]) and the line width can then be expressed in terms of elastic and inelastic collision rates. Thus, experience gained in atomic collision theory can be used as a guide in the choice of impact parameters and strong collision terms. Next, dipole, quadrupole and quadratic (the polarization r^{-4} potential) interactions are taken into account.

For transition between levels i and f, the FWHM ($W = 2w$) and the shift d can be put in the form [19, 20, 24]

$$W = 2w = N\int_0^\infty vf(v)\,\mathrm{d}v\left(\sum_{i'\neq i}\sigma_{ii'}(v) + \sum_{f'\neq f}\sigma_{ff'}(v) + \sigma_{\mathrm{el}}\right), \tag{2}$$

$$d = N\int_0^\infty vf\,(v)\,\mathrm{d}v\int_{R_3}^{R_\mathrm{D}} 2\pi\rho\,\mathrm{d}\rho\,\sin 2\phi_p. \tag{3}$$

Here i' and f' are the perturbing levels, N is the density of perturbers, v is the relative velocity and $f(v)$ is the Maxwellian distribution of velocities.

The inelastic cross sections $\sigma_{ii'}(v)$ (resp. $\sigma_{ff'}(v)$) are given by an integration over the impact parameter ρ of the transition probability $P_{ii'}(v, \rho)$ (resp. $P_{ff'}(v, \rho)$) as

$$\sum_{i'\neq i}\sigma_{ii'}\,(v) = \frac{1}{2}\pi R_1^2 + \int_{R_1}^{R_\mathrm{D}} 2\pi\rho\,\mathrm{d}\rho\sum_{i'\neq i}P_{ii'}(\rho, v). \tag{4}$$

The elastic contribution to the width or elastic cross section is given by

$$\sigma_{\mathrm{el}} = 2\pi R_2^2 + \int_{R_2}^{R_\mathrm{D}} 8\pi\rho\,\mathrm{d}\rho\,\sin^2\delta, \tag{5}$$

with

$$\delta = (\phi_\mathrm{p}^2 + \phi_\mathrm{q}^2)^{1/2}. \tag{6}$$

The phase shifts ϕ_p and ϕ_q are respectively due to the polarization and quadrupolar interactions, described in [19, 24, 26].

The cutoffs (R_1, R_2, R_3), as well as the symmetrization procedures in the inelastic cross sections, are described in [20]. R_D is the upper cutoff allowing for Debye shielding. A description of the semiclassical perturbation formalism used here is given in [19, 20, 27].

3. Results and discussion

3.1. Electronic collisional width and shift

Concerning collisions of neutral atoms with electrons, the impact approximation is usually valid for physical conditions of stellar atmospheres and of laboratory experiments. Inelastic collisions play an important role, except at very low temperatures where elastic collisions are dominant.

We have calculated the electron impact line widths and shifts for five lines of neutral copper (CuI), $4s^2\,{}^2D_{5/2}$–$4p\,{}^2P^\mathrm{o}_{3/2}$ (5105.54 Å), $4s^2\,{}^2D_{3/2}$–$4p\,{}^2P^\mathrm{o}_{3/2}$ (5700.24 Å), $4s^2\,{}^2D_{3/2}$–$4p\,{}^2P^\mathrm{o}_{1/2}$ (5782.13 Å), $4s\,{}^2S_{1/2}$–$4p\,{}^2P^\mathrm{o}_{1/2}$ (3273.96 Å) and $4s\,{}^2S_{1/2}$–$4p\,{}^2P^\mathrm{o}_{3/2}$ (3247.54 Å), using the semiclassical perturbation formalism [19, 20, 24].

In order to compare our results with other theoretical results, when only the multiplet value is given, the needed widths W_line, shifts d_line and quasistatic quadratic ion broadening parameters A_line for a particular line within a multiplet are obtained from their multiplet values W, d and A, respectively, using [36, 37]

$$W_\mathrm{line} = \left(\frac{\lambda}{\langle\lambda\rangle}\right)^2 W, \quad d_\mathrm{line} = \left(\frac{\lambda}{\langle\lambda\rangle}\right)^2 d$$

and

$$A_\mathrm{line} = \left(\frac{\lambda}{\langle\lambda\rangle}\right)^{-3/2} A, \tag{7}$$

where W, d, A and $\langle\lambda\rangle$ are values for the multiplet, and W_line, d_line, A_line and λ refer to the line within the multiplet.

In critical reviews of experimental data [28–32] there are three selected experiments [4, 5, 33], but the comparison may be performed for only the 3247.54 Å CuI resonance spectral line with experimental values from [3, 33]. Skuljan *et al* [33] described an experiment where they photoelectrically observed the CuI 3247.54 Å resonance line end on, with a pulsed arc superimposed on a glow discharge at 17 000 K electron temperature in an argon–helium plasma. Copper was evaporated from the electrodes, and it was estimated that there is no self-absorption in the resonance line because of the very low concentration of copper atoms in the argon–helium plasma. A standard deconvolution procedure was used to account for other broadening mechanisms. The other experimental results (5105.54 Å and 5782.13 Å CuI spectral lines) were taken from Fleurier [3].

In our calculations, the energy levels and oscillator strengths were taken from Corliss [34] (also given in the critical compilation of Fu *et al* [35], where they are estimated as the best values for these lines).

As already discussed by Baranger [25, 38–40] and Sahal-Bréchot [19, 20], the impact approximation is

Table 1. Electron impact widths: W_{eK}—results of Konjević and Konjević [13] obtained using the method of Dimitrijević and Konjević [15], W_{eG}—results of Grishina *et al* [6, 7] obtained using the GBKO [8, 23] semiclassical theory, W_{eB}—results of Babina *et al* [10] obtained using the semiclassical theory of Cooper and Ortel [11], W_e—our calculations according to the semiclassical perturbation formalism [19], for CuI lines as a function of temperature T with an electron density of $N_e = 10^{16}$ cm^{-3}.

λ (Å)	T (K)	W_{eK} (Å)	W_{eG} (Å)	W_{eB} (Å)	W_e (Å)
5105.54	$4s^2\ ^2D_{5/2}$–$4p\ ^2P^o_{3/2}$				
	5000	0.014 9	0.0103	0.0085	0.0093
	10000	0.0193	0.0126	0.0099	0.0102
	20 000	0.0238	0.0156	0.0123	0.0105
	30 000	0.0262	0.0177	0.0142	0.0111
5700.24	$4s^2\ ^2D_{3/2}$–$4p\ ^2P^o_{3/2}$				
	5000	0.0186	0.0128	0.0106	0.0114
	10 000	0.0240	0.0157	0.0123	0.0136
	20 000	0.0297	0.0194	0.0153	0.0127
	30 000	0.0327	0.0221	0.0177	0.0143
5782.13	$4s^2\ ^2D_{3/2}$–$4p\ ^2P^o_{1/2}$				
	5000	0.0191	0.0132	0.0109	0.0118
	10 000	0.0247	0.0162	0.0127	0.0131
	20 000	0.0306	0.0200	0.0158	0.0123
	30 000	0.0336	0.0227	0.0182	0.0136
3273.96	$4s\ ^2S_{1/2}$–$4p\ ^2P^o_{1/2}$				
	5000	–	0.003 32	0.002 67	0.003 00
	10 000	–	0.004 33	0.003 04	0.003 21
	20 000	–	0.005 81	0.004 08	0.003 30
	30 000	–	0.006 87	0.005 08	0.003 91
3247.54	$4s\ ^2S_{1/2}$–$4p\ ^2P^o_{3/2}$				
	5000	–	0.003 27	0.002 63	0.003 20
	10 000	–	0.004 26	0.002 99	0.003 01
	17 000	–	0.005 67	0.004 01	0.003 45
	20 000	–	0.005 72	0.004 01	0.003 46
	30 000	–	0.006 76	0.005 00	0.003 98

valid when the average effect of collisions is weak; in other words when strong collisions are separated in time or, equivalently, when the duration of a collision is very small compared to the separation time between strong collisions. The validity criterion for the impact approximation can be written [19] as

$$C_{\text{impact}} = N\pi\rho_{\text{typ}}^3 \ll 1, \tag{8}$$

where ρ_{typ} is a typical impact parameter for strong collisions.

The validity condition of the impact approximation for collisions with electrons is fulfilled for all lines considered here because $C_{\text{impact}} < 6.0 \times 10^{-6} \ll 1$ at $N_e = 10^{16}$ cm^{-3} and will not be displayed in the tables. It is also fulfilled for CuII ions because $C_{\text{impact}} < 2.0 \times 10^{-4} \ll 1$ at $N_e = 10^{16}$ cm^{-3}.

Tables 1 and 2 present the results of our calculations of electronic widths W_e and electronic shift d_e for CuI lines according to the semiclassical perturbation formalism [19, 20] as a function of temperature T for an electron density of $N_e = 10^{16}$ cm^{-3}. For comparison, we selected the theoretical results obtained using the GBKO semiclassical method [8, 23] of Grishina *et al* [6, 7], the results of Babina *et al* [10] obtained using the semiclassical method of Cooper and Ortel [11] and the results of Konjević and Konjević [13] obtained using the method of Dimitrijević and Konjević [15], because they are usually used without experimental oscillator strengths as in [14].

One can see that the semiclassical values for electronic width obtained here are in relatively good agreement with the values obtained using other variants of the semiclassical method [8, 11], especially for lower temperatures, and the agreement becomes worse for higher temperatures. The results of Konjević and Konjević [13] obtained with the approximate method in [15] are higher for 50% at the low-temperature limit and around 2.36 times at $T = 30\,000$ K.

Concerning the shifts we also noticed a relatively good agreement with the semiclassical results of [6, 7, 10] obtained with different variants of the semiclassical method, and a disagreement with the results of [13] obtained using the approximate method of [15].

3.2. Total collisional width and shift

If the impact approximation criterion is satisfied for collisions with ions, the resulting profile is Lorentzian, we are in the impact regime and we add the electronic and ionic contributions to the total width and shift. If not, we are in the quasistatic regime and an ion broadening parameter A is relevant for obtaining the contribution of the ions to the total width and shift. However, it must be noticed that often an intermediate region between the impact and quasistatic approximations is expected for collision with ions. For such conditions the static models employed here can only give an estimate for the ionic contribution to the total width and shift.

For collisions of neutral atoms with ions, the impact approximation is most often valid in the physical conditions of hot stellar atmospheres where the density is low (10^{14} cm^{-3}) and where the ion perturbers are light protons. In laboratory experiments, the density is higher (10^{16}–10^{17} cm^{-3}) and the perturbers are heavier. Thus, the validity condition of the

Table 2. Electron impact shifts: d_{eK}—results of Konjević and Konjević [13] obtained using the approximate method of Dimitrijević and Konjević [15], d_{eG}—results of Grishina *et al* [6, 7] obtained using the GBKO [8, 23] semiclassical theory, d_{eB}—results of Babina *et al* [10] obtained using the semiclassical theory of Cooper and Ortel [11], d_e—our calculations according to the semiclassical perturbation formalism [19], for CuI lines as a function of temperature T with an electron density of $N_e = 10^{16}$ cm^{-3}.

λ (Å)	T (K)	d_{eK} (Å)	d_{eG} (Å)	d_{eB} (Å)	d_e (Å)
5105.54	$4s^2\,^2D_{5/2}$–$4p\,^2P^o_{3/2}$				
	5000	−0.000 27	0.007 99	0.007 83	0.010 10
	10 000	−0.000 82	0.008 83	0.008 86	0.009 81
	20 000	−0.001 18	0.009 29	0.009 47	0.009 06
	30 000	−0.001 36	0.009 25	0.009 44	0.008 43
5700.24	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{3/2}$				
	5000	−0.000 34	0.009 96	0.009 76	0.011 60
	10 000	−0.001 02	0.011 01	0.011 04	0.011 30
	20 000	−0.001 47	0.011 58	0.011 80	0.010 60
	30 000	−0.00170	0.011 53	0.011 77	0.009 86
5782.13	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{1/2}$				
	5000	−0.000 35	0.010 25	0.010 04	0.010 90
	10 000	−0.001 05	0.011 33	0.011 36	0.010 70
	20 000	−0.001 52	0.011 92	0.012 15	0.009 91
	30 000	−0.001 75	0.011 86	0.012 11	0.009 24
3273.96	$4s\,^2S_{1/2}$–$4p\,^2P^o_{1/2}$				
	5 000	–	0.002 37	0.002 28	0.000 99
	10 000	–	0.002 51	0.002 54	0.001 02
	20 000	–	0.002 43	0.002 51	0.001 04
	30 000	–	0.002 27	0.002 34	0.001 03
3247.54	$4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$				
	5000	–	0.002 31	0.002 24	0.001 12
	10 000	–	0.002 47	0.002 50	0.001 15
	20 000	–	0.002 39	0.002 47	0.001 18
	30 000	–	0.002 23	0.002 30	0.001 17

impact approximation has to be checked for each case, but ion dynamics effects are generally not negligible at medium densities (10^{16} cm^{-3}). When the impact approximation is valid for ions, inelastic collisions can be neglected in comparison with elastic collision contribution, and quadrupolar interactions can play an important role for lines arising from low levels so that the polarization term can also be neglected. At high densities (10^{17} cm^{-3} and more), the impact approximation breaks down for ion perturbers and the quasistatic approximation may be used.

The quasistatic profile for quadrupolar interactions was obtained by Sahal-Bréchot, [41]. In this case, the potential has non-spherical symmetry and the correct angular average was taken into account. The resulting profile is Lorentzian for neutral atom–ion interactions. The expression of FWHM is given in [41]. We note that the quadrupolar quasistatic width is always small compared to the width due to electron collisions. One should also notice that the quasistatic profiles for isolated lines provided by Griem [23] are computed with quadratic interaction potential and are asymmetric.

If the quadratic interaction potential is dominant, the quasistatic ionic width and shift are given by Griem [23, 42]:

$$W_{iQ} = 1.75\, A \left[1 - 0.068 N_e^{1/6} T^{-1/2}\right] W_e \qquad (9)$$

and

$$d_{iQ} = 1.00\, A \left[1 - 0.068 N_e^{1/6} T^{-1/2}\right] W_e. \qquad (10)$$

W_e is the impact contribution of electrons to the total width, T is the temperature in kelvin and N_e is the electron density in cm^{-3}.

Equations (9) and (10) are applicable for [23]

$$0.05 \lesssim A \lesssim 0.5, \qquad (11)$$

$$N_e T^{-1/2} \lesssim 4.97 \times 10^5. \qquad (12)$$

For $A < 0.05$, quadrupole interaction should be included and the upper limit $A \approx 0.5$ is imposed by the transition to the linear Stark effect.

The quasistatic quadratic ion broadening parameter A is expressed in [37, 43] as follows:

$$A = \left(\frac{e F_0^2}{\hbar W_e} |\alpha_i - \alpha_f|\right)^{3/4}, \qquad (13)$$

$$F_0 = 2\pi (4/15)^{2/3} e N_e^{2/3}. \qquad (14)$$

F_0 is the normal field strength and α_i is the polarizability of the initial level (resp. α_f is the polarizability of the final level) [23], where

$$\alpha_i = 4a_0^3 \sum_{i' \neq i} f_{ii'} \left(\frac{I_H}{\Delta E_{ii'}}\right)^2. \qquad (15)$$

a_0 is the Bohr radius, I_H is the ionization energy of hydrogen and $\Delta E_{ii'}$ is the difference in energy between the i and i' levels.

We have computed the quasistatic quadratic ion broadening parameter A (see table 3) using the general atomic structure and compared the obtained results with the A-values,

Table 3. Quasistatic quadratic ion broadening parameter: A_K—results of Konjević and Konjević [13], A_G—results of Grishina *et al* [6, 7], A_B—results of Babina *et al* [10], A—present calculations according to the semiclassical perturbation formalism [19], for CuI lines with an electron density of $N_e = 10^{16}$ cm^{-3}.

λ (Å)	T (K)	A_K	A_G	A_B	A
5105.54	$4s^2\,^2D_{5/2}$–$4p\,^2P^o_{3/2}$				
	5000	0.0064	0.0280	0.0323	0.0261
	10 000	0.0051	0.0240	0.0288	0.0243
	20 000	0.0045	0.0204	0.0245	0.0238
	30 000	0.0045	0.0175	0.0219	0.0229
5700.24	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{3/2}$				
	5000	0.0054	0.0237	0.0274	0.0260
	10000	0.0043	0.0203	0.0244	0.0227
	20000	0.0038	0.0173	0.0208	0.0239
	30000	0.0038	0.0148	0.0186	0.0218
5782.13	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{1/2}$				
	5000	0.0053	0.0232	0.0268	0.0239
	10 000	0.0042	0.0199	0.0239	0.0220
	20 000	0.0037	0.0169	0.0203	0.0231
	30 000	0.0037	0.0145	0.0182	0.0215
3273.96	$4s\,^2S_{1/2}$–$4p\,^2P^o_{1/2}$				
	5000	–	0.0232	0.0273	0.0206
	10000	–	0.0190	0.0247	0.0196
	20000	–	0.0152	0.0199	0.0192
	30000	–	0.0134	0.0169	0.0169
3247.54	$4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$				
	5000	–	0.0235	0.0276	0.0219
	10 000	–	0.0192	0.0250	0.0229
	17 000	–	0.0199	0.0226	0.0207
	20 000	–	0.0154	0.0201	0.0206
	30 000	–	0.0136	0.0171	0.0186

calculated by Konjević and Konjević [13], Grishina *et al* [6, 7] and Babina *et al* [10]. We can also note the relative agreement with [6, 7, 10] and the disagreement with [13], which is a consequence of the disagreement of Stark width entering in the determination of A.

In table 4 we show total widths (electron + ion) W_I, where ion contribution is calculated according to the impact approximation [19, 20] for CuII perturbing ions, and W_Q, where ion contribution is calculated according to the quasistatic approximation [23]. Our results are compared with the total widths from [6, 7, 10], where the ion contribution is determined within the quasistatic approximation.

For all temperatures, W_Q are smaller than W_I by 8–9%. The results with ion contribution determined within the impact approximation (W_I) at low temperatures are in slightly better agreement with semiclassical calculations [6, 7] W_{eG} obtained using the GBKO theory [8, 23], whereas the results with ion contribution determined within the quasistatic approximation at low temperatures are in slightly better agreement with semiclassical results [10] W_B obtained using the theory of Cooper and Ortel [11]. At high temperatures, W_I are in slightly better agreement with W_B and W_{eG} than W_Q and are in better agreement with W_B.

In table 5, we compare our calculations of total widths W_I with the ion contribution determined according to the impact approximation [19] with the simplified theoretical estimates of Konjević and Konjević [13] (W_K) and Pichler [16] (W_P) and with the experimental results of Fleurier [3] (W_F), Skuljan *et al* [33] (W_S) and Lakićević [18] (W_L) at different temperatures and densities.

The widths and shifts in Fleurier [3] were measured for several intense lines of CuI and CuII in a plasma, at electron densities ranging from 2×10^{16} to 2×10^{17} cm^{-3} and at temperatures between 5000 and 20 000 K, where a homogeneously copper-seeded plasma was produced.

Skuljan *et al* [33] presented measured Stark width values of the 3247.54 Å CuI resonance spectral line at only 17 000 K temperature in a linear pulsed arc plasma superimposed on the glow discharge positive column plasma in an argon–helium mixture.

From table 5 we note the large disagreement of experimental values with semiclassical theoretical results, indicating that the new measurements will be important.

We also compared our semiclassical determinations of Stark widths with different approximate methods [13, 16, 18].

In Konjević and Konjević [13], the Stark widths and shifts of several CuI multiplets were calculated using the approximate method of Dimitrijević and Konjević [15]. From table 5, we note that this method gives considerably larger Stark widths for CuI lines in comparison with semiclassical results. Also the shift has different sign.

Pichler [16] presented a calculation of the quadratic Stark constant C_4, which, according to the theory of Lindholm [17], is related to Stark width and can be used for the estimation of electron impact Stark widths and shifts. We can see in table 5 that these results are too low in comparison with the semiclassical values.

On the basis of the Stark width and shift dependence on ionization potential from the lower level of the corresponding transition (effective ionization potential), Lakićević [18] estimated the Stark width and shift for the CuI $4s^2\,^2S$–$4p\,^2P^o$ transition for an electron temperature of 20 000 K and an electron density of 10^{17} cm^{-3}. He obtained 0.124 Å for the

Table 4. Total Stark widths (electron + ion): W_G—results of Grishina *et al* [6, 7], W_B—results of Babina *et al* [10], W_I—our calculations using the semiclassical perturbation method (impact approximation for CuII perturbers) [19] and W_Q—our calculations using the impact approximation for electrons and the quasistatic approximation [23] for CuII perturbers, for CuI lines as a function of temperature T with an electron density of $N_e = 10^{16}$ cm^{-3}.

λ (Å)	T (K)	W_G (Å)	W_B (Å)	W_I (Å)	W_Q (Å)
5105.54	$4s^2\,^2D_{5/2}$–$4p\,^2P^o_{3/2}$				
	5000	0.0105	0.0088	0.0104	0.0095
	10 000	0.0131	0.0139	0.0115	0.0105
	20 000	0.0163	0.0129	0.0119	0.0108
	30 000	0.0184	0.0149	0.0126	0.0115
5700.24	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{3/2}$				
	5000	–	–	0.0127	0.0117
	10 000	–	–	0.0151	0.0140
	20 000	–	–	0.0144	0.0131
	30 000	–	–	0.0162	0.0147
5782.13	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{1/2}$				
	5000	–	–	0.0131	0.0121
	10 000	–	–	00146	0.0134
	20 000	–	–	0.0139	0.0127
	30 000	–	–	0.0153	0.0140
3273.96	$4s^2S_{1/2}$–$4p\,^2P^o_{1/2}$				
	5000	0.003 39	0.002 76	0.003 32	0.003 06
	10 000	0.004 47	0.003 17	0.003 56	0.003 29
	20 000	0.006 00	0.004 25	0.003 70	0.003 39
	30 000	0.007 08	0.005 27	0.004 34	0.004 00
3247.54	$4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$				
	5 000	–	–	0.003 55	0.003 27
	10 000	–	–	0.003 40	0.003 09
	20 000	–	–	0.003 89	0.003 56
	30 000	–	–	0.004 44	0.004 09

Table 5. Total Stark widths (electron + ion): experimental results of W_F—Fleurier [3] and W_S—Skuljan *et al* [33]. Theoretical results of W_K—Konjević and Konjević [13], W_P—Pichler *et al* [16], W_L—Lakićević [18] and W_I—our calculations using the semiclassical perturbation method [19] (impact approximation for electrons and ions), for CuI lines at different experimental densities N and temperatures T.

λ (Å)	N_e (cm^{-3})	T_e (K)	W_F (Å)	W_S (Å)	W_K (Å)	W_P (Å)	W_L (Å)	W_I (Å)
5105.54	10^{17}	10 000	0.430	–	0.210	0.026	–	0.115
5700.24	10^{17}	10 000	–	–	0.260	0.032	–	0.151
5782.13	10^{17}	10 000	0.720	–	0.270	0.034	–	0.146
3273.96	10^{17}	20 000	–	–	–	–	0.124	0.037
3247.54	6.6×10^{16}	17 000	–	0.095	–	–	–	0.026

FWHM value and 0.065 Å for the shift. The obtained width value is 3.35 times larger than the semiclassical one.

In table 6, we present the results for the total impact shift d_I obtained using the semiclassical perturbation method (impact approximation for electrons and ions) [19] and the total quasistatic shift d_Q using the approximate formula [42] compared with the results of [6, 7, 10]. We can see that d_Q is smaller than d_I by 7–11% at $T = 5000$ K and by 11–19% at $T = 30\,000$ K which is larger than for the widths. Also, d_I is always in slightly better agreement with semiclassical shifts from [6, 7, 10] than d_Q. For the 5105.54 Å line the agreement of d_I with d_G and d_B is within 1–2%, whereas for 3273.960 Å the agreement is excellent for low temperatures ($\sim 1\%$ at $T = 5000$ K) but increasing temperature increases the disagreement so that at $T = 30\,000$ K the difference is around 30%.

In table 7, we compare our calculations of total shifts d_I using the semiclassical perturbation method [19] (impact approximation for electrons and CuII ions) with those of the experimental results of Fleurier [3] (d_F) and the theoretical results of Konjević and Konjević [13] (d_K) and Lakićević [18] (d_L) at different temperatures and densities.

From table 7, we see that (d_F) is 2.87 times smaller than the semiclassical one for $\lambda = 5105.54$ Å and 2.74 times smaller for $\lambda = 5782$ Å and that d_L is 3.25 times larger than the semiclassical value for 3273.96 Å.

In figure 1, we show two curves presenting the electronic Stark width W_e for the resonance line 3247.54 Å ($4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$) versus temperature T: solid line—our electronic width calculations according to the semiclassical perturbation formalism; dottted line—our electronic width calculations using the low-temperature $T^{1/6}$ scaling extrapolated from $T = 10\,000$ K. We can see that extrapolation with $T^{1/6}$ is much better for neutral atom line Stark width than with $T^{-1/2}$, which was considered in [21]. It is relatively good for the considered line for temperatures

Table 6. Total Stark shifts (electron + ion) for CuI lines as a function of temperature T for an electron density of $N_e = 10^{16}$ cm^{-3}. d_G—results of Grishina *et al* [6, 7], d_B—results of Babina *et al* [10], d_I—our calculations using the semiclassical perturbation formalism [19] and impact approximation for CuII perturbers; d_Q—our calculations using the semiclassical perturbation formalism [19] for electrons and the quasistatic approximation (see equation (10)) for ions.

λ (Å)	T (K)	d_G (Å)	d_B (Å)	d_I (Å)	d_Q (Å)
5105.54	$4s^2\,^2D_{5/2}$–$4p\,^2P^o_{3/2}$				
	5000	0.008 16	0.008 00	0.019 45	0.010 23
	10 000	0.009 12	0.009 16	0.019 17	0.009 98
	20 000	0.009 67	0.009 83	0.018 43	0.009 25
	30 000	0.009 68	0.009 85	0.017 80	0.008 64
5700.24	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{3/2}$				
	5000	–	–	0.022 30	0.011 76
	10 000	–	–	0.022 00	0.011 51
	20 000	–	–	0.021 30	0.010 84
	30 000	–	–	0.020 56	0.010 11
5782.13	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{1/2}$				
	5000	–	–	0.021 00	0.011 06
	10 000	–	–	0.020 80	0.010 90
	20 000	–	–	0.020 01	0.010 13
	30 000	–	–	0.019 34	0.009 48
3273.96	$4s\,^2s_{1/2}$–$4p\,^2P^o_{1/2}$				
	5000	0.002 42	0.002 34	0.001 92	0.001 02
	10 000	0.002 59	0.002 62	0.001 96	0.001 06
	20 000	0.002 54	0.002 60	0.001 98	0.001 09
	30 000	0.002 39	0.002 45	0.001 97	0.001 08
3247.54	$4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$				
	5000	–	–	0.002 18	0.001 16
	10 000	–	–	0.002 22	0.001 20
	20 000	–	–	0.002 25	0.001 24
	30 000	–	–	0.002 24	0.001 23

Table 7. Total Stark shifts (electron + ion) for CuI lines at an electron density N_e of 10^{17} cm^{-3}. Experimental results of Fleurier [3]—d_F and theoretical results of Konjević and Konjević [13]—d_K, Lakićević [18]—d_L and d—our calculations using the semiclassical perturbation method [19] (impact approximation for electrons and CuII ions).

λ (Å)	T (K)	d_F (Å)	d_K (Å)	d_L (Å)	d_I (Å)
5105.54	10 000	0.067	−0.010	–	0.192
5700.24	10 000	–	−0.012	–	0.220
5782.13	10 000	0.076	−0.012	–	0.208
3273.96	20 000	–	–	0.065	0.020

between approximately 8000 and 40 000 K. However, for larger and lower temperatures, it becomes unreliable as well.

The $T^{1/6}$ scaling is obtained from the low-temperature limit of the semiclassical expression for the Stark width. Namely, the electron width can be approximated by [22]

$$W_e = 2\left(\frac{32}{27}\right)^{1/2} N_e \pi \left(\frac{\hbar a_o}{m}\right)\left(\frac{E_H}{kT}\right)^{1/2} R^2_{ii'} f_w(\eta R_{ii'}), \tag{16}$$

where m and N_e are electron mass and electron density, respectively. k is the Boltzmann constant, T the temperature, E_H the hydrogen atom ionization energy and a_0 the Bohr radius, and the function $f_w(\eta_{jj'} R_{jj'})$ is an approximate fit of the expression

$$f_w(\eta R_{ii'}) = \tfrac{1}{2}\left[A^2\left(z^{\min}\right) + B^2\left(z^{\min}\right)\right]^{1/2} + a\left(z^{\min}\right), \tag{17}$$

$$R_{jj'}{}^2 = f_{jj'} \times \frac{\lambda_{jj'}(\text{Å})}{303.7}. \tag{18}$$

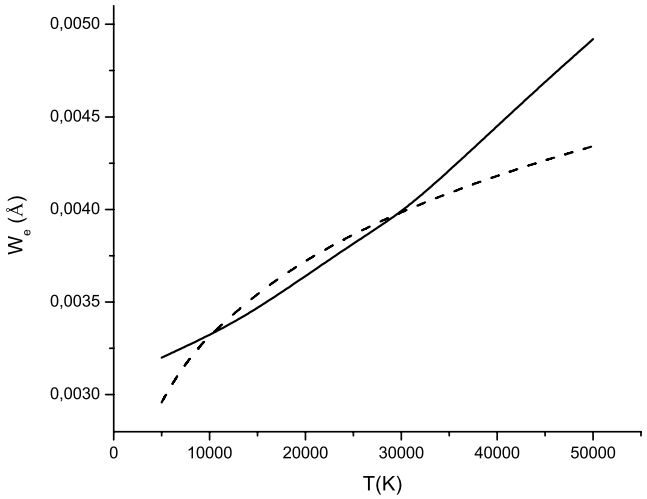

Figure 1. Electronic Stark width for the $4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$ transition of the copper resonance spectral line (3247.54 Å) as a function of temperature T. (Solid line) Our electronic width calculations using the semiclassical perturbation formalism. (Dotted line) Our electronic width calculations using the low-temperature $T^{1/6}$ scaling extrapolated from $T = 10\,000$ K. The electron density is 10^{16}cm^{-3}.

$R^2_{jj'}$ is the dipole matrix element (in units of the Bohr radius a_0^2), $f_{jj'}$ is the oscillator strength for a transition between levels j and j', $\lambda_{jj'}$ as the corresponding wavelength and

$$\eta_{jj'} = \frac{\triangle E_{jj'}}{3kT} = \frac{|E_j - E_{j'}|}{3kT}, \tag{19}$$

Table 8. Critical temperatures T_c for the CuI spectral lines.

λ (Å)	Transition	T_c (kK)
5105.54	$4s^2\,^2D_{5/2}$–$4p\,^2P^o_{3/2}$	292
5700.24	$4s^2\,^2D_{3/2}$–$4p\,^2P^o_{3/2}$	370
5782.13	$4s^2\,^2D_{3/2}$–$4p\,^2p^o_{1/2}$	301
3273.96	$4s\,^2S_{1/2}$–$4p\,^2P^o_{1/2}$	398
3247.54	$4s\,^2S_{1/2}$–$4p\,^2P^o_{3/2}$	361

where E_j and $E_{j'}$ are energies of the corresponding atomic levels.

The Stark broadening functions $a(z^{\min})$, $A(z^{\min})$ and $B(z^{\min})$ can be written in terms of modified Bessel functions (see [23], p 56). $z^{\min}$ is the dimensionless parameter, which depends on the minimal impact parameter $\rho_{\min}$ and the average velocity $\overline{v}$, and is given by

$$z^{\min} = \rho_{\min}\frac{\triangle E_{jj'}}{\hbar\overline{v}}. \tag{20}$$

For low temperatures ($\eta R_{ii'} = \frac{\Delta E_{ii'} R_{ii'}}{kT} \gg 1$),

$$f_w\,(\eta R_{ii'}) \approx 0.487\,(\eta R_{ii'})^{-2/3}\,. \tag{21}$$

Hence the electron width becomes

$$W_e = 2\times 0.487\left(\frac{32}{27}\right)^{1/2} N_e\pi\left(\frac{\hbar a_o}{m}\right)\left(\frac{E_H}{k}\right)^{1/2} \times R_{ii'}^{4/3}\left(\frac{\Delta E_{ii'}}{k}\right)^{-2/3} T^{1/6} \tag{22}$$

or

$$W_e = C\times N_e\,T^{1/6}, \tag{23}$$

where C is a constant depending on the atomic transition.

We also note that if, for neutral emitters, the width increases after a certain temperature T_c, it will start to decrease.

In table 8, we express critical temperatures T_c when the Stark width starts to decrease for all the spectral lines studied here. One can see that they are at very high temperatures where neutral copper lines do not exist; hence for the lower temperatures, of interest for the Stark broadening of CuI, Stark widths of the considered lines always increase with temperature.

4. Conclusion

We have calculated Stark widths and shifts due to collisions with electrons for five lines of neutral copper, using the semiclassical perturbation formalism. We have additionally provided Stark broadening parameters for collisions with copper ions in the impact and quasistatic approximations. The obtained data can be used for laboratory and stellar plasmas diagnostics, investigation and modelling.

These results are compared with other semi-classical and approximate calculations and with experimental data. They agree very well with other semiclassical calculations but all of the theoretical results are in disagreement with experimental findings, indicating the need for a new experimental determination of CuI Stark broadening parameters.

Our results demonstrate that the considered Stark widths increase with temperature for all T values of interest and that the critical temperature when they start to decrease is beyond the temperature range of interest. The temperature trend of Stark widths in this case is not in accordance with $T^{-1/2}$ dependence but with the low-temperature limit $T^{1/6}$ dependence.

References

[1] Djilianova O, Sadowski M J, Skladnik-Sadowska E, Malinowski K, Scholz M, Blagoev A and Paskalev K 2006 *J. Phys.: Conf. Ser.* **44** 175
[2] Holtsmark J and Trumpy B 1925 *Z. Phys.* **31** 803
[3] Fleurier C 1987 *Spectral Line Shapes* **III** 67
[4] Fleurier C and Maulat C 1985 *Proc. 17th Int. Conf. on Phenomena in Ionized Gases (Budapest, 1985)* vol 2 p 981
[5] Neger T and Jäger H 1987 *Z. Nat. forsch.* A **42** 429
[6] Grishina N A, Il'in G G, Salakhov M Kh and Sarandaev E V 1998 *19th SPIG Contributed papers* p 361
[7] Grishina N A, Il'in G G, Salakhov M Kh and Sarandaev E V 1998 *Coherent Optics and Optical Spectroscopy* (Russia: Kazan) p 43
[8] Griem H R, Baranger M, Kolb A C and Oertel G 1962 *Phys. Rev.* **125** 177
[9] Sibgatullin M E, Il'in G G, Salakhov M Kh and Sarandaev E V 2000 *Coherent Optics and Optical Spectroscopy* (Russia: Kazan) p 123
[10] Babina E M, Il'in G G, Konovalova O A, Salakhov M Kh and Sarandaev E V 2003 *Publ. Astron. Obs. Belgrade* **76** 163
[11] Cooper J and Oertel G K 1969 *Phys. Rev.* **180** 286
[12] Radzig A A and Smirnov B M 1986 *Atomic and Ionic Parameters* (Moscow: Energoizdat)
[13] Konjević R and Konjević N 1986 *Fizika* **18** 327
[14] Dimitrijević M S, Il'in G G, Salakhov M Kh and Sarandaev E V 1996 *18th Symp. on Physics of Ionized Gases (Kotor, 1996)* p 283
[15] Dimitrijević M S and Konjević N 1986 *Astron. Astrophys.* **163** 297
[16] Pichler G 1972 *Fizika* **4** 235
[17] Lindholm E 1946 *Ark. Mat. Astron. Fys.* **32** A 1
[18] Lakićević I S 1983 *Astron. Astrophys.* **127** 37
[19] Sahal-Bréchot S 1969 *Astron. Astrophys.* **1** 91
[20] Sahal-Bréchot S 1969 *Astron. Astrophys.* **2** 322
[21] Zmerli B, Ben Nessib N and Dimitrijević M S 2008 *Eur. J. Phys.* D **48** 389
[22] Freudenstein S A and Cooper J 1978 *Astrophys. J.* **224** 1079
[23] Griem H R 1974 *Spectral Line Broadening by Plasmas* (New York: Academic)
[24] Sahal-Bréchot S 1974 *Astron. Astrophys.* **35** 321
[25] Baranger M 1958 *Phys. Rev.* **111** 494
[26] Sahal-Bréchot S and Van Regemorter H 1964 *Ann. Astron.* **27** 432
[27] Dimitrijević M S and Sahal-Bréchot S 1985 *Phys. Rev.* A **31** 316
[28] Lesage A 2009 *New Astron. Rev.* **52** 471
[29] Konjevic N and Roberts J R 1976 *J. Phys. Chem. Ref. Data* **5** 209
[30] Konjevic N, Dimitrijević M S and Wiese W L 1984 *J. Phys. Chem. Ref. Data* **13** 619
[31] Konjevic N and Wiese W L 1990 *J. Phys. Chem. Ref. Data* **19** 1307
[32] Konjevic N, Lesage A, Fuhr J R and Wiese W L 2002 *J. Phys. Chem. Ref. Data* **31** 819
[33] Skuljan Lj, Bukvić S and Djeniže S 1995 *Publ. Obs. Astron. Belgrade* **50** 127
[34] Corliss C H 1970 *J. Res. Nat. Bur. Stand* A **74** 781

[35] Fu K, Jogwich M, Knebel M and Wiesemann K 1995 *At. Data Nuc. Data Tables* **61** 1
[36] Popović L Č, Milovanović N and Dimitrijević M S 2001 *Astron. Astrophys.* **365** 656
[37] Griem H R 1964 *Plasma Spectroscopy* (New York: McGraw-Hill)
[38] Baranger M 1958 *Phys. Rev.* **111** 481
[39] Baranger M 1958 *Phys. Rev.* **112** 855
[40] Baranger M 1962 *Atomic and Molecular Processes* ed D R Bates (New York: Academic)
[41] Sahal-Bréchot S 1991 *Astron. Astrophys.* **245** 322
[42] Griem H R 1962 *Phys. Rev.* **128** 515
[43] Ben Nessib N, Ben Lakhdar Z and Sahal-Bréchot S 1996 *Phys. Scr.* **54** 608

INFLUENCE OF CHEMI-IONIZATION AND CHEMI-RECOMBINATION PROCESSES ON THE PLASMA KINETICS IN THE SOLAR ATMOSPHERE

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Abstract. Results of considerations of the influence of the H atom - H ion - e and H molecular ion - e chemi-recombination processes on the highly excited hydrogen atom population in the photosphere and lower part of the chromosphere have been discussed and presented. The attention has been drawn also to investigations of the contribution of the analogous ion-atom radiative processes with the formation of quasi molecular collisional ion-atom complexes (where we have a photon instead of an electron), on the solar photosphere and chromosphere continuous spectra.

Key words: chemi-ionization/recombination – solar plasma – ion–atom radiative processes.

1. INTRODUCTION

In a plasma in general, we have neutral atoms and molecules of different species (A, B, A_2, B_2, AB, A^*, B^*, A^*_2, B^*_2, AB^*,..., where with an asterisk is denoted an atom or molecule in an excited state), atomic and molecular ions (A^+, B^+, A^+_2, B^+_2, AB^+,...), free electrons and free EM field. One must have in view however, that ion-atom and atom-atom quasimolecular collisional complexes

$$A^+ + A,\ B^+ + B,\ A^+ + B,\ B^+ + A \ldots$$

$$A^* + A,\ B^* + B,\ A^* + B,\ B^* + A \ldots$$

may be formed in the considered plasma as well. We will treat here the collisional processes involving symmetrical quasimolecular collisional complexes

$$A^+ + A \Rightarrow (A^+ + A)_{qmi} \rightarrow \ldots, \text{etc.},$$

$$A^* + A \Rightarrow (A^* + A)_{eqm} \rightarrow \ldots, \text{etc.},$$

where $(\ldots)_{qmi}$ denotes the ionized quasimolecular complex, and $(\ldots)_{eqm}$ denotes the quasimolecular complex in the corresponding excited electronic state. We will assume in further as well that the weakly bounded molecular ions are in the ground electronic state, and that the molecular ions A^+_2, B^+_2 etc., are in the rhovibrational states near the corresponding dissociation threshold.

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In several papers (Mihajlov et al., 1996a; Mihajlov et al., 1996b; Mihajlov et al., 1997a, 1997b) we have introduced and investigated, chemi-recombination processes during the free electron scattering on the quasi-molecular collisional complexes ion and molecular ions in the weakly bound rovibrational states, among them processes with A ≡ H of particular interest for solar plasma, as well as H ion - H atom radiative processes of charge exchange and association during H and H(1s) collisions (e.g. Mihajlov et al., 1994).

We discuss and present here results of our considerations of the influence of the H atom - H ion - e and H molecular ion - e chemi-recombination processes on the highly excited hydrogen atom population in the photosphere and lower part of the chromosphere. We draw attention also to our investigations of the contribution of the analogous ion-atom radiative processes with the formation of quasi-molecular collisional ion-atom complexes (where we have a photon instead of an electron), on the solar photosphere and chromosphere continuous spectra.

2. CHEMI-IONIZATION AND CHEMI-RECOMBINATION PROCESSES

It was shown in Mihajlov et al. (1996b), Mihajlov et al.(1996a) and Mihajlov et al. (1997a) that in weakly ionized gas plasmas, the dielectronic recombination processes

$$e + A + A^+ \Rightarrow A + A^*(n) \tag{1}$$

and

$$e + A^+_2(v,J) \Rightarrow A + A^*(n) \tag{2}$$

treated here as chemi-recombination processes, and their inverse collisional chemi-ionization processes

$$A + A^*(n) \Rightarrow e + A + A^+ \tag{3}$$

and

$$A + A^*(n) \Rightarrow e + A^+_2(v,J) \tag{4}$$

may be very important and sometimes even dominant in comparison with other relevant ionization-recombination processes. We have in view here the influence of these processes on populations of Rydberg atoms in weakly ionized gas plasmas. In the equations for above mentioned processes e denotes free electron, A and A^+ - atom and positive (singly charged) atomic ion in their ground states, $A^*(n)$ - atom in a highly excited (Rydberg) state with the principal quantum number $n >> 1$, $A + A^+$ - a collisional ion-atom system, which may be treated as quasi - molecular complex (within the internuclear distances range significant for the considered process), and $A^+_2(v,J)$ - molecular ion in one of the highly excited rovibrational states belonging to its ground electronic state. With v and J are denoted vibrational and rotational quantum numbers. It is assumed that at least one of them is high enough to ensure that the dissociation energy of the $A^+_2(v,J)$ state is relatively small compared to dissociation energy of the ground rovibrational state (typical dissociation energy of such rovibrational states is less than 1 eV). Moreover, it is assumed that in the considered weakly ionized plasma subsystems formed by molecular ions $A^+_2(v,J)$ and ion-atom complexes $A + A^+$, are in dissociation-association equilibrium.

In connection with the dissociative-recombination channel (2), one should draw attention that this channel should not be identified with the already mentioned standard process of dissociative recombination, where molecular ions are in lower rovibrational states (belonging also to its ground electronic state). This standard dissociative recombination process, due to clear energetic reasons, practically has no influence on populations of atoms in Rydberg states (with $n >> 1$), since in such

processes we have an atom A^* in one of low lying energetic states. However, just standard dissociation processes were considered until recently. Only in some papers, the dissociative recombination processes with molecular ions in highly excited rovibrational states were treated (Schneider et al., 1994; Chibisov et al., 1997), but only in hydrogen case and with a limited domain of applicability. For example, in Schneider et al. (1994) the recombination of H^+_2 ions was considered (related to astrophysical plasmas) in temperature domains up to 4000K, while in the important case of the solar photosphere the temperature domain of interest is above that.

For the description of the considered chemi-recombination/ionization processes one uses here the semiclassical method developed in previous articles (Mihajlov et al., 1996b; Mihajlov et al., 1996a; Mihajlov et al., 1997a), based on the mechanism of energy conversion within the electronic component of the atom - Rydberg atom or electron-ion-atom system, due to dypole interaction between an outer (weakly bound or free) electron and a quasi-molecular ion-atom subsystem.

For the solar plasma investigation, of special interest is the case $A \equiv H$. The influence of the $H - H^+ - e$ and $H^+_2 - e$ chemi-recombination processes on the highly excited hydrogen atom population in the photosphere and the lower part of the chromosphere has been considered in Mihajlov et al. (1997b). Obtained results show that the considered chemi-recombination processes evidently have an important role in the large region around the temperature minimum in the solar atmosphere, where they are comparable or dominant in relation to the other recombination processes. Within this range they may be a quite significant factor contributing to the smaller decrease from LTE. Consequently, this shows the necessity of the inclusion of the considered processes in the modeling of the weakly ionized layers in the solar atmosphere. For solar and stellar atmosphere models where $T_e = T_a = T$, the expressions (2–4) from Mihajlov et al. (1997b) for the considered chemi-recombination processes total rate coefficient may be used. However, for atmosphere models where the equality of T_e and T_a is not assumed, the corresponding tables and the general expressions for partially ionized nonequilibrium hydrogen plasms are given in Mihajlov et al. (1996a).

3. ION-ATOM RADIATIVE PROCESSES

We want also to draw attention here to colleagues interested in solar research on our investigations (Mihajlov et al., 1994) of the contribution of ion-atom radiative processes:

$$H^+ + H(1s) \leftrightarrow \varepsilon_\lambda + H^+_2 (1\Sigma_g), \tag{5}$$

$$H^+ + H(1s) \leftrightarrow \varepsilon_\lambda + H(1s) + H^+, \tag{6}$$

to the solar photosphere and chromosphere continuous spectra in the optical range. Here ε_λ is the energy of phototn with wavelength λ, and the wavelength range investigated in Mihajlov et al. (1994) was 365 nm $\leq \lambda \leq$ 820 nm. Such processes are analogous to processes (1–4) but with a photon instead of an electron.

The results obtained in Mihajlov et al. (1994) illustrate the influence of (5, 6) radiative processes involving H^+ and H(1s) on spectral characteristics for particular photospheric and chromospheric layers. The numerical results presented in Mihajlov et al. (1994) enable the inclusion of ion-atom radiative processes (5, 6) in the optical depth calculation for the mentioned layers.

Our results concerning the processes involving the collisional ion-atom complexes might be of interest not only for solar, but as well for other astrophysical plasmas with a dominant hydrogen component and temperatures around 6000 K.

REFERENCES

Chibisov, M. I., Mitchell, J. B. A., Van der Donk, P. J. T., Yousif, F. B., Morgan, T. J.: 1997, *Phys. Rev. A*, **56**, 443.
Mihajlov, A. A., Dimitrijević, M. S., Djurić, Z.: 1996a, *Phys. Scripta*, **53**, 159.
Mihajlov, A. A., Djurić, Z., Dimitrijević, M. S.: 1996b, *J. Quant. Spectrosc. Radiat. Transfer*, **55**, 141.
Mihajlov, A. A., Dimitrijević, M. S., Ignjatović, Lj., Djurić, Z.: 1994, *Astron. Astrophys. Suppl. Series*, **103**, 57.
Mihajlov, A. A., Djurić, Z., Dimitrijević, M. S., Ljepojević, N. N.: 1997a, *Phys. Scripta*, **56**, 631.
Mihajlov, A. A., Ignjatović, Lj. M., Vasilijević, M. M., Dimitrijević, M. S.: 1997b, *Astron. Astrophys.*, **324**, 1206.
Schneider, I. F., Dulieu, O., Giusti-Suzor, A., Roueff, E.: 1994, *Astrophys. J.*, **424**, 983.

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Stark Broadening of Al I Spectral Lines

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Abstract

Using a semiclassical approach, we have calculated electron-, proton- and ionized helium-impact line widths and shifts for 22 Al I multiplets. The resulting data have been compared with existing experimental and theoretical values.

1. Introduction

Stark broadening parameters of neutral aluminium lines are of interest for laboratory plasma diagnostics and they have been determined experimentally [1–10] and theoretically [1, 5, 11–13] several times. The astrophysical importance of aluminium lines is due to its high cosmic abundance and its presence in the solar atmosphere [14] and stellar spectra [15]. Particularly important are the Al I resonance lines $\lambda\lambda$ 3944 Å and 3961 Å which appear in A0 type stars (where Stark broadening is not negligible) and become stronger when the temperature decreases [15].

By using the semiclassical-perturbation formalism [16, 17] we have calculated electron-, proton- and ionized helium-impact line widths and shifts for 22 Al I multiplets. A summary of the formalism is given in Ref. [18]. Here, we present and discuss the results for Al I, along with a comparison with experimental data [1–6] and other theoretical results [5, 12, 13].

2. Results and discussion

Energy levels for Al I lines have been taken from Ref. [19]. Oscillator strengths have been calculated by using the method of Bates and Damgaard [20, 21]. For higher levels, the method described in Ref. [22] has been used. For three lowest energy levels, $3p^2P^o$, $4s^2S$ and $3d^2D^o$, oscillator strengths given in Ref. [23] have been used.

In addition to electron-impact full halfwidths and shifts, Stark-broadening parameters due to proton- and ionized-helium impacts have been calculated, in order to provide data for principal constituents of stellar plasma. Our results are shown in Table I for a perturber density of $10^{15}\,\mathrm{cm}^{-3}$ and temperatures $T = 3000$–$50\,000\,\mathrm{K}$. For perturber densities lower than $10^{15}\,\mathrm{cm}^{-3}$, all of the data are practically linear functions of the density because the effect of Debye screening is negligible. We also specify a parameter [18] C which, when it is divided by the corresponding electron-impact full width at half maximum, gives an estimate for the maximum perturber density for which the line may be treated as isolated.

For each value given in Table I, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid [16, 17]. Values of $0.1 < NV \leqslant 0.5$ are denoted by an asterisk. When the impact approximation is not valid, the ion-broadening contribution may be estimated by using quasistatic estimations [13, 24]. The accuracy of the results obtained decreases when broadening by ion interactions becomes important. At high densities, the results are no longer linear with density due to Debye screening. This effect is more important for the shift than for the width. Stark-broadening parameter tables for high densities will be published elsewhere [25].

In Tables II and III, the present results are compared with experimental data [1–6], and with other semiclassical calculations [5, 12, 13]. In order to avoid different procedures for ion broadening contribution calculation within different theories, and to better compare different theoretical approaches, only theoretical electron impact broadening parameters are presented. We see that different theoretical approaches agree very well. If one takes into account that the ion broadening contribution, analysed in detail in Refs [1] and [5], will increase the Stark broadening parameters with around 10%, the agreement with experimental data is also good. Particularly satisfactory is the mutual agreement in the case of a shift, since the shift values are more complicated for reliable semiclassical calculations than the widths [26–28].

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Table I. *This table shows electron-, proton- and He II-impact broadening parameters for Al I lines, for perturber densities of* 10^{15} *cm*$^{-3}$ *and temperatures from 3000 to 50 000 K. Transitions and averaged wavelengths for the multiplet (in Å) are also given. By using C {see eq. (5) of Ref. [18]}, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the collision volume multiplied by the perturber density (the condition for validity of the impact approximation) lies between 0.1 and 0.5*

Perturber density = $1 \cdot 10^{15}$ cm^{-3}

Perturbers are		Electrons		Protons		Ionized helium	
Transition	T [K]	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
3P–4S	3 000	0.210×10^{-2}	0.172×10^{-2}	0.526×10^{-3}	0.477×10^{-3}	0.428×10^{-3}	0.383×10^{-3}
3958.3 Å	5 000	0.239×10^{-2}	0.193×10^{-2}	0.571×10^{-3}	0.524×10^{-3}	0.465×10^{-3}	0.422×10^{-3}
$C = 0.12 \times 10^{19}$	10 000	0.279×10^{-2}	0.232×10^{-2}	0.639×10^{-3}	0.593×10^{-3}	0.519×10^{-3}	0.478×10^{-3}
	20 000	0.310×10^{-2}	0.263×10^{-2}	0.716×10^{-3}	0.667×10^{-3}	0.581×10^{-3}	0.539×10^{-3}
	30 000	0.317×10^{-2}	0.251×10^{-2}	0.765×10^{-3}	0.715×10^{-3}	0.621×10^{-3}	0.577×10^{-3}
	50 000	0.341×10^{-2}	0.248×10^{-2}	0.832×10^{-3}	0.780×10^{-3}	0.675×10^{-3}	0.630×10^{-3}
3P–5S	3 000	0.472×10^{-2}	0.348×10^{-2}	0.104×10^{-2}	0.927×10^{-3}	0.838×10^{-3}	0.739×10^{-3}
2659.2 Å	5 000	0.528×10^{-2}	0.400×10^{-2}	0.113×10^{-2}	0.103×10^{-2}	0.912×10^{-3}	0.822×10^{-3}
$C = 0.18 \times 10^{18}$	10 000	0.584×10^{-2}	0.472×10^{-2}	0.127×10^{-2}	0.117×10^{-2}	0.102×10^{-2}	0.939×10^{-3}
	20 000	0.620×10^{-2}	0.457×10^{-2}	0.142×10^{-2}	0.133×10^{-2}	0.115×10^{-2}	0.107×10^{-2}
	30 000	0.650×10^{-2}	0.450×10^{-2}	0.152×10^{-2}	0.143×10^{-2}	0.123×10^{-2}	0.115×10^{-2}
	50 000	0.686×10^{-2}	0.388×10^{-2}	0.166×10^{-2}	0.155×10^{-2}	0.134×10^{-2}	0.126×10^{-2}
3P–3D	3 000	0.392×10^{-2}	0.262×10^{-2}	0.102×10^{-2}	0.858×10^{-3}	0.851×10^{-3}	0.686×10^{-3}
3091.0 Å	5 000	0.417×10^{-2}	0.242×10^{-2}	0.110×10^{-2}	0.947×10^{-3}	0.913×10^{-3}	0.759×10^{-3}
$C = 0.49 \times 10^{17}$	10 000	0.432×10^{-2}	0.215×10^{-2}	0.122×10^{-2}	0.108×10^{-2}	0.101×10^{-2}	0.865×10^{-3}
	20 000	0.420×10^{-2}	0.180×10^{-2}	0.136×10^{-2}	0.122×10^{-2}	0.111×10^{-2}	0.981×10^{-3}
	30 000	0.407×10^{-2}	0.160×10^{-2}	0.145×10^{-2}	0.131×10^{-2}	0.118×10^{-2}	0.105×10^{-2}
	50 000	0.390×10^{-2}	0.128×10^{-2}	0.157×10^{-2}	0.142×10^{-2}	0.128×10^{-2}	0.115×10^{-2}
3P–4D	3 000	0.448×10^{-2}	0.325×10^{-2}	0.141×10^{-2}	0.855×10^{-3}	0.130×10^{-2}	0.682×10^{-3}
2601.0 Å	5 000	0.500×10^{-2}	0.379×10^{-2}	0.146×10^{-2}	0.946×10^{-3}	0.134×10^{-2}	0.757×10^{-3}
$C = 0.12 \times 10^{18}$	10 000	0.558×10^{-2}	0.419×10^{-2}	0.155×10^{-2}	0.108×10^{-2}	0.140×10^{-2}	0.865×10^{-3}
	20 000	0.611×10^{-2}	0.416×10^{-2}	0.166×10^{-2}	0.122×10^{-2}	0.148×10^{-2}	0.982×10^{-3}
	30 000	0.642×10^{-2}	0.386×10^{-2}	0.173×10^{-2}	0.131×10^{-2}	0.153×10^{-2}	0.106×10^{-2}
	50 000	0.693×10^{-2}	0.327×10^{-2}	0.183×10^{-2}	0.143×10^{-2}	0.160×10^{-2}	0.116×10^{-2}
3P–5D	3 000	0.853×10^{-2}	0.439×10^{-2}	0.302×10^{-2}	0.110×10^{-2}	$*0.295 \times 10^{-2}$	$*0.874 \times 10^{-3}$
2372.4 Å	5 000	0.981×10^{-2}	0.488×10^{-2}	0.306×10^{-2}	0.122×10^{-2}	0.298×10^{-2}	0.976×10^{-3}
$C = 0.52 \times 10^{17}$	10 000	0.118×10^{-1}	0.539×10^{-2}	0.312×10^{-2}	0.140×10^{-2}	0.302×10^{-2}	0.112×10^{-2}
	20 000	0.142×10^{-1}	0.525×10^{-2}	0.320×10^{-2}	0.159×10^{-2}	0.307×10^{-2}	0.128×10^{-2}
	30 000	0.158×10^{-1}	0.485×10^{-2}	0.326×10^{-2}	0.171×10^{-2}	0.311×10^{-2}	0.137×10^{-2}
	50 000	0.177×10^{-1}	0.412×10^{-2}	0.334×10^{-2}	0.187×10^{-2}	0.316×10^{-2}	0.151×10^{-2}
3D–4P	3 000	36.4	−16.7	6.93	−5.68	5.83	−4.53
193 106.1 Å	5 000	38.2	−12.9	7.46	−6.30	6.24	−5.04
$C = 0.19 \times 10^{21}$	10 000	40.7	−8.57	8.26	−7.19	6.86	−5.77
	20 000	40.4	−5.47	9.18	−8.15	7.58	−6.56
	30 000	40.1	−3.63	9.77	−8.76	8.04	−7.06
	50 000	40.0	−2.24	10.6	−9.56	8.68	−7.72
3D–5P	3 000	0.188	0.637×10^{-1}	0.613×10^{-1}	0.149×10^{-1}	0.607×10^{-1}	0.119×10^{-1}
12 759.1 Å	5 000	0.217	0.771×10^{-1}	0.616×10^{-1}	0.164×10^{-1}	0.610×10^{-1}	0.132×10^{-1}
$C = 0.84 \times 10^{18}$	10 000	0.259	0.853×10^{-1}	0.620×10^{-1}	0.187×10^{-1}	0.614×10^{-1}	0.150×10^{-1}
	20 000	0.307	0.863×10^{-1}	0.626×10^{-1}	0.211×10^{-1}	0.617×10^{-1}	0.170×10^{-1}
	30 000	0.337	0.764×10^{-1}	0.629×10^{-1}	0.226×10^{-1}	0.619×10^{-1}	0.183×10^{-1}
	50 000	0.375	0.654×10^{-1}	0.635×10^{-1}	0.247×10^{-1}	0.623×10^{-1}	0.199×10^{-1}
3D–6P	3 000	0.294	0.175	$*0.959 \times 10^{-1}$	$*0.421 \times 10^{-1}$	$*0.916 \times 10^{-1}$	$*0.330 \times 10^{-1}$
9174.6 Å	5 000	0.331	0.203	0.983×10^{-1}	0.474×10^{-1}	$*0.937 \times 10^{-1}$	$*0.376 \times 10^{-1}$
$C = 0.44 \times 10^{18}$	10 000	0.388	0.193	0.102	0.549×10^{-1}	$*0.962 \times 10^{-1}$	$*0.438 \times 10^{-1}$
	20 000	0.458	0.176	0.106	0.628×10^{-1}	0.991×10^{-1}	0.504×10^{-1}
	30 000	0.507	0.153	0.109	0.677×10^{-1}	0.101	0.544×10^{-1}
	50 000	0.564	0.128	0.113	0.742×10^{-1}	0.104	0.597×10^{-1}
3D–7P	3 000	0.610	0.410				
8004.5 Å	5 000	0.670	0.437	*0.185	*0.103		
$C = 0.27 \times 10^{18}$	10 000	0.764	0.438	*0.196	*0.122		
	20 000	0.882	0.341	*0.209	*0.142	*0.188	*0.113
	30 000	0.967	0.280	*0.217	*0.154	*0.194	*0.123
	50 000	1.05	0.224	0.229	0.170	*0.202	*0.136

Table I. (*continued*)

Perturber density = $1 \cdot 10^{15}$ cm^{-3}

Perturbers are		Electrons		Protons		Ionized helium	
Transition	T [K]	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
4*S*–4*P*	3000	0.113	-0.496×10^{-1}	0.268×10^{-1}	-0.195×10^{-1}	0.236×10^{-1}	-0.156×10^{-1}
13147.3 Å	5000	0.118	-0.388×10^{-1}	0.284×10^{-1}	-0.216×10^{-1}	0.248×10^{-1}	-0.173×10^{-1}
$C = 0.90 \times 10^{18}$	10000	0.127	-0.298×10^{-1}	0.308×10^{-1}	-0.246×10^{-1}	0.266×10^{-1}	-0.197×10^{-1}
	20000	0.134	-0.225×10^{-1}	0.337×10^{-1}	-0.279×10^{-1}	0.287×10^{-1}	-0.224×10^{-1}
	30000	0.140	-0.175×10^{-1}	0.356×10^{-1}	-0.299×10^{-1}	0.301×10^{-1}	-0.241×10^{-1}
	50000	0.149	-0.131×10^{-1}	0.383×10^{-1}	-0.326×10^{-1}	0.321×10^{-1}	-0.263×10^{-1}
4*S*–5*P*	3000	0.435×10^{-1}	0.239×10^{-1}	0.184×10^{-1}	0.604×10^{-2}	0.181×10^{-1}	0.481×10^{-2}
6699.8 Å	5000	0.490×10^{-1}	0.274×10^{-1}	0.186×10^{-1}	0.669×10^{-2}	0.182×10^{-1}	0.535×10^{-2}
$C = 0.78 \times 10^{18}$	10000	0.587×10^{-1}	0.267×10^{-1}	0.189×10^{-1}	0.762×10^{-2}	0.184×10^{-1}	0.612×10^{-2}
	20000	0.724×10^{-1}	0.249×10^{-1}	0.193×10^{-1}	0.864×10^{-2}	0.187×10^{-1}	0.695×10^{-2}
	30000	0.820×10^{-1}	0.214×10^{-1}	0.195×10^{-1}	0.929×10^{-2}	0.188×10^{-1}	0.748×10^{-2}
	50000	0.947×10^{-1}	0.179×10^{-1}	0.199×10^{-1}	0.101×10^{-1}	0.191×10^{-1}	0.818×10^{-2}
4*S*–6*P*	3000	0.103	0.679×10^{-1}	$*0.362 \times 10^{-1}$	$*0.160 \times 10^{-1}$	$*0.346 \times 10^{-1}$	$*0.125 \times 10^{-1}$
5559.3 Å	5000	0.115	0.751×10^{-1}	$*0.372 \times 10^{-1}$	$*0.180 \times 10^{-1}$	$*0.353 \times 10^{-1}$	$*0.143 \times 10^{-1}$
$C = 0.26 \times 10^{18}$	10000	0.134	0.762×10^{-1}	0.385×10^{-1}	0.209×10^{-1}	$*0.363 \times 10^{-1}$	$*0.167 \times 10^{-1}$
	20000	0.160	0.646×10^{-1}	0.402×10^{-1}	0.239×10^{-1}	0.374×10^{-1}	0.192×10^{-1}
	30000	0.179	0.572×10^{-1}	0.413×10^{-1}	0.258×10^{-1}	0.382×10^{-1}	0.207×10^{-1}
	50000	0.201	0.468×10^{-1}	0.430×10^{-1}	0.283×10^{-1}	0.393×10^{-1}	0.228×10^{-1}
4*S*–7*P*	3000	0.243	0.162				
5106.9 Å	5000	0.267	0.184	$*0.762 \times 10^{-1}$	$*0.422 \times 10^{-1}$		
$C = 0.11 \times 10^{18}$	10000	0.304	0.172	$*0.807 \times 10^{-1}$	$*0.501 \times 10^{-1}$		
	20000	0.353	0.140	$*0.859 \times 10^{-1}$	$*0.582 \times 10^{-1}$	$*0.772 \times 10^{-1}$	$*0.464 \times 10^{-1}$
	30000	0.388	0.113	$*0.893 \times 10^{-1}$	$*0.631 \times 10^{-1}$	$*0.797 \times 10^{-1}$	$*0.505 \times 10^{-1}$
	50000	0.424	0.887×10^{-1}	0.941×10^{-1}	0.696×10^{-1}	$*0.832 \times 10^{-1}$	0.558×10^{-1}
4*P*–5*S*	3000	0.542	0.316	0.101	0.825×10^{-1}	0.852×10^{-1}	0.656×10^{-1}
21117.0 Å	5000	0.572	0.328	0.109	0.916×10^{-1}	0.912×10^{-1}	0.732×10^{-1}
$C = 0.23 \times 10^{19}$	10000	0.600	0.335	0.121	0.105	0.100	0.840×10^{-1}
	20000	0.640	0.310	0.134	0.119	0.111	0.956×10^{-1}
	30000	0.667	0.267	0.143	0.128	0.118	0.103
	50000	0.729	0.219	0.154	0.140	0.127	0.113
4*P*–4*D*	3000	0.384	0.222	0.767×10^{-1}	0.582×10^{-1}	0.663×10^{-1}	0.463×10^{-1}
17929.8 Å	5000	0.405	0.240	0.817×10^{-1}	0.646×10^{-1}	0.701×10^{-1}	0.516×10^{-1}
$C = 0.17 \times 10^{19}$	10000	0.425	0.223	0.894×10^{-1}	0.738×10^{-1}	0.760×10^{-1}	0.592×10^{-1}
	20000	0.451	0.198	0.984×10^{-1}	0.838×10^{-1}	0.829×10^{-1}	0.674×10^{-1}
	30000	0.474	0.169	0.104	0.902×10^{-1}	0.874×10^{-1}	0.726×10^{-1}
	50000	0.513	0.138	0.112	0.984×10^{-1}	0.936×10^{-1}	0.795×10^{-1}
4*P*–5*D*	3000	0.236	0.110	0.595×10^{-1}	0.279×10^{-1}	$*0.569 \times 10^{-1}$	$*0.221 \times 10^{-1}$
10774 Å	5000	0.264	0.125	0.610×10^{-1}	0.311×10^{-1}	0.580×10^{-1}	0.248×10^{-1}
$C = 0.60 \times 10^{18}$	10000	0.304	0.119	0.633×10^{-1}	0.356×10^{-1}	0.595×10^{-1}	0.285×10^{-1}
	20000	0.354	0.110	0.661×10^{-1}	0.405×10^{-1}	0.614×10^{-1}	0.325×10^{-1}
	30000	0.388	0.962×10^{-1}	0.680×10^{-1}	0.435×10^{-1}	0.627×10^{-1}	0.350×10^{-1}
	50000	0.432	0.802×10^{-1}	0.708×10^{-1}	0.476×10^{-1}	0.646×10^{-1}	0.384×10^{-1}
4*D*–5*P*	3000	2.56	0.429	1.08	0.145	1.08	0.116
57393.7 Å	5000	3.15	0.345	1.08	0.159	1.08	0.128
$C = 0.57 \times 10^{20}$	10000	4.43	0.240	1.08	0.180	1.08	0.145
	20000	6.18	0.207	1.09	0.203	1.08	0.164
	30000	7.29	0.177	1.09	0.218	1.08	0.176
	50000	8.62	0.148	1.09	0.238	1.09	0.192
4*D*–6*P*	3000	1.40	0.915	*0.467	*0.210	*0.445	*0.165
20813.7 Å	5000	1.57	0.914	0.479	0.237	*0.455	*0.188
$C = 0.36 \times 10^{19}$	10000	1.90	0.921	0.497	0.274	*0.468	*0.219
	20000	2.34	0.760	0.519	0.313	0.483	0.251
	30000	2.67	0.633	0.534	0.337	0.493	0.271
	50000	3.04	0.591	0.556	0.370	0.508	0.298
4*D*–7*P*	3000	2.27	1.49				
15630.4 Å	5000	2.49	1.63	*0.693	*0.391		
$C = 0.10 \times 10^{19}$	10000	2.87	1.57	*0.736	*0.464		
	20000	3.37	1.20	*0.784	*0.538	*0.703	*0.429
	30000	3.73	0.949	*0.816	*0.584	*0.726	*0.467
	50000	4.10	0.773	0.861	0.643	*0.759	*0.516

Table I. (*continued*)

Perturber density = $1 \cdot 10^{15}$ cm^{-3}

Perturbers are		Electrons		Protons		Ionized helium	
Transition	T [K]	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
5S–5P	3000	1.26	0.845×10^{-1}	0.596	0.520×10^{-1}	0.594	0.418×10^{-1}
38697.4 Å	5000	1.52	0.158×10^{-1}	0.597	0.571×10^{-1}	0.596	0.459×10^{-1}
$C = 0.26 \times 10^{20}$	10000	2.11	-0.277×10^{-1}	0.598	0.647×10^{-1}	0.597	0.521×10^{-1}
	20000	2.94	-0.659×10^{-1}	0.598	0.728×10^{-1}	0.598	0.587×10^{-1}
	30000	3.47	-0.536×10^{-1}	0.598	0.780×10^{-1}	0.598	0.630×10^{-1}
	50000	4.12	-0.427×10^{-1}	0.599	0.851×10^{-1}	0.598	0.687×10^{-1}
5S–6P	3000	1.02	0.657	*0.362	*0.151	*0.347	*0.119
17710.6 Å	5000	1.14	0.651	0.370	0.171	*0.355	*0.135
$C = 0.26 \times 10^{19}$	10000	1.39	0.647	0.382	0.197	*0.363	*0.157
	20000	1.72	0.513	0.397	0.225	0.373	0.181
	30000	1.97	0.441	0.407	0.243	0.380	0.195
	50000	2.24	0.389	0.421	0.267	0.389	0.215
5S–7P	3000	1.78	1.16				
13813.0 Å	5000	1.95	1.25	*0.554	*0.305		
$C = 0.79 \times 10^{18}$	10000	2.25	1.24	*0.586	*0.362		
	20000	2.65	0.924	*0.623	*0.420	*0.562	*0.335
	30000	2.93	0.735	*0.648	*0.455	*0.579	*0.364
	50000	3.23	0.593	0.682	0.502	*0.604	*0.403
5P–5D	3000	3.75	1.13	1.12	0.276	1.11	0.221
50974.9 Å	5000	4.57	1.20	1.13	0.305	1.12	0.245
$C = 0.24 \times 10^{20}$	10000	6.23	1.02	1.14	0.347	1.13	0.279
	20000	8.53	0.827	1.15	0.394	1.13	0.317
	30000	9.99	0.785	1.16	0.423	1.14	0.341
	50000	11.7	0.667	1.17	0.461	1.14	0.372
5D–6P	3000	28.2	15.7	*7.99	*3.70	*7.60	*2.91
90873.6 Å	5000	32.5	16.0	8.21	4.16	*7.77	*3.30
$C = 0.69 \times 10^{20}$	10000	41.2	14.5	8.53	4.81	*8.00	*3.84
	20000	53.8	11.6	8.93	5.49	8.27	4.41
	30000	62.1	10.2	9.20	5.92	8.45	4.76
	50000	71.2	8.67	9.59	6.50	8.72	5.23
5D–7P	3000	13.2	8.24	*3.56	*1.87		
37123.9 Å	5000	14.5	8.75	*3.73	*2.17		
$C = 0.57 \times 10^{19}$	10000	17.1	8.57	*3.97	*2.58	*3.58	*2.04
	20000	20.4	6.42	*4.25	*2.99	*3.78	*2.39
	30000	22.8	5.33	*4.43	*3.25	*3.91	*2.60
	50000	25.3	4.00	4.69	3.58	*4.10	*2.87

Table II. *Comparison between the experimental Stark full half-widths of Al I lines (denoted by Wm – corresponding references are given in the last column) with different calculations. Semiclassical calculations: WDSB-present results; WBG – Benett and Griem (1971) [12, 13]. WB – Calculations of Bach (1978) [5], by using the theory of Cooper and Oertel (1969) [29]. The electron density N is equal to* 10^{17} *cm*$^{-3}$

Transition	Lambda (Å)	T (K)	$N(10^{17}$ cm$^{-3})$	Wm (Å)	WDSB (Å)	WBG (Å)	WB (Å)	Ref.
3p–4s	3961.52	9670	1.42	0.63	0.39	0.44	0.34	[1]
		11000*	0.1*	0.038*	0.028	0.031		[2]
		11700	2.5	0.84	0.72	0.80		[3, 4]
		13200	1.28	0.54	0.37	0.42		[5]
		13600	4.5	1.30	1.32	1.48		[6]
	3944.01	9670	1.42	0.46	0.39	0.44	0.34	[1]
		11000*	0.1*	0.037*	0.028	0.031		[2]
		11700	2.5	0.84	0.72	0.80		[3, 4]
		13200	1.28	0.54	0.37	0.42		[5]
		13600	4.5	1.40	1.32	1.48		[6]
3p–3d	3082.15	11000*	0.1*	0.045*	0.043	0.52		[2]
		13200	1.28	0.51	0.55	0.66		[5]
	3092.71	11000*	0.1*	0.049*	0.043	0.52		[2]
		13200	1.28	0.51	0.55	0.66		[5]

* Results taken in the electron density range (0.15–0.60) 10^{17} cm^{-3} and T-range 10000–12000 K.

Table III. *Same as in Table II but for the shift*

Transition	Lambda (Å)	T (K)	$N(10^{17}\,cm^{-3})$	dm (Å)	dDSB (Å)	dBG (Å)	dB (Å)	Ref.
$3p$–$4s$	3961.52	9 670	1.42	0.14	0.32	0.26	0.23	[1]
		11 700	2.5	0.42	0.57	0.48		[3, 4]
		13 200	1.28	0.31	0.30	0.25		[5]
		13 600	4.5	0.86	1.05	0.88		[6]
	3944.01	9 670	1.42	0.14	0.32	0.26	0.23	[1]
		11 700	2.5	0.42	0.57	0.48		[3, 4]
		13 200	1.28	0.31	0.30	0.25		[5]
		13 600	4.5	0.93	1.05	0.88		[6]
$3p$–$3d$	3082.15	13 200	1.28	0.19	0.26	0.25		[5]
	3092.71	13 200	1.28	0.19	0.26	0.25		[5]

References

1. Bach, T., JQSRT **19**, 483 (1978).
2. Röndigs, G. and Kusch, H. J., Astron. Astrophys. **71**, 44 (1979).
3. Fishman, I. S., Salakhov, M. Kh., Sarandaev, E. V. and Semin, P. S., Opt. Spectr. (USSR) **51**, 435 (1981).
4. Salakhov, M. Kh., Sarandaev, E. V. and Fishman, I. S., Comput. Enhanced Spectr. **1**, 213 (1983).
5. Fleurier, C., Sahal-Bréchot, S. and Chapelle, J., J. Phys. B **10**, 3435 (1977).
6. Fishman, I. S., Semin, P. S. and Desyatnik, G. Ya., Opt. Spectr. (USSR) **47**, 245 (1979).
7. Kondrat'eva, E. V. and Fomichenko, L. I., Opt. Spectr. (USSR) **29**, 434 (1970).
8. Kyukov, V. V., Ilin, G. G. and Fishman, I. S., Opt. Spectr. (USSR) **32**, 585 (1972).
9. Sultanov, M. A. and Ageev, V. A., Dokl. Akad. Nauk Tadzhik, SSR **16**, No. 7, 26 (1973).
10. Wei, P. S. P., Tang, K. T. and Hall, R. B., J. Chem. Phys. **61**, 3593 (1974).
11. Bach, T., Z. Phys. **A285**, 1 (1978).
12. Benett, S. M. and Griem, H. R., "Calculated Stark Broadening Parameters for Isolated Spectral Lines from the Atom Helium through Calcium and Cesium", Univ. Maryland, Tech. Rep. No. 71-097 (College Park, Maryland 1971).
13. Griem, H. R., "Spectral Line Broadening by Plasmas" (Academic Press, New York 1974).
14. Goldberg, L., Muller, E. A. and Aller, L. H., Astrophys. J. Suppl. **5**, 1 (1960).
15. Meril, P. W., "Lines of the Chemical Elements in Astronomical Spectra" (Carnegie Institution of Washington Publ. G10, Washington D.C. 1956).
16. Sahal-Bréchot, S., Astron. Astrophys. **1**, 91 (1969).
17. Sahal-Bréchot, S., Astron. Astrophys. **2**, 322 (1969).
18. Dimitrijević, M. S. and Sahal-Bréchot, S., JQSRT **31**, 301 (1984).
19. Bashkin, S. and Stoner, J. J. Jr., "Atomic Energy Levels and Grotrian Diagrams" (North Holland, Amsterdam 1975), vol. 1.
20. Bates, D. R. and Damgaard, A., Trans. Roy. Soc. London, Ser. **A242**, 101 (1949).
21. Oertel, G. K. and Shomo, L. P., Astrophys. J. Suppl. Series **16**, 175 (1968).
22. Van Regemorter, H., Hoang Binh Dy and Prud'homme, M., J. Phys. **B12**, 1073 (1979).
23. Wiese, W. L., Smith, M. W. and Miles, B. M., "Atomic Transition Probabilities" NSRDS-NBS 22 (U.S. Government Printing Office, Washington 1969), vol. 2.
24. Sahal-Bréchot, S., Astron. Astrophys. **245**, 322 (1991).
25. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **146**, 83 (1992).
26. Griem, H. R. and Shen, C. S., Phys. Rev. **125**, 196 (1962).
27. Roberts, D. E., J. Phys. **B1**, 53 (1968).
28. Dimitrijević, M. S., Feautrier, N. and Sahal-Bréchot, S., J. Phys. **B14**, 2559 (1981).
29. Cooper, J. and Oertel, G. K., Phys. Rev. **180**, 286 (1969).

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Stark Broadening of Rb I Spectral Lines

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Abstract

Using a semiclassical approach, we have calculated electron-, proton-, and ionized-argon-impact line widths and shifts for 24 Rb I multiplets. The resulting data have been compared with existing experimental and theoretical values.

1. Introduction

Neutral Rubidium Stark-broadening parameters are of interest for laboratory plasma spectroscopy and have been investigated several times [1–3]. Moreover, rubidium lines have been observed in Solar and stellar spectra as well [4, 5], and their Stark broadening parameters are consequently of interest also to astrophysicists.

By using the semiclassical-perturbation formalism [6, 7] we have calculated electron-, proton-, and ionized argon-impact line widths and shifts for 24 Rb I multiplets. A summary of the formalism is given in Ref. [8]. Here, we present and discuss the results for Rb I, along with a comparison with experimental data [1, 2] and other theoretical results [1, 3].

2. Results and discussion

Energy levels for Rb I lines have been taken from Ref. [9]. Oscillator strengths have been calculated by using the method of Bates and Damgaard [10, 11]. For higher levels, the method described in Ref. [12] has been used. In addition to electron-impact full halfwidths and shifts, Stark-broadening parameters due to proton- and ionized-argon impacts have been calculated, for astrophysical, and laboratory plasma research respectively. Our results are shown in Table I for a perturber density of $10^{15}\,\mathrm{cm}^{-3}$ and temperatures $T = 2500$–$50\,000$ K. For perturber densities lower than $10^{15}\,\mathrm{cm}^{-3}$, all of the data are practically linear functions of the density because the effect of Debye screening is negligible. We also specify a parameter [8] c which, when it is divided by the corresponding electron-impact full width at half maximum, gives an estimate for the maximum perturber density for which the line may be treated as isolated. For each value given in Table I, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid [6, 7]. Values for $0.1 < NV \leqslant 0.5$ are denoted by an asterisk. When the impact approximation is not valid, the ion-broadening contribution may be estimated by using quasistatic estimations [13, 14]. The accuracy of the results obtained decreases when broadening by ion interactions becomes important. At high densities, the results are no longer linear with density due to Debye screening. This effect is more important for the shift than for the width. Stark-broadening parameter tables for high densities will be published elsewhere [15].

In Tables II and III, the present results with Ar II – impact contribution included, are compared with experimental data [1, 2], with other semiclassical [3], and with semiempirical calculations [1, 2]. In all cases we added to Stark broadening parameters due to electron-impacts, our results for Ar II – impact broadening. One must take into account however, that the collision volume (V) multiplied by the electron density (N) (the condition for validity of the impact approximation [6, 7] $NV \ll 1$) lies between 0.31 and 0.46, which is on the very limit of validity. We see that the agreement between experimental and theoretical values is particularly good for shifts.

In order to see the influence of oscillator strength values on the results, calculations have been repeated with oscillator strengths calculated by using the relativistic single-configuration Hartree–Fock method with allowance for core polarization, which have been taken from Table IV (values denoted as RHF + CP) in Ref. [16], and with oscillator strengths from Ref. [18], where allowance for configuration mixing and for spin–orbit interaction has been made. Different oscillator strengths are compared in Table IV and one can see that the most important difference is for $5p\,^2P^o$–$5d\,^2D$ transition where with the Bates and Damgaard method the value of 0.731 have been obtained while in Refs [16] (Table IV, values under RHF + CP) and [18] we have 0.0396 and 0.0265 respectively. In Ref. [17], several effective single- and multiple-parameter model potentials have been compared, and for the critical $5p$–$5d$ transition the corresponding f-value varies between 0.0396 and 0.0360. In Ref. [17] authors concluded that there is no significant improvement in computed oscillator strengths and sometimes even deterioration of accuracy is observed for more sophisticated calculations.

We can see in Tables II and III, that the best agreement with experimental Stark broadening parameters is for the oscillator strengths obtained within the Coulomb approximation, while in the case of more sophisticated f-values even the sign of shift is different from the experimental one.

Table I. *This table shows electron-, proton-, and Ar II-impact broadening parameters for Rb I lines, for perturber densities of 10^{15} cm^{-3} and temperatures from 2500 to 50 000 K. Transitions and averaged wavelengths for the multiplet (in Å) are also given. By using c (see eq. (5) of Ref. [8]), we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the collision volume (V) multiplied by the perturber density (N) (the condition for validity of the impact approximation [6, 7] is NV ≪ 1) lies between 0.1 and 0.5.*

Perturber density = 1 × 10^{15} cm^{-3}

Perturbers are		Electrons		Protons		Ionized Argon	
Transition	T [K]	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
4D–5P	2500	0.367E − 01	0.123E − 01	0.123E − 01	0.324E − 02	0.121E − 01	0.184E − 02
15156.1 Å	5000	0.403E − 01	0.151E − 01	0.123E − 01	0.366E − 02	0.121E − 01	0.209E − 02
c = 0.10E + 20	10000	0.479E − 01	0.149E − 01	0.124E − 01	0.413E − 02	0.121E − 01	0.237E − 02
	20000	0.616E − 01	0.143E − 01	0.126E − 01	0.465E − 02	0.122E − 01	0.267E − 02
	30000	0.722E − 01	0.123E − 01	0.127E − 01	0.498E − 02	0.122E − 01	0.287E − 02
	50000	0.872E − 01	0.102E − 01	0.128E − 01	0.542E − 02	0.122E − 01	0.313E − 02
4D–6P	2500	0.429	0.285	0.134	0.730E − 01	*0.118	*0.400E − 01
22634.0 Å	5000	0.492	0.343	0.140	0.841E − 01	*0.121	*0.470E − 01
c = 0.99E + 19	10000	0.551	0.360	0.147	0.958E − 01	0.123	0.543E − 01
	20000	0.629	0.345	0.156	0.109	0.126	0.620E − 01
	30000	0.682	0.303	0.162	0.117	0.129	0.668E − 01
	50000	0.768	0.257	0.171	0.128	0.132	0.733E − 01
4D–7P	2500	0.403	0.280	*0.122	*0.668E − 01		
11756.1 Å	5000	0.461	0.334	0.129	0.789E − 01		
c = 0.11E + 19	10000	0.513	0.328	0.137	0.914E − 01	*0.111	*0.508E − 01
	20000	0.573	0.303	0.146	0.105	*0.115	*0.590E − 01
	30000	0.620	0.272	0.152	0.113	*0.117	*0.639E − 01
	50000	0.682	0.219	0.161	0.124	*0.121	*0.705E − 01
4D–8P	2500	0.708	0.484	*0.200	*0.106		
9529.3 Å	5000	0.797	0.560	*0.214	*0.131		
c = 0.39E + 18	10000	0.885	0.563	*0.229	*0.155		
	20000	0.988	0.450	*0.246	*0.179		
	30000	1.07	0.374	0.257	0.194		
	50000	1.16	0.298	0.273	0.214		
5S–5P	2500	0.722E − 02	0.448E − 02	0.325E − 02	0.118E − 02	0.314E − 02	0.667E − 03
7838.7 Å	5000	0.783E − 02	0.535E − 02	0.330E − 02	0.133E − 02	0.316E − 02	0.760E − 03
c = 0.41E + 19	1000	0.877E − 02	0.539E − 02	0.336E − 02	0.150E − 02	0.318E − 02	0.863E − 03
	20000	0.109E − 01	0.463E − 02	0.344E − 02	0.169E − 02	0.320E − 02	0.975E − 03
	30000	0.126E − 01	0.380E − 02	0.349E − 02	0.181E − 02	0.321E − 02	0.104E − 02
	50000	0.154E − 01	0.299E − 02	0.358E − 02	0.198E − 02	0.324E − 02	0.114E − 02
5S–6P	2500	0.141E − 01	0.981E − 02	0.508E − 02	0.255E − 02	*0.458E − 02	*0.140E − 02
4206.4 Å	5000	0.162E − 01	0.115E − 01	0.527E − 02	0.294E − 02	*0.467E − 02	*0.164E − 02
c = 0.34E + 18	10000	0.182E − 01	0.125E − 01	0.550E − 02	0.335E − 02	0.476E − 02	0.190E − 02
	20000	0.206E − 01	0.121E − 01	0.579E − 02	0.380E − 02	0.486E − 02	0.217E − 02
	30000	0.222E − 01	0.106E − 01	0.599E − 02	0.408E − 02	0.492E − 02	0.233E − 02
	50000	0.248E − 01	0.897E − 02	0.626E − 02	0.446E − 02	0.502E − 02	0.256E − 02
5S–7P	2500	0.370E − 01	0.256E − 01	0.117E − 01	*0.624E − 02		
3589.2 Å	5000	0.424E − 01	0.311E − 01	0.123E − 01	0.737E − 02		
c = 0.11E + 18	10000	0.472E − 01	0.307E − 01	0.131E − 01	0.853E − 02	*0.107E − 01	*0.474E − 02
	20000	0.527E − 01	0.281E − 01	0.139E − 01	0.976E − 02	*0.111E − 01	*0.550E − 02
	30000	0.568E − 01	0.242E − 01	0.145E − 01	0.105E − 01	*0.113E − 01	*0.597E − 02
	50000	0.623E − 01	0.205E − 01	0.153E − 01	0.115E − 01	*0.116E − 01	*0.658E − 02
5S–8P	2500	0.870E − 01	0.599E − 01	*0.250E − 01	*0.131E − 01		
3350.2 Å	5000	0.980E − 01	0.693E − 01	*0.267E − 01	*0.161E − 01		
c = 0.48E + 17	10000	0.109	0.698E − 01	*0.285E − 01	*0.191E − 01		
	20000	0.121	0.565E − 01	*0.306E − 01	*0.221E − 01		
	30000	0.131	0.470E − 01	0.320E − 01	0.240E − 01		
	50000	0.142	0.373E − 01	0.339E − 01	0.264E − 01		
5P–6S	2500	0.690E − 01	0.474E − 01	0.162E − 01	0.126E − 01	0.117E − 01	0.703E − 02
13556.7 Å	5000	0.792E − 01	0.566E − 01	0.177E − 01	0.144E − 01	0.124E − 01	0.814E − 02
c = 0.67E + 19	10000	0.889E − 01	0.657E − 01	0.194E − 01	0.163E − 01	0.132E − 01	0.931E − 02
	20000	0.103	0.651E − 01	0.214E − 01	0.185E − 01	0.142E − 01	0.106E − 01
	30000	0.112	0.582E − 01	0.227E − 01	0.198E − 01	0.148E − 01	0.114E − 01
	50000	0.129	0.487E − 01	0.244E − 01	0.216E − 01	0.157E − 01	0.124E − 01

(*continued*)

Table I (*Continued*)

Perturber density = $1 \times 10^{15}\,cm^{-3}$

Perturbers are		Electrons		Protons		Ionized Argon	
Transition	T [K]	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
5P–7S	2500	0.749E − 01	0.533E − 01	0.160E − 01	0.136E − 01	*0.943E − 02	*0.732E − 02
7377.7 Å	5000	0.859E − 01	0.630E − 01	0.179E − 01	0.158E − 01	0.105E − 01	0.876E − 02
c = 0.84E + 18	10000	0.928E − 01	0.685E − 01	0.200E − 01	0.182E − 01	0.117E − 01	0.102E − 01
	20000	0.104	0.673E − 01	0.225E − 01	0.207E − 01	0.131E − 01	0.117E − 01
	30000	0.110	0.597E − 01	0.240E − 01	0.222E − 01	0.140E − 01	0.127E − 01
	50000	0.126	0.505E − 01	0.261E − 01	0.244E − 01	0.152E − 01	0.139E − 01
5P–8S	2500	0.141	0.984E − 01	0.285E − 01	0.231E − 01	*0.165E − 01	*0.118E − 01
6138.9 Å	5000	0.164	0.118	0.320E − 01	0.276E − 01	*0.185E − 01	*0.148E − 01
c = 0.30E + 18	10000	0.171	0.117	0.359E − 01	0.321E − 01	*0.208E − 01	*0.177E − 01
	20000	0.191	0.108	0.403E − 01	0.368E − 01	*0.233E − 01	*0.207E − 01
	30000	0.210	0.943E − 01	0.431E − 01	0.397E − 01	*0.249E − 01	*0.225E − 01
	50000	0.238	0.760E − 01	0.470E − 01	0.436E − 01	*0.272E − 01	*0.248E − 01
5P–5D	2500	0.620E − 01	0.416E − 01	0.179E − 01	0.103E − 01	*0.154E − 01	*0.563E − 02
7724.8 Å	5000	0.694E − 01	0.440E − 01	0.189E − 01	0.119E − 01	*0.158E − 01	*0.665E − 02
c = 0.65E + 18	10000	0.806E − 01	0.420E − 01	0.200E − 01	0.136E − 01	0.163E − 01	0.770E − 02
	20000	0.977E − 01	0.333E − 01	0.213E − 01	0.155E − 01	0.168E − 01	0.881E − 02
	30000	0.109	0.292E − 01	0.222E − 01	0.166E − 01	0.171E − 01	0.950E − 02
	50000	0.121	0.258E − 01	0.235E − 01	0.182E − 01	0.176E − 01	0.104E − 01
5P–6D	2500	0.128	0.868E − 01	*0.361E − 01	*0.197E − 01		
6276.9 Å	5000	0.148	0.902E − 01	0.381E − 01	0.233E − 01		
c = 0.23E + 18	10000	0.175	0.855E − 01	0.404E − 01	0.270E − 01	*0.327E − 01	*0.150E − 01
	20000	0.210	0.664E − 01	0.432E − 01	0.309E − 01	*0.338E − 01	*0.174E − 01
	30000	0.231	0.580E − 01	0.450E − 01	0.334E − 01	*0.346E − 01	*0.189E − 01
	50000	0.252	0.459E − 01	0.476E − 01	0.366E − 01	*0.356E − 01	*0.209E − 01
5D–6P	2500	2.24	−0.380	0.660	−0.205	*0.639	*−0.114
51837.9 Å	5000	3.14	−0.369E − 01	0.668	−0.235	*0.647	*−0.133
c = 0.29E + 20	10000	4.44	0.150	0.677	−0.267	0.651	−0.152
	20000	5.87	0.230	0.690	−0.302	0.654	−0.173
	30000	6.73	0.199	0.698	−0.324	0.656	−0.186
	50000	7.70	0.205	0.712	−0.353	0.660	−0.203
5D–7P	2500	6.10	3.78	1.66	0.902		
46318.6 Å	5000	7.34	4.35	1.75	1.06		
c = 0.18E + 20	10000	8.85	4.42	1.85	1.23	*1.51	*0.683
	20000	10.7	3.70	1.97	1.40	*1.56	*0.792
	30000	11.9	3.19	2.05	1.51	*1.59	*0.857
	50000	13.3	2.81	2.17	1.66	*1.64	*0.944
5D–8P	2500	4.54	3.00	*1.22	*0.662		
24115.6 Å	5000	5.18	3.39	*1.31	*0.812		
c = 0.25E + 19	10000	5.92	3.39	*1.40	*0.960		
	20000	6.81	2.63	*1.51	*1.11		
	30000	7.47	2.13	1.58	1.20		
	50000	8.12	1.75	1.68	1.33	*1.21	*0.751
6S–6P	2500	0.527	0.313	0.203	0.813E − 01	*0.192	*0.449E − 01
27474.6 Å	5000	0.604	0.330	0.208	0.933E − 01	*0.195	*0.524E − 01
c = 0.15E + 20	10000	0.751	0.311	0.213	0.106	0.197	0.603E − 01
	20000	0.969	0.224	0.220	0.120	0.199	0.687E − 01
	30000	1.13	0.190	0.225	0.129	0.200	0.739E − 01
	50000	1.33	0.171	0.232	0.141	0.202	0.811E − 01
6S–7P	2500	0.477	0.328	*0.150	*0.783E − 01		
12940.3 Å	5000	0.546	0.379	0.158	0.925E − 01		
c = 0.14E + 19	10000	0.619	0.384	0.167	0.107	*0.138	*0.595E − 01
	20000	0.707	0.309	0.177	0.122	*0.142	*0.691E − 01
	30000	0.782	0.273	0.184	0.132	*0.145	*0.749E − 01
	50000	0.872	0.228	0.194	0.145	*0.149	*0.825E − 01
6S–8P	2500	0.821	0.564	*0.235	*0.123		
10292.8 Å	5000	0.926	0.636	*0.251	*0.151		
c = 0.46E + 18	10000	1.04	0.637	*0.268	*0.179		
	20000	1.17	0.499	*0.287	*0.207		
	30000	1.27	0.407	0.300	0.225		
	50000	1.38	0.331	0.319	0.247		

(*continued*)

Table I (*Continued*)

Perturber density = $1 \times 10^{15}\,cm^{-3}$

Perturbers are		Electrons		Protons		Ionized Argon	
Transition	T [K]	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
6*P*–7*S*	2500	1.84	1.15	0.482	0.280	*0.412	*0.152
39398.9 Å	5000	2.21	1.30	0.508	0.324	*0.424	*0.180
$c = 0.24E + 20$	10000	2.82	1.31	0.539	0.370	0.436	0.209
	20000	3.67	1.06	0.576	0.420	0.450	0.239
	30000	4.31	0.937	0.601	0.452	0.460	0.258
	50000	5.05	0.854	0.635	0.494	0.474	0.283
6*P*–8*S*	2500	1.28	0.882	0.266	0.208	*0.166	*0.106
18962.7 Å	5000	1.44	1.04	0.296	0.247	*0.183	*0.133
$c = 0.29E + 19$	10000	1.69	1.04	0.330	0.287	*0.202	*0.159
	20000	1.99	0.858	0.368	0.329	*0.223	*0.185
	30000	2.28	0.725	0.393	0.355	*0.236	*0.201
	50000	2.62	0.645	0.427	0.389	0.255	0.222
6*P*–6*D*	2500	1.26	0.788	0.339	0.190		
20344.9 Å	5000	1.51	0.757	0.358	0.224		
$c = 0.24E + 19$	10000	1.86	0.639	0.381	0.259	*0.306	*0.144
	20000	2.38	0.480	0.407	0.296	*0.316	*0.167
	30000	2.67	0.434	0.425	0.319	*0.324	*0.181
	50000	2.93	0.321	0.451	0.350	*0.334	*0.200
7*S*–7*P*	2500	10.5	6.50	3.47	1.53		
64519.9 Å	5000	12.6	6.13	3.59	1.79		
$c = 0.34E + 20$	10000	15.9	5.44	3.73	2.07	*3.31	*1.16
	20000	20.8	4.30	3.89	2.36	*3.37	*1.34
	30000	23.9	3.75	4.01	2.54	*3.41	*1.45
	50000	27.1	3.10	4.17	2.79	*3.46	*1.59
7*S*–8*P*	2500	6.08	4.16	*1.73	*0.890		
28267.4 Å	5000	6.89	4.26	*1.85	*1.09		
$c = 0.35E + 19$	10000	7.98	4.09	*1.97	*1.29		
	20000	9.41	3.08	*2.10	*1.49		
	30000	10.5	2.39	2.19	1.61		
	50000	11.5	1.98	2.32	1.78		

Table II. *Comparison between the experimental Stark full half-widths of Rb I lines (Wm – Purić et al. (1977) [2]) within the $5s^2S$–$5p^2P^o$ multiplet with different calculations. Semi-classical calculations: WDSB-present results; WDK – Dimitrijević and Konjević (1983) [3] (by using the semiclassical theory of Griem (1974) [13]). Semiempirical calculations: WSE – Purić et al. (1977) [2] (by using Griem's semiempirical method [19]). The electron density N is equal to $10^{17}\,cm^{-3}$.*

λ (Å)	T (K)	*Wm* (Å)	*Wm*/WDSB	*Wm*/WDK	*Wm*/WSE
7800.2	15000	1.66	1.31	1.60	1.91
	17500	1.70	1.35	1.68	1.97
	20800	1.76	1.42	1.77	2.08
	26000	1.92	1.51	1.88	2.16
7947.6	15000	1.82	1.31	1.60	1.91
	17500	1.92	1.35	1.68	1.97
	20800	2.00	1.42	1.77	2.08
	26000	2.20	1.51	1.88	2.16

Table III. *As in Table II but for the shift (d)*

λ (Å)	T (K)	*dm* (Å)	*dm*/dDSB	*dm*/dDK
7800.2	15000	0.52	0.59	0.48
	17500	0.50	0.57	0.48
	20800	0.47	0.54	0.48
	26000	0.51	0.50	0.47
7947.6	15000	0.55	0.59	0.48
	17500	0.53	0.57	0.48
	20800	0.50	0.54	0.48
	26000	0.45	0.50	0.47

This may be a consequence of the fact that within the Coulomb approximation we have a summation over the complete and consistent set of atomic data. In the case of more sophisticated calculations, there is no *f*-data for, e.g. transitions from important 4*d* levels and missing *f*-values calculated here within the Coulomb approximation are not consistent with the rest of the *f*-value set.

Table IV. *Comparison between different oscillator strengths for Rb I: fC – present calculations by using Bates and Damgaard method [10]; fMBA – values under A in Table II of Migdalek and Banasinska (1992) [17]; fMBE – values under E in Table II of Migdalek and Banasinska (1992) [17]; fMB1 – derived from RHF + CP values in Table IV of Migdalek and Baylis (1979) [16]; fMB2 – derived from RHF values in Table IV of Migdalek and Baylis (1979) [16]; fW – Warner (1968) [18]*

Transition	*fC*	*fMBA*	*fMBE*	*fMB1*	*fMB2*	*fW*
5*p*–6*s*	0.181	0.204	0.193	0.203	0.212	0.300
5*p*–7*s*	0.0172	0.0216	0.0191	0.0191	0.0199	0.0270
5*p*–8*s*	0.00597	0.00735	0.0065	0.00636	0.00651	0.00872
5*s*–5*p*	1.014	1.10	0.987	1.02	1.33	1.03
5*s*–6*p*	0.0212	0.0132	0.00663	0.0125	0.01934	0.0260
5*s*–7*p*	0.00383	0.00193	0.000468	0.00174	0.00344	0.00614
5*p*–5*d*	0.732	0.0526	0.360	0.0396	0.00323	0.0265
5*p*–6*d*	0.0310	0.0328	0.0284	0.0302	0.0874	0.0212
5*p*–7*d*	0.0254	0.0187	0.0171	0.0179	0.00677	0.0126
5*p*–8*d*	0.0155	0.0114	0.0107	0.0111	0.00472	0.00782

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References

1. Lakićević, I., Purić, J. and Labat, J., Proc. of the XIII Int. Conf. Phen. Ioniz. Gases, Part I, Physical Society of GDR, Berlin (1977), p. 123.
2. Purić, J., Labat, J., Ćirković, Lj., Lakićević, I and Djeniže, S., J. Phys. **B10**, 2375 (1977).
3. Dimitrijević, M. S. and Konjević, N., J. Quant. Spectr. Radiat. Transfer **30**, 45 (1983).
4. Merrill, P. W., "Lines of the Chemical Elements in Astronomical Spectra" (Carnegie Institution of Washington Publ. 610, Washington D.C. 1956).
5. Davis, D. N., Astrophys, J. **106**, 28 (1947).
6. Sahal-Bréchot, S., Astron. Astrophys. **1**, 91 (1969).
7. Sahal-Bréchot, S., Astron. Astrophys. **2**, 322 (1969).
8. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectr. Radiat. Transfer **31**, 301 (1984).
9. Moore, C., "Atomic Energy Levels III, NSRDS-NBS 35" (U.S. Govt. Printing Office, Washington D.C. 1971).
10. Bates, D. R. and Damgaard, A., Trans. Roy. Soc. London, Ser. **A242**, 101 (1949).
11. Oertel, G. K. and Shomo, L. P., Astrophys. J. Suppl. Series **16**, 175 (1968).
12. Van Regemorter, H., Hoang Binh Dy and Prud'homme, M., J. Phys. **B12**, 1073 (1979).
13. Griem, H. R., "Spectral Line Broadening by Plasmas" (Academic Press, New York 1974).
14. Sahal-Bréchot, S., Astron. Astrophys. **245**, 322 (1991).
15. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Astron. Belgrade **146**, 97 (1992).
16. Migdalek, J. and Baylis, W. E., Can. J. Phys. **57**, 1708 (1979).
17. Migdalek, J. and Banasinska, E., J. Quant. Spectr. Radiat. Transfer **48**, 347 (1992).
18. Warner, B., Mon. Not. R. Astr. Soc. **139**, 115 (1968).
19. Griem, H. R., Phys. Rev. **165**, 268 (1968).

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Stark Broadening of Mg I Spectral Lines

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Abstract

Using a semiclassical approach, we have calculated electron-, proton- and ionized argon-impact line widths and shifts for 99 Mg I multiplets. The resulting data have been compared with existing experimental and theoretical values.

1. Introduction

Stark-broadening parameters for neutral magnesium lines are of interest for laboratory plasma diagnostics and have been investigated expermentally [1–3] and theoretically [4–9]. Moreover, lines of neutral magnesium are present in the solar spectrum and the corresponding Stark broadening parameters are of interest for their analysis as well as for diagnostics of solar plasma. Especially the infrared lines of Mg I have been observed in the solar spectrum at Kitt Peak and during the Atmos experiment on Spacelab [10–12]. Due to the fact that with the increase of the principal quantum number the importance of the Stark broadening increases as well, the corresponding Stark widths and shifts are of importance for the structure of solar atmosphere diagnostics.

By using the semiclassical-perturbation formalism [13, 14], we have calculated electron-, proton- and ionized argon-impact line widths and shifts for 99 Mg I multiplets. A summary of the formalism is given in Ref. [15]. Here, we present and discuss the results for Mg I, along with a comparison with experimental data [1–3] and other theoretical results [4, 7].

2. Results and discussion

Energy levels for Mg I lines have been taken from Ref. [16]. Oscillator strengths have been calculated by using the method of Bates and Damgaard [17, 18]. For higher levels, the method described in Ref. [19] has been used. In addition to electron-impact full halfwidths and shifts, Stark-broadening parameters due to proton- and ionized-argon impacts have been calculated. Our results are shown in Table I for a perturber density of $10^{15}\,\mathrm{cm}^{-3}$ and temperatures $T = 2500$–$50\,000$ K. We also specify a parameter c [15, 20] which, when it is divided by the corresponding electron-impact full width at half maximum, gives an estimate for the maximum perturber density for which the line may be treated as isolated. For each value given in Table I, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid [13, 14]. Values for $0.1 < NV \leqslant 0.5$ are denoted by an asterisk. When the impact approximation is not valid, the ion-broadening contribution may be estimated by using quasistatic estimations [7, 21]. The accuracy of the results obtained decreases when broadening by ion interactions becomes important. At high densities, the results are no longer linear with density due to Debye screening. This effect is more important for the shift than for the width. Stark-broadening parameter tables for high densities will be published elsewhere [22].

In Table II, the present results are compared with experimental data [1–3] and with semiclassical calculations of Benett and Griem [7, 8]. According to our checks, the impact approximation is not applicable for ion broadening contributions, for the experimental plasma conditions in Table II. Consequently, in all cases the quasistatic ion broadening contribution has been included by using the quasistatic ion broadening parameter given in Ref. [7]. One can see that the present calculations are in better agreement with experimental widths, while shift calculations have a mutual agreement but large differences with experimental shifts. We have also calculated the Stark broadening parameters of the lines of Table II by using the sophisticated *ab initio* line strengths from the TOP base (the complete package of the Opacity Project (OP) data with the database management system is usually referred to as TOP base) [23, 24], and the measured energy levels of [16] when they exist. Comparison with experiments show that the improvement is only significant for the resonance line ($3s$–$3p$, 2852.13 Å). For transitions between excited levels the use of Bates and Damgaard and OP line strengths lead to the same widths. This is expected because interaction configuration effects are principally important for the lowest levels. For the shift there is no real improvement when OP line strengths are used and the disagreement remains for the $3p$–$5d$ line (4702.99 Å). For Mg I $3s^2\,{}^1S$–$3p\,{}^1P^o$, exist as well the Model Microfield Method (MMM) semiclassical results [4]. The ratio of experimental and MMM widths is 0.68 at $T = 12\,970$ K and 0.76 at 13 370 K. New high precision measurements for different temperatures and other Mg I lines are needed for checking and improving the semiclassical theoretical approach.

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Table I. *This table shows electron-, proton- and ionized argon-impact broadening parameters for Mg I for a perturber density of 10^{15} cm^{-3} and temperatures from 2500 up to 50 000 K. Transitions and averaged wavelengths for the multiplet (in Å) are also given. If one divides the c value with the linewidth value, one obtains an estimate for the maximum perturber density (in cm^{-3}) for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the collision volume multiplied by the perturber density (the condition for validity of the impact approximation) lies between 0.1 and 0.5*

Perturber density = 1 × 10^{+15} cm^{-3}							
Perturbers are:		Electrons		Protons		Ionized argon	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
3*s*–3*p*	2500	0.537E−03	0.406E−03	0.257E−03	0.114E−03	0.245E−03	0.712E−04
2853.0 A	5000	0.630E−03	0.473E−03	0.263E−03	0.129E−03	0.247E−03	0.809E−04
c = 0.69E + 18	10000	0.718E−03	0.549E−03	0.271E−03	0.145E−03	0.249E−03	0.916E−04
	20000	0.804E−03	0.588E−03	0.281E−03	0.163E−03	0.253E−03	0.103E−03
	30000	0.876E−03	0.604E−03	0.288E−03	0.175E−03	0.256E−03	0.111E−03
	50000	0.974E−03	0.525E−03	0.298E−03	0.191E−03	0.259E−03	0.121E−03
3*s*–4*p*	2500	0.163E−02	0.909E−03	0.687E−03	0.246E−03	0.664E−03	0.152E−03
2026.5 A	5000	0.185E−02	0.108E−02	0.698E−03	0.280E−03	0.670E−03	0.175E−03
c = 0.12E + 18	10000	0.211E−02	0.121E−02	0.711E−03	0.318E−03	0.675E−03	0.199E−03
	20000	0.245E−02	0.127E−02	0.729E−03	0.360E−03	0.681E−03	0.226E−03
	30000	0.268E−02	0.118E−02	0.741E−03	0.385E−03	0.685E−03	0.243E−03
	50000	0.301E−02	0.102E−02	0.761E−03	0.420E−03	0.692E−03	0.265E−03
3*s*–5*p*	2500	0.436E−02	0.258E−02	0,185E−02	0.656E−03	*0.176E−02	*0.396E−03
1827.9 A	5000	0.510E−02	0.301E−02	0.188E−02	0.759E−03	*0.179E−02	*0.467E−03
c = 0.49E + 17	10000	0.602E−02	0.333E−02	0.192E−02	0.869E−03	*0.181E−02	*0.540E−03
	20000	0.723E−02	0.304E−02	0.197E−02	0.987E−03	0.183E−02	0.618E−03
	30000	0.806E−02	0.278E−02	0.201E−02	0.106E−02	0.185E−02	0.666E−03
	50000	0.914E−02	0.232E−02	0.206E−02	0.116E−02	0.187E−02	0.730E−03
3*s*–6*p*	2500	0.107E−01	0.644E−02	*0.423E−02	*0.155E−02		
1747.8 A	5000	0.127E−01	0.739E−02	*0.436E−02	*0.184E−02		
c = 0.24E + 17	10000	0.152E−01	0.752E−02	0.448E−02	0.213E−02		
	20000	0.185E−01	0.673E−02	0.462E−02	0.244E−02	*0.423E−02	*0.151E−02
	30000	0.208E−01	0.580E−02	0.472E−02	0.263E−02	*0.427E−02	*0.164E−02
	50000	0.233E−01	0.477E−02	0.486E−02	0.288E−02	*0.432E−02	*0.181E−02
3*s*–7*p*	2500	0.235E−01	0.140E−01				
1707.1 A	5000	0.279E−01	0.159E−01	*0.885E−02	*0.384E−02		
c = 0.13E + 17	10000	0.339E−01	0.152E−01	*0.917E−02	*0.453E−02		
	20000	0.416E−01	0.127E−01	*0.952E−02	*0.524E−02		
	30000	0.464E−01	0.108E−01	*0.975E−02	*0.567E−02		
	50000	0.516E−01	0.865E−02	0.101E−01	0.624E−02		
3*s*–8*p*	2500	0.463E−01	0.271E−01				
1683.4 A	5000	0.554E−01	0.294E−01				
c = 0.81E + 16	10000	0.677E−01	0.277E−01				
	20000	0.835E−01	0.215E−01	*0.178E−01	*0.100E−01		
	30000	0.928E−01	0.180E−01	*0.183E−01	*0.109E−01		
	50000	0.102	0.141E−01	*0.190E−01	*0.121E−01		
3*s*–9*p*	2500	0.839E−01	0.488E−01				
1668.4 A	5000	0.101	0.495E−01				
c = 0.53E + 16	10000	0.124	0.446E−01				
	20000	0.154	0.334E−01				
	30000	0.170	0.277E−01				
	50000	0.184	0.206E−01				
4*s*–4*p*	2500	0.111	0.443E−01	0.477E−01	0.116E−01	0.470E−01	0.719E−02
17112.5 A	5000	0.123	0.491E−01	0.480E−01	0.132E−01	0.473E−01	0.823E−02
c = 0.86E + 19	10000	0.148	0.491E−01	0.483E−01	0.149E−01	0.474E−01	0.936E−02
	20000	0.191	0.374E−01	0.487E−01	0.168E−01	0.476E−01	0.106E−01
	30000	0.225	0.311E−01	0.491E−01	0.180E−01	0.477E−01	0.114E−01
	50000	0.270	0.273E−01	0.496E−01	0.197E−01	0.478E−01	0.124E−01
4*s*–5*p*	2500	0.105	0.597E−01	0.438E−01	0.149E−01	*0.418E−01	*0.899E−02
8925.8 A	5000	0.122	0.707E−01	0.445E−01	0.172E−01	*0.427E−01	*0.106E−01
c = 0.12E + 19	10000	0.146	0.717E−01	0.454E−01	0.197E−01	*0.431E−01	*0.122E−01
	20000	0.179	0.615E−01	0.465E−01	0.223E−01	0.435E−01	0.140E−01
	30000	0.203	0.527E−01	0.472E−01	0.240E−01	0.438E−01	0.151E−01
	50000	0.234	0.456E−01	0.483E−01	0.263E−01	0.442E−01	0.165E−01

Table I (*Continued*)

Perturber density = $1 \times 10^{+15}$ cm^{-3} Perturbers are:		Electrons		Protons		Ionized argon	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
4*s*–6*p*	2500	0.188	0.111	*0.736E−01	*0.268E−01		
7292.9 A	5000	0.222	0.126	*0.757E−01	*0.317E−01		
c = 0.42E + 18	10000	0.268	0.132	0.777E−01	0.367E−01		
	20000	0.328	0.110	0.802E−01	0.420E−01	*0.735E−01	*0.261E−01
	30000	0.369	0.927E−01	0.818E−01	0.453E−01	*0.742E−01	*0.283E−01
	50000	0.417	0.791E−01	0.843E−01	0.497E−01	*0.751E−01	*0.311E−01
4*s*–7*p*	2500	0.356	0.213				
6632.5 A	5000	0.423	0.246	*0.134	*0.578E−01		
c = 0.20E + 18	10000	0.514	0.226	*0.138	*0.681E−01		
	20000	0.632	0.184	*0.144	*0.788E−01		
	30000	0.708	0.156	*0.147	*0.853E−01		
	50000	0.788	0.120	0.152	0.939E−01		
4*s*–8*p*	2500	0.648	0.376				
6289.3 A	5000	0.776	0.409				
c = 0.11E + 18	10000	0.947	0.391				
	20000	1.17	0.295	*0.248	*0.140		
	30000	1.30	0.238	*0.255	*0.152		
	50000	1.43	0.180	*0.265	*0.168		
4*s*–9*p*	2500	1.12	0.640				
6085.1 A	5000	1.35	0.659				
c = 0.71E + 17	10000	1.66	0.605				
	20000	2.05	0.441				
	30000	2.26	0.349				
	50000	2.46	0.256				
5*s*–5*p*	2500	2.42	0.695	1.15	0.195	*1.12	*0.120
46508.0 A	5000	3.08	0.547	1.16	0.224	*1.14	*0.139
c = 0.32E + 20	10000	4.25	0.365	1.16	0.254	*1.15	*0.159
	20000	5.91	0.283	1.16	0.288	1.15	0.181
	30000	6.96	0.241	1.17	0.309	1.16	0.195
	50000	8.23	0.191	1.17	0.337	1.16	0.213
5*s*–6*p*	2500	1.59	0.930	*0.630	*0.211		
21465.6 A	5000	1.90	0.953	*0.645	*0.249		
c = 0.37E + 19	10000	2.39	0.895	0.660	0.288		
	20000	3.06	0.705	0.677	0.329	*0.631	*0.205
	30000	3.51	0.608	0.688	0.355	*0.635	*0.222
	50000	4.02	0.531	0.706	0.389	*0.642	*0.244
5*s*–7*p*	2500	2.22	1.28				
16600.7 A	5000	2.66	1.40	*0.832	*0.353		
c = 0.13E + 19	10000	3.28	1.33	*0.860	*0.416		
	20000	4.10	0.995	*0.891	*0.481		
	30000	4.63	0.807	*0.912	*0.520		
	50000	5.18	0.660	0.943	0.573		
5*s*–8*p*	2500	3.50	2.00				
14605.5 A	5000	4.20	2.12				
c = 0.61E + 18	10000	5.17	1.95				
	20000	6.43	1.35	*1.33	*0.748		
	30000	7.17	1.09	*1.37	*0.814		
	50000	7.90	0.759	*1.42	*0.900		
5*s*–9*p*	2500	5.55	3.20				
13549.7 A	5000	6.71	3.19				
c = 0.35E + 18	10000	8.28	2.81				
	20000	10.3	1.83				
	30000	11.4	1.50				
	50000	12.4	0.897				
3*p*–4*s*	2500	0.253E−01	0.159E−01	0.598E−02	0.430E−02	0.482E−02	0.268E−02
11832.0 A	5000	0.281E−01	0.192E−01	0.643E−02	0.488E−02	0.504E−02	0.306E−02
c = 0.82E + 19	10000	0.306E−01	0.212E−01	0.696E−02	0.553E−02	0.530E−02	0.347E−02
	20000	0.364E−01	0.213E−01	0.757E−02	0.622E−02	0.562E−02	0.393E−02
	30000	0.403E−01	0.187E−01	0.798E−02	0.667E−02	0.583E−02	0.421E−02
	50000	0.485E−01	0.156E−01	0.854E−02	0.727E−02	0.614E−02	0.460E−02

Table I (*Continued*)

Perturber density = $1 \times 10^{+15}$ cm^{-3}

Perturbers are:		Electrons		Protons		Ionized argon	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
3*p*–5*s*	2500	0.269E−01	0.193E−01	0.575E−02	0.502E−02	0.370E−02	0.305E−02
5712.7 A	5000	0.311E−01	0.231E−01	0.644E−02	0.579E−02	0.413E−02	0.357E−02
c = 0.70E + 18	10000	0.339E−01	0.254E−01	0.722E−02	0.661E−02	0.462E−02	0.412E−02
	20000	0.381E−01	0.252E−01	0.809E−02	0.749E−02	0.516E−02	0.470E−02
	30000	0.401E−01	0.225E−01	0.865E−02	0.806E−02	0.552E−02	0.506E−02
	50000	0.456E−01	0.186E−01	0.941E−02	0.880E−02	0.600E−02	0.555E−02
3*p*–6*s*	2500	0.555E−01	0.404E−01	0.116E−01	0.970E−02	*0.736E−02	*0.568E−02
4731.4 A	5000	0.636E−01	0.460E−01	0.130E−01	0.114E−01	*0.826E−02	*0.690E−02
c = 0.23E + 18	10000	0.695E−01	0.487E−01	0.146E−01	0.132E−01	0.927E−02	0.812E−02
	20000	0.782E−01	0.463E−01	0.164E−01	0.151E−01	0.104E−01	0.938E−02
	30000	0.848E−01	0.405E−01	0.176E−01	0.162E−01	0.111E−01	0.102E−01
	50000	0.964E−01	0.338E−01	0.191E−01	0.178E−01	0.121E−01	0.112E−01
3*p*–7*s*	2500	0.115	0.794E−01	*0.231E−01	*0.180E−01		
4355.8 A	5000	0.131	0.931E−01	*0.259E−01	*0.218E−01	*0.164E−01	*0.128E−01
c = 0.11E + 18	10000	0.142	0.906E−01	0.291E−01	0.256E−01	*0.184E−01	*0.155E−01
	20000	0.162	0.797E−01	0.327E−01	0.296E−01	*0.207E−01	*0.182E−01
	30000	0.181	0.666E−01	0.350E−01	0.320E−01	*0.221E−01	*0.198E−01
	50000	0.204	0.534E−01	0.381E−01	0.352E−01	*0.241E−01	*0.220E−01
3*p*–8*s*	2500	0.215	0.145	*0.429E−01	*0.303E−01		
4166.3 A	5000	0.240	0.164	*0.482E−01	*0.383E−01		
c = 0.61E + 17	10000	0.279	0.163	*0.541E−01	*0.461E−01		
	20000	0.320	0.125	*0.607E−01	*0.539E−01		
	30000	0.359	0.103	*0.650E−01	*0.585E−01		
	50000	0.402	0.800E−01	*0.708E−01	*0.647E−01	*0.448E−01	*0.401E−01
3*p*–9*s*	2500	0.398	0.254				
4055.8 A	5000	0.422	0.269				
c = 0.38E + 17	10000	0.492	0.258				
	20000	0.593	0.188	*0.106	*0.914E−01		
	30000	0.671	0.152	*0.113	*0.100		
	50000	0.726	0.114	*0.123	*0.111		
4*p*–5*s*	2500	0.829	0.525	0.203	0.129	0.172	0.783E−01
31155.6 A	5000	0.948	0.610	0.216	0.148	0.178	0.915E−01
c = 0.21E + 20	10000	1.11	0.627	0.231	0.169	0.185	0.105
	20000	1.36	0.540	0.249	0.191	0.193	0.120
	30000	1.57	0.463	0.260	0.206	0.199	0.129
	50000	1.87	0.406	0.277	0.224	0.208	0.142
4*p*–6*s*	2500	0.542	0.375	0.112	0.903E−01	*0.745E−01	*0.529E−01
14619.5 A	5000	0.619	0.446	0.125	0.106	*0.823E−01	*0.642E−01
c = 0.22E + 19	10000	0.690	0.456	0.139	0.123	0.911E−01	0.755E−01
	20000	0.793	0.394	0.155	0.140	0.101	0.872E−01
	30000	0.894	0.350	0.166	0.151	0.108	0.943E−01
	50000	1.03	0.291	0.180	0.166	0.116	0.104
4*p*–7*s*	2500	0.808	0.555	*0.162	*0.125		
11543.6 A	5000	0.911	0.644	*0.182	*0.152	*0.116	*0.893E−01
c = 0.76E + 18	10000	1.02	0.651	0.204	0.179	*0.130	*0.108
	20000	1.18	0.522	0.229	0.206	*0.146	*0.127
	30000	1.33	0.449	0.245	0.223	*0.156	*0.138
	50000	1.50	0.347	0.266	0.245	*0.169	*0.153
4*p*–8*s*	2500	1.31	0.888	*0.262	*0.185		
10302.0 A	5000	1.47	0.993	*0.294	*0.234		
c = 0.37E + 18	10000	1.71	0.977	*0.330	*0.281		
	20000	1.99	0.733	*0.371	*0.328		
	30000	2.24	0.582	*0.397	*0.357		
	50000	2.51	0.461	*0.432	*0.395	*0.274	*0.245
4*p*–9*s*	2500	2.26	1.44				
9652.1 A	5000	2.40	1.51				
c = 0.21E + 18	10000	2.79	1.43				
	20000	3.40	1.03	*0.598	*0.517		
	30000	3.80	0.789	*0.640	*0.566		
	50000	4.16	0.601	*0.697	*0.629		

Table I (*Continued*)

Perturber density = $1 \times 10^{+15}$ cm^{-3} Perturbers are:		Electrons		Protons		Ionized argon	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
5*p*–7*s*	2500	5.50	3.76	*1.14	*0.828		
30276.2 A	5000	6.26	4.04	*1.26	*1.00		
c = 0.52E + 19	10000	7.50	4.07	1.40	1.18	*0.948	*0.712
	20000	9.15	3.20	1.56	1.36	*1.04	*0.836
	30000	10.5	2.59	1.66	1.47	*1.10	*0.910
	50000	12.0	2.27	1.80	1.61	*1.19	*1.01
5*p*–8*s*	2500	6.55	4.31	*1.31	*0.911		
23004.5 A	5000	7.36	4.80	*1.46	*1.15		
c = 0.19E + 19	10000	8.64	4.56	*1.64	*1.38		
	20000	10.6	3.31	*1.83	*1.61		
	30000	12.0	2.60	*1.96	*1.75		
	50000	13.4	1.98	*2.13	*1.94	*1.36	*1.20
5*p*–9*s*	2500	9.20	6.03				
19997.7 A	5000	10.4	6.30				
c = 0.92E + 18	10000	12.1	5.77				
	20000	15.1	3.79	*2.56	*2.21		
	30000	16.9	3.07	*2.74	*2.41		
	50000	18.6	1.95	*2.98	*2.68		
3*p*–3*d*	2500	0.105E−01	0.607E−02	0.511E−02	0.161E−02	0.500E−02	0.101E−02
8809.2 A	5000	0.118E−01	0.594E−02	0.516E−02	0.183E−02	0.502E−02	0.115E−02
c = 0.23E + 19	10000	0.141E−01	0.501E−02	0.523E−02	0.206E−02	0.505E−02	0.130E−02
	20000	0.178E−01	0.330E−02	0.532E−02	0.232E−02	0.507E−02	0.147E−02
	30000	0.206E−01	0.264E−02	0.539E−02	0.249E−02	0.509E−02	0.157E−02
	50000	0.240E−01	0.192E−02	0.550E−02	0.272E−02	0.513E−02	0.172E−02
3*p*–4*d*	2500	0.302E−01	0.217E−01	0.925E−02	0.557E−02	*0.794E−02	*0.337E−02
5530.0 A	5000	0.346E−01	0.265E−01	0.978E−02	0.644E−02	0.821E−02	0.396E−02
c = 0.47E + 18	10000	0.382E−01	0.261E−01	0.104E−01	0.736E−02	0.850E−02	0.458E−02
	20000	0.424E−01	0.243E−01	0.112E−01	0.835E−02	0.886E−02	0.523E−02
	30000	0.455E−01	0.207E−01	0.117E−01	0.899E−02	0.910E−02	0.564E−02
	50000	0.504E−01	0.175E−01	0.124E−01	0.983E−02	0.945E−02	0.618E−02
3*p*–5*d*	2500	0.617E−01	0.439E−01	0.186E−01	0.105E−01		
4704.3 A	5000	0.707E−01	0.522E−01	0.197E−01	0.124E−01	*0.165E−01	*0.747E−02
c = 0.20E + 18	10000	0.789E−01	0.511E−01	0.209E−01	0.143E−01	*0.172E−01	*0.882E−02
	20000	0.885E−01	0.470E−01	0.224E−01	0.164E−01	*0.179E−01	*0.102E−01
	30000	0.964E−01	0.399E−01	0.235E−01	0.177E−01	*0.184E−01	*0.110E−01
	50000	0.107	0.338E−01	0.249E−01	0.194E−01	0.191E−01	0.122E−01
3*p*–6*d*	2500	0.115	0.780E−01	*0.348E−01	*0.176E−01		
4353.1 A	5000	0.132	0.902E−01	*0.369E−01	*0.214E−01		
c = 0.10E + 18	10000	0.152	0.909E−01	*0.391E−01	*0.251E−01		
	20000	0.178	0.741E−01	0.416E−01	0.289E−01		
	30000	0.197	0.623E−01	0.434E−01	0.313E−01	*0.347E−01	*0.194E−01
	50000	0.217	0.508E−01	0.460E−01	0.344E−01	*0.359E−01	*0.215E−01
3*p*–7*d*	2500	0.200	0.125				
4168.5 A	5000	0.234	0.140				
c = 0.62E + 17	10000	0.280	0.136	*0.675E−01	*0.399E−01		
	20000	0.341	0.104	*0.714E−01	*0.465E−01		
	30000	0.379	0.852E−01	*0.741E−01	*0.505E−01		
	50000	0.417	0.670E−01	*0.778E−01	*0.557E−01		
3*p*–8*d*	2500	0.328	0.185				
4058.7 A	5000	0.399	0.198				
c = 0.40E + 17	10000	0.496	0.185				
	20000	0.619	0.137	*0.115	*0.689E−01		
	30000	0.687	0.108	*0.119	*0.751E−01		
	50000	0.752	0.832E−01	*0.124	*0.832E−01		
3*p*–9*d*	2500	0.518	0.252				
3987.9 A	5000	0.657	0.261				
c = 0.28E + 17	10000	0.846	0.234				
	20000	1.07	0.171				
	30000	1.18	0.131				
	50000	1.28	0.990E−01				

Table I (*Continued*)

Perturber density = $1 \times 10^{+15}$ cm^{-3} Perturbers are:		Electrons		Protons		Ionized argon	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
4*p*–4*d*	2500	0.714	0.449	0.236	0.114	*0.217	*0.688E−01
26398.9 A	5000	0.812	0.505	0.244	0.131	*0.221	*0.808E−01
c = 0.11E + 20	10000	0.959	0.501	0.254	0.150	0.225	0.932E−01
	20000	1.15	0.382	0.266	0.170	0.230	0.106
	30000	1.30	0.330	0.275	0.183	0.234	0.115
	50000	1.49	0.290	0.287	0.199	0.239	0.126
4*p*–5*d*	2500	0.588	0.400	*0.177	*0.958E−01		
14364.2 A	5000	0.673	0.467	0.187	0.113	*0.160	*0.682E−01
c = 0.18E + 19	10000	0.764	0.476	0.198	0.131	*0.165	*0.804E−01
	20000	0.877	0.389	0.211	0.149	*0.171	*0.929E−01
	30000	0.972	0.345	0.220	0.161	*0.175	*0.101
	50000	1.09	0.277	0.233	0.177	0.181	0.111
4*p*–6*d*	2500	0.818	0.541	*0.246	*0.123		
11525.3 A	5000	0.940	0.618	*0.260	*0.149		
c = 0.73E + 18	10000	1.09	0.621	*0.275	*0.174		
	20000	1.28	0.484	0.293	0.201		
	30000	1.43	0.415	0.305	0.218	*0.246	*0.135
	50000	1.58	0.331	0.323	0.239	*0.254	*0.149
4*p*–7*d*	2500	1.23	0.788				
10315.2 A	5000	1.45	0.841				
c = 0.38E + 18	10000	1.73	0.814	*0.414	*0.244		
	20000	2.12	0.605	*0.438	*0.284		
	30000	2.36	0.486	*0.455	*0.308		
	50000	2.60	0.382	*0.477	*0.340		
4*p*–8*d*	2500	1.87	1.05				
9668.0 A	5000	2.27	1.11				
c = 0.23E + 18	10000	2.83	1.02				
	20000	3.54	0.738	*0.652	*0.390		
	30000	3.93	0.571	*0.674	*0.426		
	50000	4.31	0.432	*0.704	*0.471		
4*p*–9*d*	2500	2.81	1.40				
9275.9 A	5000	3.57	1.40				
c = 0.15E + 18	10000	4.60	1.24				
	20000	5.79	0.871				
	30000	6.41	0.668				
	50000	6.98	0.473				
5*p*–5*d*	2500	11.0	6.82	*3.82	*1.56		
62426.3 A	5000	13.1	6.79	3.94	1.83		
c = 0.35E + 20	10000	16.3	6.64	4.07	2.11	*3.72	*1.30
	20000	20.8	5.29	4.22	2.41	*3.79	*1.50
	30000	23.8	4.62	4.33	2.59	*3.83	*1.62
	50000	27.1	4.07	4.50	2.84	*3.89	*1.78
5*p*–6*d*	2500	5.63	3.70	*1.74	*0.804		
30150.2 A	5000	6.57	3.86	*1.83	*0.972		
c = 0.50E + 19	10000	7.90	3.77	*1.92	*1.14		
	20000	9.71	2.91	2.03	1.31		
	30000	11.0	2.40	2.10	1.42	*1.75	*0.882
	50000	12.3	2.04	2.21	1.56	*1.80	*0.976
5*p*–7*d*	2500	6.21	3.71				
23070.4 A	5000	7.36	3.96				
c = 0.19E + 19	10000	8.96	3.72	*2.09	*1.20		
	20000	11.1	2.69	*2.21	*1.39		
	30000	12.5	2.12	*2.28	*1.51		
	50000	13.9	1.61	*2.39	*1.67		
5*p*–8*d*	2500	8.10	4.64				
20066.3 A	5000	9.92	4.59				
c = 0.99E + 18	10000	12.4	4.05				
	20000	15.7	2.72	*2.82	*1.67		
	30000	17.5	2.20	*2.91	*1.82		
	50000	19.2	1.42	*3.04	*2.01		

Table I (*Continued*)

Perturber density = $1 \times 10^{+15}$ cm^{-3} Perturbers are:		Electrons		Protons		Ionized argon	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
5*p*–9*d*	2500	11.2	5.65				
18447.6 A	5000	14.2	5.37				
c = 0.59E + 18	10000	18.4	4.52				
	20000	23.3	2.94				
	30000	25.8	2.39				
	50000	28.2	1.37				
3*d*–4*p*	2500	0.462	0.201	0.207	0.543E−01	0.203	0.336E−01
33972.8 A	5000	0.535	0.241	0.209	0.618E−01	0.205	0.386E−01
c = 0.34E + 20	10000	0.642	0.271	0.210	0.701E−01	0.206	0.440E−01
	20000	0.791	0.262	0.213	0.790E−01	0.207	0.499E−01
	30000	0.893	0.242	0.215	0.847E−01	0.207	0.535E−01
	50000	1.03	0.200	0.218	0.925E−01	0.208	0.584E−01
3*d*–5*p*	2500	0.192	0.112	0.812E−01	0.276E−01	*0.776E−01	*0.167E−01
12043.3 A	5000	0.225	0.130	0.826E−01	0.319E−01	*0.792E−01	*0.196E−01
c = 0.21E + 19	10000	0.269	0.134	0.842E−01	0.365E−01	*0.801E−01	*0.227E−01
	20000	0.328	0.126	0.862E−01	0.414E−01	0.808E−01	0.259E−01
	30000	0.368	0.110	0.876E−01	0.446E−01	0.813E−01	0.280E−01
	50000	0.420	0.944E−01	0.897E−01	0.487E−01	0.821E−01	0.307E−01
3*d*–6*p*	2500	0.303	0.184	*0.119	*0.432E−01		
9249.1 A	5000	0.359	0.205	*0.122	*0.511E−01		
c = 0.68E + 18	10000	0.432	0.213	0.126	0.592E−01		
	20000	0.528	0.185	0.130	0.678E−01	*0.119	*0.421E−01
	30000	0.593	0.161	0.132	0.731E−01	*0.120	*0.456E−01
	50000	0.668	0.135	0.136	0.802E−01	*0.122	*0.502E−01
3*d*–7*p*	2500	0.545	0.326				
8212.1 A	5000	0.650	0.368	*0.205	*0.886E−01		
c = 0.31E + 18	10000	0.789	0.360	*0.213	*0.105		
	20000	0.969	0.283	*0.221	*0.121		
	30000	1.08	0.236	*0.226	*0.131		
	50000	1.21	0.190	0.234	0.144		
3*d*–8*p*	2500	0.969	0.580				
7692.3 A	5000	1.16	0.614				
c = 0.17E + 18	10000	1.42	0.581				
	20000	1.75	0.423	*0.371	*0.209		
	30000	1.95	0.333	*0.381	*0.228		
	50000	2.14	0.257	*0.396	*0.252		
3*d*–9*p*	2500	1.65	0.919				
7389.1 A	5000	1.99	1.00				
c = 0.10E + 18	10000	2.45	0.877				
	20000	3.03	0.606				
	30000	3.34	0.466				
	50000	3.62	0.333				
4*d*–5*p*	2500	4.73	0.631	2.47	0.171	*2.42	*0.106
63619.7 A	5000	6.25	0.636	2.48	0.195	*2.46	*0.122
c = 0.60E + 20	10000	8.70	0.616	2.48	0.221	*2.48	*0.139
	20000	11.8	0.558	2.49	0.249	*2.48	*0.157
	30000	13.8	0.500	2.49	0.267	2.48	0.169
	50000	16.0	0.418	2.49	0.291	2.49	0.184
4*d*–6*p*	2500	2.06	1.19	*0.848	*0.266		
24508.1 A	5000	2.51	1.18	*0.867	*0.313		
c = 0.48E + 19	10000	3.18	1.16	0.884	0.362		
	20000	4.08	0.916	0.903	0.414	*0.851	*0.258
	30000	4.67	0.867	0.917	0.446	*0.857	*0.279
	50000	5.30	0.700	0.937	0.489	*0.864	*0.307
4*d*–7*p*	2500	2.72	1.67				
18363.7 A	5000	3.27	1.78	*1.03	*0.428		
c = 0.16E + 19	10000	4.05	1.68	*1.06	*0.504		
	20000	5.07	1.30	*1.10	*0.583		
	30000	5.71	1.08	*1.12	*0.631		
	50000	6.37	0.806	1.16	0.695		

Table I (*Continued*)

Perturber density = $1 \times 10^{+15}$ cm^{-3} Perturbers are:		Electrons		Protons		Ionized argon	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
4*d*–8*p*	2500	4.17	2.37				
15953.0 A	5000	5.03	2.49				
c = 0.73E + 18	10000	6.19	2.24				
	20000	7.71	1.58	*1.59	*0.889		
	30000	8.59	1.20	*1.64	*0.968		
	50000	9.45	0.891	*1.70	*1.07		
4*d*–9*p*	2500	6.54	3.76				
14701.7 A	5000	7.91	3.59				
c = 0.41E + 18	10000	9.78	2.87				
	20000	12.1	1.68				
	30000	13.4	1.38				
	50000	14.6	0.984				
4*d*–4*f*	2500	5.42	−2.93	1.68	−0.745	*1.57	*−0.450
64864.3 A	5000	6.34	−3.20	1.73	−0.860	*1.60	*−0.530
c = 0.65E + 20	10000	7.71	−3.16	1.79	−0.983	1.63	−0.612
	20000	9.41	−2.40	1.87	−1.12	1.66	−0.699
	30000	10.7	−2.04	1.92	−1.20	1.68	−0.753
	50000	12.1	−1.87	1.99	−1.31	1.71	−0.826
4*f*–5*d*	2500	11.6	7.39	*3.34	*1.77		
61272.6 A	5000	13.5	8.62	3.52	2.09	*3.03	*1.26
c = 0.34E + 20	10000	15.6	8.90	3.72	2.42	*3.13	*1.49
	20000	18.1	7.45	3.96	2.77	*3.24	*1.72
	30000	20.1	6.31	4.12	2.98	*3.32	*1.86
	50000	22.6	5.68	4.36	3.27	3.42	2.05
4*f*–6*d*	2500	5.70	3.73	*1.67	*0.829		
29878.5 A	5000	6.61	4.18	*1.77	*1.00		
c = 0.49E + 19	10000	7.71	4.24	*1.87	*1.18		
	20000	9.12	3.41	1.99	1.36		
	30000	10.1	2.79	2.07	1.47	*1.67	*0.913
	50000	11.3	2.40	2.19	1.62	*1.72	*1.01
4*f*–7*d*	2500	6.20	3.77				
22911.0 A	5000	7.30	4.16				
c = 0.19E + 19	10000	8.77	4.00	*2.05	*1.20		
	20000	10.7	2.94	*2.17	*1.40		
	30000	12.0	2.39	*2.25	*1.52		
	50000	13.2	1.83	*2.36	*1.68		
4*f*–8*d*	2500	8.04	4.59				
19945.6 A	5000	9.80	4.71				
c = 0.98E + 18	10000	12.2	4.27				
	20000	15.3	2.92	*2.78	*1.66		
	30000	17.0	2.47	*2.87	*1.81		
	50000	18.6	1.59	*3.00	*2.01		
4*s*–4*p*	2500	0.405	0.167	0.114	0.923E−01	*0.738E−01	*0.542E−01
15036.2 A	5000	0.404	0.130	0.128	0.109	*0.820E−01	*0.657E−01
c = 0.25E + 18	10000	0.386	0.855E−01	0.146	0.125	0.912E−01	0.772E−01
	20000	0.365	0.449E−01	0.170	0.143	0.102	0.891E−01
	30000	0.353	0.288E−01	0.187	0.154	0.108	0.963E−01
	50000	0.338	0.104E−01	0.216	0.170	0.118	0.106
4*s*–5*p*	2500	0.467	−0.174	*0.124	*−0.877E−01		
7660.5 A	5000	0.464	−0.139	*0.140	*−0.109		
c = 0.35E + 17	10000	0.435	−0.931E−01	*0.159	*−0.131		
	20000	0.403	−0.554E−01	*0.184	*−0.152		
	30000	0.383	−0.364E−01	*0.202	*−0.165	*0.118	*−0.102
	50000	0.358	−0.186E−01	*0.232	*−0.183	*0.128	*−0.113
4*s*–6*p*	2500	0.736	−0.306				
6320.7 A	5000	0.763	−0.237				
c = 0.20E + 17	10000	0.736	−0.175				
	20000	0.695	−0.102	*0.276	*−0.225		
	30000	0.668	−0.663E−01	*0.301	*−0.246		
	50000	0.630	−0.328E−01	*0.341	*−0.273		

Table I (*Continued*)

Perturber density = $1 \times 10^{+15}$ cm^{-3} Perturbers are:		Electrons		Protons		Ionized argon	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
5*s*–5*p*	2500	14.6	−5.92	*3.77	*−2.67		
42035.5 A	5000	14.5	−4.79	*4.26	*−3.33		
c = 0.10E + 19	10000	13.9	−3.12	*4.84	*−3.98		
	20000	13.2	−2.09	*5.59	*−4.64		
	30000	12.7	−1.58	*6.16	*−5.03	*3.60	*−3.10
	50000	12.2	−0.969	*7.06	*−5.57	*3.91	*−3.45
5*s*–6*p*	2500	7.01	−3.05				
19432.8 A	5000	7.26	−2.38				
c = 0.19E + 18	10000	7.07	−1.51				
	20000	6.76	−1.02	*2.61	*−2.13		
	30000	6.55	−0.444	*2.86	*−2.33		
	50000	6.25	−0.322	*3.23	*−2.59		
3*p*–4*s*	2500	0.388E−02	0.314E−02	0.987E−03	0.874E−03	0.658E−03	0.543E−03
5179.6 A	5000	0.460E−02	0.369E−02	0.110E−02	0.993E−03	0.726E−03	0.621E−03
c = 0.18E + 19	10000	0.532E−02	0.437E−02	0.123E−02	0.112E−02	0.804E−03	0.706E−03
	20000	0.582E−02	0.490E−02	0.137E−02	0.127E−02	0.892E−03	0.799E−03
	30000	0.610E−02	0.480E−02	0.146E−02	0.136E−02	0.949E−03	0.856E−03
	50000	0.649E−02	0.445E−02	0.159E−02	0.148E−02	0.103E−02	0.934E−03
3*p*–5*s*	2500	0.809E−02	0.593E−02	0.178E−02	0.157E−02	0.113E−02	0.955E−03
3335.4 A	5000	0.942E−02	0.709E−02	0.199E−02	0.181E−02	0.127E−02	0.112E−02
c = 0.26E + 18	10000	0.104E−01	0.792E−02	0.224E−02	0.206E−02	0.142E−02	0.129E−02
	20000	0.111E−01	0.817E−02	0.251E−02	0.234E−02	0.159E−02	0.147E−02
	30000	0.118E−01	0.773E−02	0.269E−02	0.251E−02	0.170E−02	0.158E−02
	50000	0.126E−01	0.652E−02	0.292E−02	0.274E−02	0.185E−02	0.173E−02
3*p*–6*s*	2500	0.189E−01	0.134E−01	0.396E−02	0.334E−02	*0.251E−02	*0.197E−02
2941.1 A	5000	0.217E−01	0.158E−01	0.445E−02	0.392E−02	*0.282E−02	*0.238E−02
c = 0.97E + 17	10000	0.237E−01	0.170E−01	0.499E−02	0.452E−02	0.316E−02	0.279E−02
	20000	0.267E−01	0.162E−01	0.560E−02	0.516E−02	0.355E−02	0.322E−02
	30000	0.283E−01	0.142E−01	0.600E−02	0.556E−02	0.380E−02	0.348E−02
	50000	0.318E−01	0.118E−01	0.653E−02	0.610E−02	0.414E−02	0.382E−02
3*p*–7*s*	2500	0.400E−01	0.275E−01	*0.812E−02	*0.642E−02		
2780.5 A	5000	0.456E−01	0.326E−01	0.911E−02	0.773E−02	*0.577E−02	*0.457E−02
c = 0.48E + 17	10000	0.509E−01	0.321E−01	0.102E−01	0.905E−02	*0.648E−02	*0.550E−02
	20000	0.585E−01	0.284E−01	0.115E−01	0.104E−01	*0.727E−02	*0.644E−02
	30000	0.649E−01	0.242E−01	0.123E−01	0.113E−01	*0.778E−02	*0.700E−02
	50000	0.733E−01	0.197E−01	0.134E−01	0.124E−01	*0.847E−02	*0.774E−02
3*p*–8*s*	2500	0.771E−01	0.514E−01	*0.151E−01	*0.110E−01		
2697.5 A	5000	0.878E−01	0.578E−01	*0.169E−01	*0.137E−01		
c = 0.28E + 17	10000	0.103	0.564E−01	*0.190E−01	*0.163E−01		
	20000	0.120	0.450E−01	*0.213E−01	*0.190E−01		
	30000	0.135	0.376E−01	*0.228E−01	*0.207E−01	*0.145E−01	*0.127E−01
	50000	0.151	0.298E−01	0.249E−01	0.228E−01	*0.157E−01	*0.142E−01
3*p*–9*s*	2500	0.136	0.870E−01				
2648.4 A	5000	0.156	0.941E−01				
c = 0.17E + 17	10000	0.187	0.881E−01	*0.329E−01	*0.273E−01		
	20000	0.229	0.668E−01	*0.369E−01	*0.322E−01		
	30000	0.257	0.550E−01	*0.395E−01	*0.352E−01		
	50000	0.284	0.414E−01	*0.430E−01	*0.390E−01		
3*p*–10*s*	2500	0.224	0.139				
2616.9 A	5000	0.263	0.140				
c = 0.12E + 17	10000	0.322	0.125				
	20000	0.405	0.917E−01				
	30000	0.452	0.749E−01				
	50000	0.493	0.533E−01	*0.686E−01	*0.614E−01		
4*p*–5*s*	2500	1.36	−0.163	0.277	−0.225	*0.181	*−0.133
24848.7 A	5000	1.44	0.159E−01	0.312	−0.263	*0.201	*−0.160
c = 0.67E + 18	10000	1.47	0.188	0.356	−0.303	0.223	−0.187
	20000	1.46	0.266	0.416	−0.346	0.248	−0.216
	30000	1.45	0.261	0.462	−0.373	0.264	−0.233
	50000	1.47	0.247	0.537	−0.412	0.286	−0.256

Table I (*Continued*)

Perturber density = $1 \times 10^{+15}$ cm^{-3}

Perturbers are:		Electrons		Protons		Ionized argon	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
4*p*–6*s*	2500	0.538	0.142	0.254E−01	−0.150E−01	0.210E−01	−0.918E−02
12431.9 A	5000	0.607	0.197	0.282E−01	−0.172E−01	0.217E−01	−0.107E−01
c = 0.17E + 18	10000	0.642	0.233	0.335E−01	−0.197E−01	0.225E−01	−0.122E−01
	20000	0.679	0.240	0.434E−01	−0.233E−01	0.235E−01	−0.139E−01
	30000	0.708	0.213	0.516E−01	−0.263E−01	0.242E−01	−0.149E−01
	50000	0.763	0.186	0.633E−01	−0.309E−01	0.254E−01	−0.164E−01
4*p*–7*s*	2500	0.642	0.309	0.821E−01	0.656E−01	*0.524E−01	*0.374E−01
9992.8 A	5000	0.727	0.377	0.925E−01	0.782E−01	*0.586E−01	*0.467E−01
c = 0.11E + 18	10000	0.798	0.390	0.105	0.911E−01	*0.656E−01	*0.557E−01
	20000	0.889	0.333	0.119	0.105	*0.734E−01	*0.648E−01
	30000	0.970	0.287	0.129	0.113	*0.784E−01	*0.703E−01
	50000	1.07	0.236	0.143	0.124	0.853E−01	0.776E−01
4*p*–8*s*	2500	0.953	0.537	*0.155	*0.114		
8997.3 A	5000	1.08	0.611	*0.174	*0.141		
c = 0.88E + 17	10000	1.23	0.604	*0.197	*0.168		
	20000	1.44	0.467	*0.222	*0.196	*0.139	*0.120
	30000	1.61	0.387	*0.240	*0.212	*0.148	*0.131
	50000	1.78	0.304	0.264	0.234	*0.162	*0.146
4*p*–9*s*	2500	1.48	0.889				
8473.8 A	5000	1.69	0.968				
c = 0.78E + 17	10000	2.01	0.889	*0.327	*0.271		
	20000	2.44	0.650	*0.369	*0.320		
	30000	2.72	0.522	*0.396	*0.349		
	50000	2.99	0.393	*0.434	*0.387		
4*p*–10*s*	2500	2.26	1.28				
8159.6 A	5000	2.65	1.35				
c = 0.73E + 17	10000	3.22	1.22				
	20000	4.03	0.878				
	30000	4.48	0.664				
	50000	4.87	0.488	*0.664	*0.588		
5*p*–7*s*	2500	9.90	4.92				
27747.6 A	5000	10.3	4.95	*2.23	*1.73		
c = 0.45E + 18	10000	10.5	4.53	*2.53	*2.08		
	20000	10.8	3.36	*2.91	*2.44		
	30000	11.3	2.81	*3.19	*2.65		
	50000	11.8	2.09	*3.62	*2.93	*2.05	*1.82
5*p*–8*s*	2500	8.25	4.25				
21226.1 A	5000	8.80	4.47				
c = 0.27E + 18	10000	9.46	4.19	*1.90	*1.56		
	20000	10.4	3.04	*2.17	*1.83		
	30000	11.2	2.42	*2.37	*2.00		
	50000	12.0	1.83	*2.66	*2.21		
5*p*–9*s*	2500	9.36	5.11				
18525.9 A	5000	10.3	5.22				
c = 0.20E + 18	10000	11.6	4.81				
	20000	13.5	3.38	*2.33	*1.96		
	30000	14.8	2.60	*2.52	*2.15		
	50000	15.9	1.91	*2.81	*2.39		
3*p*–3*d*	2500	0.192E−01	−0.593E−02	0.517E−02	−0.431E−02	*0.332E−02	*−0.256E−02
3836.4 A	5000	0.182E−01	−0.384E−02	0.586E−02	−0.502E−02	0.369E−02	−0.306E−02
c = 0.16E + 17	10000	0.168E−01	−0.169E−02	0.672E−02	−0.576E−02	0.412E−02	−0.357E−02
	20000	0.151E−01	−0.439E−03	0.789E−02	−0.656E−02	0.460E−02	−0.410E−02
	30000	0.141E−01	0.408E−03	0.880E−02	−0.708E−02	0.491E−02	−0.443E−02
	50000	0.129E−01	0.706E−03	0.102E−01	−0.782E−02	0.534E−02	−0.486E−02

Table II. *Experimental (W_m) Stark widths (FWHM) and (d_m) shifts in Å for Mg I lines [1–3], compared with the theory. W_{DSB} and d_{DSB} – the present semi-classical calculations; W_{DSB^*} and d_{DSB^*} – same, but with the line strengths of the TOPbase (Opacity Project, OP) and with the measured energy levels when they exist; W_G – Griem (1974) [7, 8]*

Transition/ Wavelength (Å)	T (K)	N_e (10^{17} cm^{-3})	W_m (Å)	W_m/W_{DSB}	W_m/W_{DSB^*}	W_m/W_G	d_m (Å)	d_m/d_{DSB}	d_m/d_{DSB^*}	d_m/d_G	Ref.
$3p\,^1P^o$–$4d\,^1D$	10000	1	4.28	1.00	1.08	0.72	1.88	0.64	0.73	0.55	[3]
5518.41 Å											
$3p\,^1P^o$–$5d\,^1D$	10000	1	8.44	0.92	0.94	0.61	1.98	0.33	0.37	0.26	[3]
4702.99 Å	10000	1	7.2	0.78	0.8	0.52	1.62	0.27	0.3	0.21	[2]
$3s^2\,^1S$–$3s3p\,^1P^o$	12970	1.1	0.054	0.63	0.79	0.51					[2]
2852.13 Å	13370	1.28	0.071	0.70	0.88	0.57					[2]

References

1. Kusch, H. J. and Schweicker, H., Astron. Astrophys. **53**, 59 (1976).
2. Goldbach, C., Nollez, G., Plomdeur, P. and Zimmermann, P., Phys. Rev. **A25**, 2596 (1982).
3. Helbig, V. and Kusch, H. J., Astron. Astrophys. **20**, 299 (1972).
4. Brissaud, A., Goldbach, C., Leorat, J., Mazure, A. and Nollez, G., J. Phys. **B9**, 1147 (1976).
5. Dimitrijević, M. S. and Konjević, N., Astron. Astrophys. **163**, 297 (1986).
6. Marasinghe, P. A. B. and Lovett, R. J., Spectrochim. Acta **B41**, 349 (1986).
7. Griem, H. R., "Spectral Line Broadening by Plasmas" (Academic Press, New York 1974).
8. Benett, S. M. and Griem, H. R., "Calculated Stark Broadening Parameters for Isolated Spectral Lines from the Atoms Helium through Calcium and Cesium", Techn. Rep. No 71–097, Univ. Maryland (1971).
9. Regemorter, H. van and Hoang Binh, D., Astron. Astrophys. **277**, 623 (1993).
10. Brault, J. and Noyes, R. W., Astrophys. J. **269**, L61 (1983).
11. Farmer, C. B. and Norton, R. H., "A High Resolution Atlas of the Infrared Spectra of the Sun" (NASA Reference Publication 1, 1988), p. 1224.
12. Jefferies, J. T., Astrophys. J. **377**, 337 (1991).
13. Sahal-Bréchot, S., Astron. Astrophys **1**, 91 (1969).
14. Sahal-Bréchot, S., Astron. Astrophys **2**, 322 (1969).
15. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Trans. **31**, 301 (1984).
16. Bashkin, S. and Stoner Jr., J. J., "Atomic Energy Levels and Grotrian Diagrams" (North Holland, Amsterdam 1975), vol. 1.
17. Bates, D. R. and Damgaard, A., Trans. Roy. Soc. London, Ser. **A242**, 101 (1949).
18. Oertel, G. K. and Shomo, L. P., Astrophys. J. Suppl. Series **16**, 175 (1968).
19. Van Regemorter, H., Hoang Binh Dy and Prud'homme, M., J. Phys. **B12**, 1073 (1979).
20. Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V., Astron. Astrophys. Suppl. Series **89**, 581 (1991).
21. Sahal-Bréchot, S., Astron. Astrophys **245**, 322 (1991).
22. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Astron. Belgrade **149**, 31 (1994).
23. Butler, K., Mendoza, C. and Zeippen, C. J., J. Phys. **B26**, 4409 (1993).
24. Cunto, W., Mendoza, C., Ochsenbein, F. and Zeippen, C. J., Astron. Astrophys. **275**, L5 (1993).

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Stark Broadening of Heavy Ion Lines: As II, Br II, Sb II and I II

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Abstract

Stark width and shift data for several As II, Br II, Sb II and I II lines obtained within the modified semiempirical approach are presented as a function of temperature for an electron density of $10^{23}\,\mathrm{m}^{-3}$. Our results have been compared with available experimental data.

1. Introduction

Stark broadening data for large number of transitions in many atomic and ionic spectra are needed for evaluation and modelling of a stellar plasma, investigation of its physical properties and abundance determinations. Stark broadening is the dominant pressure broadening mechanism for hot stars with $T_{\mathrm{eff}} \gtrapprox 10\,000$ K. However, Stark broadening of lines originating from energy levels with large principal quantum numbers may be important also for cooler stars (as e.g. for Sun, see Ref. [1]). In order to provide astrophysicists with the relevant data needed for the theoretical modelling of stellar spectra and stellar atmospheres, as well as for abundance determination and opacity calculation, an effort is made to determine the relevant Stark broadening parameters within the semiclassical perturbation formalism ([2, 3] and see e.g. Ref. [4] and references therein). In order to complete the required Stark broadening data, with the atom and ion lines for which the semiclassical perturbation formalism [2, 3] cannot be applied in the appropriate way due to the lack of reliable data for the needed atomic energy levels, we apply to such cases the simpler, modified semiempirical method [5, 6]. Here, we present Stark broadening data for As II, Br II, Sb II and I II spectral lines. For these heavy ions a sufficiently complete set of reliable atomic data for more sophisticated semiclassical calculations does not exist. Strong heavy ion spectral lines have been observed many times in hot star spectra [7–10]. Although, in general, abundances of these elements are small, the lines are present mainly in the spectra of CP stars, as e.g. very strong absorption Sb II lines in spectra of Hg-Mn star HR7775 [7].

The modified semiempirical (MSE) formula [5, 6] applied here, was tested several times on numerous examples (see e.g. Ref. [11] and references therein). Moreover, this method has been tested and applied by us for the particular lines of the following complex heavy ions: Ti II, Mn II [12], Fe II [13], Zn II and Cd II [14], Bi II [15], Pt II [16] and Cu IV [17]. We continue here our investigation of the applicability of the MSE approach for complex spectra, as well as our effort to complete the set of available Stark broadening data by considering As II, Br II, Sb II and I II spectral lines. The results obtained have been compared with available experimental values [18–20] and width simple estimates [21].

2. Method of calculation

According to the MSE approach [2, 3] the electron full width (FWHM) of an ion line is given as

$$
\begin{aligned}
w_{\mathrm{MSE}} = N\,\frac{8\pi}{3}\,\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}
&\times\left\{\sum_{l_i\pm1}\sum_{A_{i'}J_{i'}}\Re^2[n_i l_i A_i J_i,\, n_i(l_i\pm1)A_{i'}J_{i'}]\tilde{g}\left(\frac{E}{\Delta E_{l_i,\,l_i\pm1}}\right)\right.\\
&+\sum_{l_f\pm1}\sum_{A_{f'}J_{f'}}\Re^2[n_f l_f A_f J_f,\, n_f(l_f\pm1)A_{f'}J_{f'}]\\
&\times\tilde{g}\left(\frac{E}{\Delta E_{l_f,\,l_f\pm1}}\right)+\left(\sum_{i'}\Re^2_{ii'}\right)_{\Delta n\neq0}g(x_{n_i,\,n_i+1})\\
&\left.+\left(\sum_{f'}\Re^2_{ff'}\right)_{\Delta n\neq0}g(x_{n_f,\,n_f+1})\right\},
\end{aligned}
\tag{1}
$$

and the corresponding Stark shift as

$$
\begin{aligned}
d = N\,\frac{4\pi}{3}\,\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}
&\times\left\{\sum_{A_{i'}J_{i'}}\sigma_{J_iJ_{i'}}\Re^2[n_i l_i A_i J_i,\, n_i(l_i+1)A_{i'}J_{i'}]\right.\\
&\times\tilde{g}_{\mathrm{sh}}\left(\frac{E}{\Delta E_{l_i,\,l_i+1}}\right)-\sum_{A_{i'}J_{i'}}\sigma_{J_iJ_{i'}}\\
&\times\Re^2[n_i l_i A_i J_i,\, n_i(l_i-1)A_{i'}J_{i'}]\\
&\times\tilde{g}_{\mathrm{sh}}\left(\frac{E}{\Delta E_{l_i,\,l_i-1}}\right)-\sum_{A_{f'}J_{f'}}\sigma_{J_fJ_{f'}}\\
&\times\Re^2[n_f l_f A_f J_f,\, n_f(l_f+1)A_{f'}J_{f'}]\\
&\times\tilde{g}_{\mathrm{sh}}\left(\frac{E}{\Delta E_{l_f,\,l_f+1}}\right)+\sum_{A_{f'}J_{f'}}\sigma_{J_fJ_{f'}}\\
&\times\Re^2[n_f l_f A_f J_f,\, n_f(l_f-1)A_{f'}J_{f'}]\\
&\times\tilde{g}_{\mathrm{sh}}\left(\frac{E}{\Delta E_{l_f,\,l_f-1}}\right)+\left(\sum_{i'}\Re^2_{ii'}\right)_{\Delta n\neq0}g_{\mathrm{sh}}(x_{n_i},\,x_{n_i+1})\\
&-2\sum_{i'(\Delta E_{ff'}<0)}\sum_{A_{f'}J_{f'}}\Re^2(n_i l_i A_i J_i,\, n_i l_{i'} A_{i'} J_{i'})\\
&\times g_{\mathrm{sh}}\left(\frac{E}{\Delta E_{l_i,\,l_{i'}}}\right)-\left(\sum_{f'}\Re^2_{ff'}\right)_{\Delta n\neq0}g_{\mathrm{sh}}(x_{n_f},\,x_{n_f+1})\\
&+2\sum_{f'(\Delta E_{ff'}<0)}\sum_{A_{f'}J_{f'}}\Re^2(n_f l_f A_f J_f,\, n_f l_{f'} A_{f'} J_{f'})\\
&\left.\times g_{\mathrm{sh}}\left(\frac{E}{\Delta E_{l_f,\,l_{f'}}}\right)+\sum_k\delta_k\right\}
\end{aligned}
\tag{2}
$$

where the initial level is denoted with i and the final one with f and the square of the matrix element $\{\Re^2[n_k l_k A_k J_k,$

$n_k(l_k \pm 1)A'_k J'_k], k = i, f\}$ is

$$\Re^2[n_k l_k A_k J_k, n_k(l_k \pm 1)A'_k J'_k]$$
$$= \frac{l_>}{2J_k + 1} Q[l_k A_k, (l_k \pm 1)A'_k] Q(J_k, J'_k)[R^{n_k(l_k \pm 1)}_{n_k l_k}]^2 \quad (3)$$

and

$$\left(\sum_{k'} \Re^2_{kk'}\right)_{\Delta n \neq 0} = \left(\frac{3n_k}{2Z}\right)^2 \frac{1}{9}(n_k^2 + 3l_k^2 + 3l_k + 11) \quad (4)$$

where $l_> = \max(l_k, l_k \pm 1)$.

If we have an oscillator strength, e.g. from literature, the corresponding matrix element may be calculated as

$$\Re^2_{k,k'} \approx 3 \frac{E_H}{E_{k'} - E_k} \cdot f_{k'k} \quad (E_{j'} > E_k),$$

or

$$\Re^2_{k,k'} \approx 3 \frac{E_H}{E_k - E_{k'}} \frac{2k' + 1}{2k + 1} \cdot f_{kk'} \quad (E_{k'} < E_k), \quad (5)$$

where $f_{k'k}$ (for $E_{k'} > E_k$) and $f_{kk'}$ (for $E_{k'} < E_k$) are oscillator strengths.

The eventual configuration mixing (as in the case of the As II and Sb II, where *npms* terms may be taken into account by representing the corresponding term as a mixture of singlet and triplet states [23]) may be taken into account if one represents $\Re^2_{\alpha\beta}$ as

$$\Re^2_{\alpha\beta} = K_\alpha \cdot \Re^2_{\alpha\alpha'} + K_\beta \cdot \Re^2_{\beta\beta'}, \quad (6)$$

where K_α and K_β are mixing coefficients for two configurations and $K_\alpha + K_\beta = 1$.

In eqs (1)–(6) N and T are electron density and temperature, respectively. $Q(lA, l'A')$ and $Q(J, J')$ are multiplet and line factors, respectively. They depend on the coupling approximation (see e.g. [32]). The quantum number A depends on the coupling approximation. In the case of the LS coupling approximation $A = L$, for the jK approximation $A = K$, for the jj approximation $A = j$. The $[R^{n_k l_k \pm 1}_{n_k l_k}]$ is the radial integral, $\tilde{g}(x)$, $g(x)$, $g_{sh}(x)$ and $\tilde{g}_{sh}(x)$ are the semiempirical [4] and the modified semiempirical [5, 6] Gaunt factors for Stark width and shift, respectively. The factor $\sigma_{kk'} = (E_{k'} - E_k)/|E_{k'} - E_k|$, where E_k and $E_{k'}$ are the energy of the considered and its perturbing level. The sum $\sum_k \delta_k$ is different from zero only if perturbing levels strongly violating the assumed approximations exist and may be evaluated as

$$\delta_i = \pm \Re^2_{ii'}\left[g_{sh}\left(\frac{E}{\Delta E_{i,i'}}\right) \mp g_{sh}(x_{n_i, n_i+1})\right], \quad (7)$$

for the upper level, and

$$\delta_f = \mp \Re^2_{ff'}\left[g_{sh}\left(\frac{E}{\Delta E_{f,f'}}\right) \mp g_{sh}(x_{n_f, n_f \pm 1})\right] \quad (8)$$

for the lower level. In eqs (7) and (8) lower signs correspond to $\Delta E_{jj'} < 0$ and $x_{n_k, n_k \pm 1} \approx 3kTn_k^{*3}/(2Z^2 E_H)$, where $\Delta E_{kk'} = |E_k - E_{k'}|$, n_k^* is the effective principal quantum number and $(Z - 1)$ is the ionic charge.

In comparison with the semiclassical perturbation approach [2, 3], the modified semiempirical approach needs a considerably smaller number of atomic data. In fact, if there are not perturbing levels strongly violating the assumed approximation, for e.g. the line width calculations, we need only the energy levels with $\Delta n = 0$ and $l_{if} = l_{if} \pm 1$, since all perturbing levels with $\Delta n \neq 0$, needed for a full semiclassical investigation are lumped together and approximately estimated.

3. Results and discussion

The necessary matrix elements have been calculated by using eqs (3)–(6). When possible they have been derived using more accurate oscillator strengths from: Refs [23, 24] for As II and Sb II, Refs [25, 26] for Br II, Ref. [27] for Sb II, Ref. [25] for Br II and I II lines.

The atomic energy levels have been taken from Ref. [28] for all considered ions and from Refs [29–31] for As II. In the case of As II and Sb II the departure from *LS* coupling has been taken into account (see Ref. [15]) for np^2 and *npms* terms treating the corresponding term as a mixture of singlet and triplet states [23, 31]. In the case of Br II and I II, for np^4 terms departure from *LS* coupling has been also taken into account [32].

In Tables I–IV we present results of our calculation of Stark widths and shifts for As II, Br II, Sb II and I II spectral lines, respectively. In Table V our results have been shown with experimental data [18–20]. For As II spectral lines there are no experimental Stark broadening data. However, for two As II spectral lines ($5s^1P^o$–$5p^1P$ and $5p^3D$–$5d^3F^o$) estimates on the basis of regularities and systematic trends are given in Ref. [21].

In Fig. 1 our results for Stark width of Br II ($5s^2S^o$–$5p^5P$ transitions) have been shown with available experimental data [19]. Calculations of Stark width have been performed by using (*i*) the oscillator strengths given in Ref. [26] (full line) and (*ii*) by using the Coulomb approximation [22] and

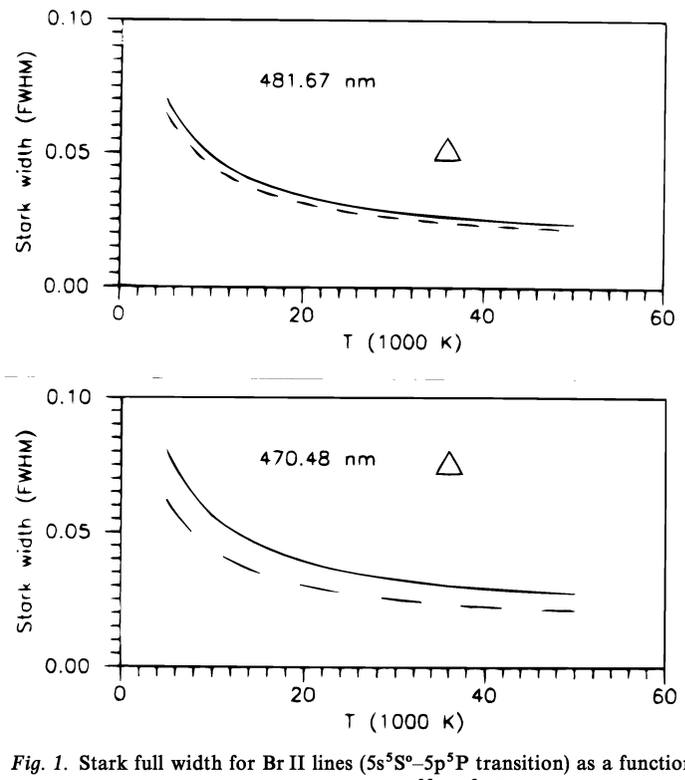

Fig. 1. Stark full width for Br II lines ($5s^5S^o$–$5p^5P$ transition) as a function of temperature at an electron density of $10^{23}\,m^{-3}$. The used notation is: (——) present results with oscillator strengths by Ref. [26] when available (– – –) results with Coulomb approximation only for oscillator strengths, (△) experimental data by Ref. [19].

Table I. *Stark width (FWHM) and shift of As II spectral lines for electron density of $10^{23}\,m^{-3}$ as a function of temperature. The averaged wavelength of the multiplet is denoted by $\bar{\lambda}$*

Transition	T (K)	Width (nm)	Shift (nm)	Transition	Width (nm)	Shift (nm)
$5s^3P^o_0$–$5p^3D_1$	5000	0.822E−01	−0.851E−02	$5s^3P^o_0$–$5p^3P_1$	0.111	0.102E−03
λ = 549.77 nm	10000	0.575E−01	−0.462E−02	λ = 488.85 nm	0.905E−01	0.325E−02
	20000	0.412E−01	−0.117E−03		0.874E−01	0.534E−02
	30000	0.352E−01	0.157E−02		0.778E−01	0.532E−02
	40000	0.327E−01	0.223E−02		0.721E−01	0.468E−02
	50000	0.315E−01	0.275E−02		0.683E−01	0.462E−02
$5s^3P^o_0$–$5p^3S_1$	5000	0.121	−0.160E−01	$5s^3P^o_1$–$5p^3D_1$	0.108	−0.250E−01
λ = 447.12 nm	10000	0.848E−01	−0.103E−01	λ = 562.06 nm	0.751E−01	−0.178E−01
	20000	0.613E−01	−0.466E−02		0.537E−01	−0.130E−01
	30000	0.531E−01	−0.137E−02		0.456E−01	−0.114E−01
	40000	0.491E−01	0.178E−02		0.422E−01	−0.110E−01
	50000	0.471E−01	0.149E−02		0.406E−01	−0.107E−01
$5s^3P^o_1$–$5p^3D_2$	5000	0.117	−0.264E−01	$5s^3P^o_1$–$5p^3P_0$	0.862E−01	−0.110E−01
λ = 555.81 nm	10000	0.841E−01	−0.189E−01	λ = 523.13 nm	0.649E−01	−0.624E−02
	20000	0.582E−01	−0.138E−01		0.454E−01	−0.461E−02
	30000	0.496E−01	−0.121E−01		0.450E−01	−0.323E−02
	40000	0.459E−01	−0.117E−01		0.449E−01	−0.370E−02
	50000	0.441E−01	−0.113E−01		0.427E−01	−0.329E−02
$5s^3P^o_1$–$5p^3P_1$	5000	0.132	−0.125E−01	$5s^3P^o_1$–$5p^3P_2$	0.253	0.137E−01
λ = 498.54 nm	10000	0.106	−0.679E−02	λ = 473.07 nm	0.228	0.115E−01
	20000	0.992E−01	−0.451E−02		0.198	0.725E−02
	30000	0.878E−01	−0.467E−02		0.183	0.504E−02
	40000	0.813E−01	−0.524E−02		0.174	0.339E−02
	50000	0.770E−01	−0.575E−02		0.167	0.179E−02
$5s^3P^o_1$–$5p^3S_1$	5000	0.140	−0.271E−01	$5s^3P^o_2$–$5p^3D_1$	0.153	−0.374E−01
λ = 455.21 nm	10000	0.978E−01	−0.192E−01	λ = 648.58 nm	0.107	−0.268E−01
	20000	0.704E−01	−0.133E−01		0.764E−01	−0.197E−01
	30000	0.609E−01	−0.998E−02		0.650E−01	−0.175E−01
	40000	0.562E−01	−0.690E−02		0.602E−01	−0.171E−01
	50000	0.538E−01	−0.733E−02		0.580E−01	−0.162E−01
$5s^3P^o_3$–$5p^3D_2$	5000	0.164	−0.392E−01	$5s^3P^o_2$–$5p^3D_3$	0.167	−0.354E−02
λ = 640.59 nm	10000	0.115	−0.281E−01	λ = 565.13 nm	0.145	0.674E−02
	20000	0.820E−01	−0.207E−01		0.111	0.930E−02
	30000	0.699E−01	−0.183E−01		0.933E−01	0.788E−02
	40000	0.647E−01	−0.179E−01		0.887E−01	0.579E−02
	50000	0.623E−01	−0.174E−01		0.865E−01	0.366E−02
$5s^3P^o_2$–$5p^3P_1$	5000	0.178	−0.192E−01	$5s^3P^o_2$–$5p^3P_2$	0.102	−0.252E−01
λ = 565.13 nm	10000	0.141	−0.111E−01	λ = 533.12 nm	0.268	−0.126E−01
	20000	0.131	−0.764E−02		0.216	−0.758E−02
	30000	0.116	−0.777E−02		0.191	−0.484E−02
	40000	0.108	−0.858E−02		0.175	−0.268E−02
	50000	0.102	−0.926E−02		0.163	−0.634E−03
$5s^3P^o_2$–$5p^3S_1$	5000	0.182	−0.367E−01	$5s^1P^o_1$–$5p^1P_1$	0.256	−0.101
λ = 510.56 nm	10000	0.127	−0.261E−01	λ = 799.05 nm	0.181	−0.748E−01
	20000	0.916E−01	−0.182E−01		0.136	−0.565E−01
	30000	0.791E−01	−0.140E−01		0.123	−0.510E−01
	40000	0.731E−01	−0.101E−01		0.117	−0.511E−01
	50000	0.700E−01	−0.107E−01		0.114	−0.517E−01
$5s^1P^o_1$–$5p^1D_2$	5000	0.656	0.635E−01	$5s^1P^o_1$–$5p^1S_0$	0.769E−01	−0.252E−01
λ = 510.75 nm	10000	0.554	0.429E−01	λ = 435.21 nm	0.534E−01	−0.182E−01
	20000	0.457	0.274E−01		0.379E−01	−0.135E−01
	30000	0.404	0.198E−01		0.323E−01	−0.117E−01
	40000	0.368	0.139E−01		0.297E−01	−0.104E−01
	50000	0.343	0.801E−02		0.284E−01	−0.101E−01

pure *LS* coupling (broken line). In spite of the fact that the difference between experimental and calculated values is smaller when the oscillator strengths of Ref. [26] have been used, one can see in Fig. 1 that the improvement is not significant.

In Figs 2 and 3 our results for Stark width and shift of the Sb II $6s^3P^o_1$–$6p^3D_2$ line are shown with available experimental data [20]. The dashed line corresponds to calculations with pure *LS* coupling. The full line corresponds to calculations which take into account the departure from *LS* coupling. As one can see in Figs 1 and 2 the calculated results agree better with the experimental ones for Stark widths, if the configuration mixing has been taken into account, while for Stark shifts the calculations within the Coulomb approximation with pure *LS* coupling agree better with the experimental data.

Table II. *Same as in Table I, but for Br II spectral lines*

Transition	T (K)	Width (nm)	Shift (nm)	Transition	Width (nm)	Shift (nm)
$5s'^3D^o$–$5p'^3D$	5000	0.705E−01	−0.180E−01	$5s'^3D^o$–$5p'^3F$	0.682E−01	−0.153E−01
$\bar{\lambda}$ = 498.19 nm	10000	0.518E−01	−0.127E−01	$\bar{\lambda}$ = 467.87 nm	0.472E−01	−0.107E−01
	20000	0.366E−01	−0.895E−02		0.334E−01	−0.744E−02
	30000	0.312E−01	−0.716E−02		0.286E−01	−0.583E−02
	40000	0.290E−01	−0.595E−02		0.266E−01	−0.455E−02
	50000	0.282E−01	−0.488E−02		0.260E−01	−0.369E−02
$5s'^3D^o$–$5p'^3P$	5000	0.560E−01	−0.913E−02	$5s^3S^0$–$5p^3P$	0.866E−01	0.302E−01
$\bar{\lambda}$ = 426.21 nm	10000	0.388E−01	−0.626E−02	$\bar{\lambda}$ = 520.02 nm	0.600E−01	0.327E−01
	20000	0.276E−01	−0.403E−02		0.420E−01	0.301E−01
	30000	0.238E−01	−0.281E−02		0.350E−01	0.275E−01
	40000	0.224E−01	−0.153E−02		0.316E−01	0.255E−01
	50000	0.218E−01	−0.112E−02		0.300E−01	0.232E−01
$5s^5S^o_2$–$5p^5P_1$	5000	0.703E−01	−0.165E−02	$5s^5S^o_2$–$5p^5P_2$	0.827E−01	0.356E−02
λ = 481.67 nm	10000	0.488E−01	−0.112E−02	λ = 478.54 nm	0.574E−01	0.267E−02
	20000	0.341E−01	−0.711E−03		0.401E−01	0.212E−02
	30000	0.282E−01	−0.490E−03		0.332E−01	0.196E−02
	40000	0.253E−01	−0.350E−03		0.298E−01	0.193E−02
	50000	0.239E−01	0.313E−03		0.281E−01	0.192E−02
$5s^5S^o_2$–$5p^5P_3$	5000	0.808E−01	0.460E−02	$5s'^1D^o$–$5p'^1P$	0.956E−01	−0.208E−01
λ = 470.48 nm	10000	0.561E−01	0.342E−02	λ = 559.15 nm	0.660E−01	−0.147E−01
	20000	0.392E−01	0.269E−02		0.468E−01	−0.103E−01
	30000	0.325E−01	0.245E−02		0.404E−01	−0.834E−02
	40000	0.291E−01	0.239E−01		0.378E−01	−0.690E−02
	50000	0.257E−01	0.237E−02		0.370E−01	−0.565E−02
$5s'^1D^o$–$5p'^1F$	5000	0.888E−01	−0.182E−01	$5s'^1D^o$–$5p'^1D$	0.538E−01	−0.670E−02
λ = 533.35 nm	10000	0.614E−01	−0.128E−01	λ = 422.39 nm	0.374E−01	−0.438E−02
	20000	0.436E−01	−0.886E−02		0.270E−01	−0.238E−02
	30000	0.376E−01	−0.702E−02		0.240E−01	−0.106E−02
	40000	0.354E−01	−0.550E−02		0.230E−01	0.297E−03
	50000	0.346E−01	−0.448E−02		0.228E−01	0.345E−03

From Table V one can see that the MSE approach gives smaller Stark width values than measured ones for the considered heavy ion lines. The differences between theoretical and experimental results are largest for Br II $5s^5S^o$–$5p^5P$ transitions. As one can see from Table II, the ratio of theoretical Stark widths for two lines within this multiplet is $(w_{470.48}/w_{481.67})_{th} = 1.15$, but the ratio of the corresponding measured Stark width (Labat *et al.* 1991) is $(w_{470.48}/w_{481.67})_{exp} = 1.38$ for a temperature of 36 000 K. Such difference between measured Stark widths for $5s^5S^o_2$–$5p^5P_1$ and $5s^5S^o_2$–$5p^5P_3$ transitions is eventually possible if intersystem combination connects the terms $(^4S^o)5p^5P_{1,2,3}$ and $(^2P^o)5s^1P^o_1$. A new high precision experimental determination of the corresponding Stark broadening parameters will be of help to clarify the reason for such differences between components of the same multiplet.

We can see generally that the difference between simpler calculations and calculations with more sophisticated oscillator strengths or the inclusion of configuration mixing is not significant, which implies that for astrophysical problems where the calculation of a large number of lines of various radiators must be performed (as e.g. opacity calculations, radiative transfer research or stellar atmosphere

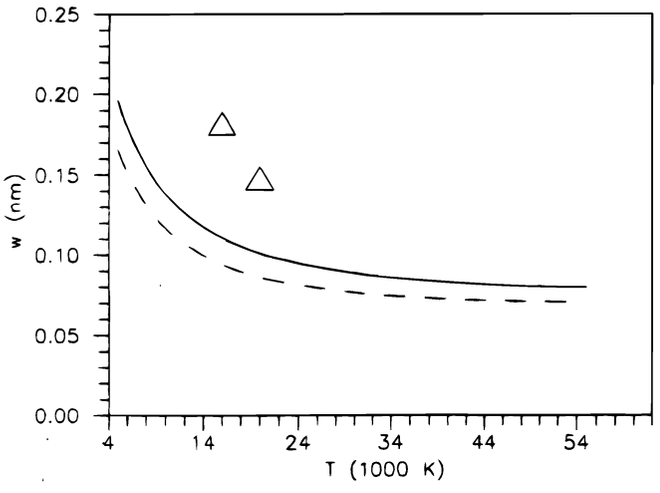

Fig. 2. Stark full width for the Sb II 600.5 nm ($6s^3P^o_1$–$6p^3D_2$) spectral line as a function of temperature, at an electron density of $N = 10^{23}\,m^{-3}$. The used notation is: (——) present results, (– – –) pure *LS* coupling assumption, (△) experimental data [20].

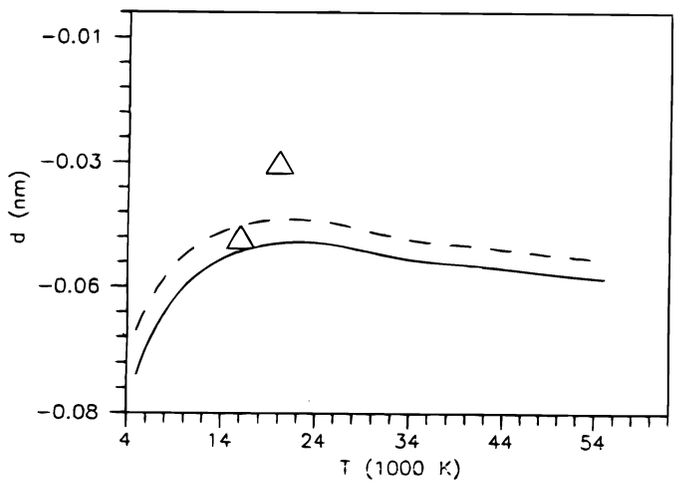

Fig. 3. Same as in Fig. 2, but for the Stark shift.

Table III. *Same as Table I, but for Sb II spectral lines*

Transition	T (K)	Width (nm)	Shift (nm)	Transition	Width (nm)	Shift (nm)
$6s^3P^o_0$–$6p^3D_1$	5000	0.112	−0.179E−01	$6s^3P^o_0$–$6p^3P_1$	0.184	−0.634E−01
$\lambda = 680.7$ nm	10000	0.774E−01	−0.128E−01	$\lambda = 591.1$ nm	0.129	−0.492E−01
	20000	0.548E−01	−0.928E−02		0.982E−01	−0.433E−01
	30000	0.470E−01	−0.790E−02		0.894E−01	−0.483E−01
	40000	0.441E−01	−0.714E−02		0.858E−01	−0.512E−01
	50000	0.429E−01	−0.591E−02		0.847E−01	−0.546E−01
$6s^3P^o_0$–$6p^3S_1$	5000	0.112	−0.141E−01	$6s^3P^o_1$–$6p^3D_1$	0.198	−0.557E−01
$\lambda = 419.0$ nm	10000	0.849E−01	−0.738E−02	$\lambda = 699.7$ nm	0.137	−0.404E−01
	20000	0.737E−01	0.268E−02		0.970E−01	−0.300E−01
	30000	0.718E−01	0.721E−02		0.820E−01	−0.261E−01
	40000	0.714E−01	0.748E−02		0.753E−01	−0.247E−01
	50000	0.694E−01	0.712E−02		0.720E−01	−0.232E−01
$6s^3P^o_1$–$6p^3D_2$	5000	0.196	−0.724E−01	$6s^3P^o_1$–$6p^3P_0$	0.157	−0.488E−01
$\lambda = 600.5$ nm	10000	0.137	−0.549E−01	$\lambda = 589.6$ nm	0.110	−0.362E−01
	20000	0.996E−01	−0.462E−01		0.797E−01	−0.288E−01
	30000	0.868E−01	−0.480E−01		0.693E−01	−0.281E−01
	40000	0.810E−01	−0.505E−01		0.647E−01	−0.283E−01
	50000	0.782E−01	−0.524E−01		0.624E−01	−0.287E−01
$6s^3P^o_1$–$6p^3P_1$	5000	0.233	−0.941E−01	$6s^3P^o_1$–$6p^3P_2$	0.163	−0.599E−01
$\lambda = 605.4$ nm	10000	0.163	−0.715E−01	$\lambda = 450.7$ nm	0.115	−0.440E−01
	20000	0.122	−0.605E−01		0.862E−01	−0.322E−01
	30000	0.110	−0.640E−01		0.753E−01	−0.294E−01
	40000	0.105	−0.666E−01		0.708E−01	−0.305E−01
	50000	0.103	−0.700E−01		0.682E−01	−0.338E−01
$6s^3P^o_1$–$6p^3S_1$	5000	0.145	−0.282E−01	$6s^3P^o_2$–$6p^3D_1$	0.625	−0.342
$\lambda = 426.1$ nm	10000	0.108	−0.175E−01	$\lambda = 1169.4$ nm	0.433	−0.251
	20000	0.907E−01	−0.472E−02		0.308	−0.193
	30000	0.861E−01	0.863E−04		0.266	−0.176
	40000	0.845E−01	0.138E−02		0.249	−0.172
	50000	0.817E−01	0.105E−02		0.242	−0.167
$6s^3P^o_0$–$6p^3D_2$	5000	0.510	−0.260	$6s^3P^o_2$–$6p^3D_3$	0.294	−0.982E−01
$\lambda = 916.6$ nm	10000	0.354	−0.192	$\lambda = 613.0$ nm	0.204	−0.727E−01
	20000	0.257	−0.151		0.146	−0.565E−01
	30000	0.227	−0.140		0.125	−0.536E−01
	40000	0.216	−0.137		0.116	−0.526E−01
	50000	0.212	−0.132		0.112	−0.542E−01
$6s^3P^o_2$–$6p^3P_1$	5000	0.638	−0.338	$6s^3P^o_2$–$6p^3P_2$	0.337	−0.159
$\lambda = 927.8$ nm	10000	0.448	−0.256	$\lambda = 608.1$ nm	0.238	−0.118
	20000	0.334	−0.211		0.177	−0.881E−01
	30000	0.300	−0.215		0.155	−0.813E−01
	40000	0.286	−0.221		0.146	−0.833E−01
	50000	0.281	−0.229		0.141	−0.892E−01
$6s^3P^o_2$–$6p^3S_1$	5000	0.271	−0.929E−01	$6s^3P^o_2$–$6p^3S_1$	0.271	−0.929E−01
$\lambda = 564.1$ nm	10000	0.202	−0.631E−01	$\lambda = 564.1$ nm	0.202	−0.631E−01
	20000	0.168	−0.336E−01		0.168	−0.336E−01
	30000	0.160	−0.224E−01		0.160	−0.224E−01
	40000	0.157	−0.214E−01		0.157	−0.214E−01
	50000	0.153	−0.219E−01		0.153	−0.219E−01
$5p^2\,{}^3P$–$5p^3\,{}^3D^o$	5000	0.478E−02	0.102E−02	$6p^2\,{}^3P$–$6s^3P^o$	0.551E−02	0.194E−02
$\bar{\lambda} = 158.9$ nm	10000	0.323E−02	0.828E−03	$\bar{\lambda} = 145.9$ nm	0.414E−02	0.143E−02
	20000	0.249E−02	0.751E−03		0.321E−02	0.111E−02
	30000	0.190E−02	0.764E−03		0.285E−02	0.100E−02
	40000	0.108E−02	0.817E−03		0.267E−02	0.983E−03
	50000	0.961E−02	0.897E−03		0.258E−02	0.986E−03

modelling) the general use of Coulomb approximation will not substantially influence on results for ions like As II, Br II, Sb II and I II.

Concerning the comparison of the calculated and experimental values in Figs 1–3 and in Table V we can see that the agreement for shifts is good but the disagreements for widths are larger than for lighter emitters. Since the average deviations for semiempirical methods are estimated as ±50% [4] it seems that the MSE method is less adequate for the widths of considered complex emitter lines. However, since for other complex emitters like Ti II and Mn II [12], Fe II [13], Zn II and Cd II [14] and Bi II [15] the agreement between the MSE results and the experiment and more sophisticated semiclassical method is much better, and since the few available experimental data for comparison here are practically from the same laboratory, new experimental data at different temperatures are needed for the final conclusions.

Table IV. *Same as in Table I, but for I II spectral lines*

Transition	T (K)	Width (nm)	Shift (nm)	Transition	Width (nm)	Shift (nm)
$5p^4\,{}^3P$–$5d\,{}^3D^o$	5000	0.157E−02	0.206E−03	$5p^4\,{}^3P$–$6s\,{}^3S^o$	0.312E−02	0.122E−02
$\bar{\lambda} = 111.78$ nm	10000	0.108E−02	0.161E−03	$\bar{\lambda} = 122.29$ nm	0.216E−02	0.901E−03
	20000	0.742E−03	0.139E−03		0.152E−02	0.695E−03
	30000	0.620E−03	0.136E−03		0.126E−02	0.632E−03
	40000	0.556E−03	0.142E−03		0.113E−02	0.623E−03
	70000	0.506E−03	0.186E−03		0.976E−03	0.626E−03
$6s\,{}^5S^o$–$6p\,{}^5P$	5000	0.942E−01	−0.193E−01	$6s\,{}^5S^o$–$7p\,{}^5P$	0.500E−01	−0.669E−02
$\bar{\lambda} = 532.63$ nm	10000	0.654E−01	−0.140E−01	$\bar{\lambda} = 247.42$ nm	0.354E−01	−0.511E−02
	20000	0.456E−01	−0.104E−01		0.320E−01	−0.524E−02
	30000	0.382E−01	−0.898E−02		0.280E−01	−0.451E−02
	40000	0.348E−01	−0.855E−02		0.260E−01	−0.411E−02
	70000	0.318E−01	−0.723E−02		0.238E−01	−0.397E−02
$5d\,{}^5D^o$–$6p\,{}^5P$	5000	0.154	−0.413E−02	$5d\,{}^5D^o$–$7p\,{}^5P$	0.610E−01	−0.464E−02
$\bar{\lambda} = 743.31$ nm	10000	0.107	−0.277E−02	$\bar{\lambda} = 257.14$ nm	0.432E−01	−0.368E−02
	20000	0.742E−01	−0.168E−02		0.322E−01	−0.328E−02
	30000	0.618E−01	−0.117E−02		0.283E−01	−0.265E−02
	40000	0.516E−01	−0.840E−02		0.262E−01	−0.223E−02
	70000	0.516E−01	−0.133E−02		0.236E−01	−0.211E−02
$6p\,{}^5P$–$7s\,{}^5S$	5000	0.268	0.859E−01	$7s\,{}^5S^o$–$7p\,{}^5P$	3.30	−0.796
$\bar{\lambda} = 531.91$ nm	10000	0.190	0.671E−01	$\bar{\lambda} = 1506.83$ nm	2.36	−0.628
	20000	0.145	0.627E−01		1.83	−0.590
	30000	0.131	0.612E−01		1.68	−0.561
	40000	0.126	0.559E−01		1.63	−0.505
	70000	0.122	0.365E−01		1.56	−0.358

Transition	T (K)	Width (nm)	Shift (nm)	T (K)	Width (nm)	Shift (nm)
$6s\,{}^3S^o$–$6p\,{}^3P$	5000	0.112	−0.286E−01	30000	0.462E−01	−0.139E−01
$\bar{\lambda} = 571.73$ nm	10000	0.778E−01	−0.208E−01	40000	0.426E−01	−0135E−01
	20000	0.548E−01	−0.156E−01	70000	0.398E−01	−0.120E−01

If we have reliable experimental data for the considered or analogous transitions, we might improve the accuracy of the presented data by the corresponding scaling using the knowledge on regularities and systematic trends [33]. One must take into account as well that for problems such as e.g. stellar atmospheres modelling or radiative transfer considerations, a large number of lines is needed. For lines where more reliable data do not exist, the standard damping value of ten times the classical natural damping value is usually used for such problems (see e.g. [34]).

Table V. *Comparison of our results with experimental data and simple estimates for Stark widths and shifts for As II, Br II, Sb II and I II.* a – *the estimate on the basis of regularities and systematic trends given in Ref.* [*21*]. *Experimental data:* b – [*19*], c – [*20*]. d – [*18*]. w_{MSE} *and* d_{MSE} *are Stark width and shift values calculated by us within the modified semiempirical approach* [*5, 6*]. *The electron density is* $10^{23}\,m^{-3}$

Transition	λ (nm)	T (10^3 K)	w/w_{MSE}	d/d_{MSE}	Ref.
As II					
$5s\,{}^1P^o_1$–$5p\,{}^1P_1$	799.05	20000	1.2	—	a
Br II					
$5s\,{}^5S^o_2$–$5p\,{}^5P_3$	470.48	36000	2.5		b
$5s\,{}^5S^o_2$–$5p\,{}^5P_1$	481.67	—	1.9		b
$5s'\,{}^1D^o_2$–$5p'\,{}^1D_2$	422.39	—	2.1		b
$5s'\,{}^1D^o_2$–$5p'\,{}^1F_3$	533.20	—	1.4		b
$5s'\,{}^3D^o_2$–$5p'\,{}^3P_0$	417.96	—	1.9		b
$5s'\,{}^3D^o_2$–$5p'\,{}^3D_2$	492.88	—	1.5		b
$5s'\,{}^3D^o_2$–$5p'\,{}^3D_3$	493.88	—	1.3		b
Sb II					
$6s\,{}^3P^o_1$–$6p\,{}^3D_2$	600.5	16000	2.0	1.2	c
		20000	1.8	0.9	c
$6s\,{}^3P^o_2$–$6p\,{}^3D_3$	612.99	20000	2.2	—	a
I II					
$6s\,{}^5S^o_2$–$6p\,{}^5P_3$	516.12	64000	1.3		d
$6s\,{}^3S^o_1$–$6p\,{}^3P_2$	562.57	—	1.9		d

References

1. Vince, I., Dimitrijević, M. S. and Kršljanin, V., in: "Progress in Stellar Spectral Line Formation Theory" (Edited by J. Beckman, L. Crivelari) (Reidel, Dordrecht/Boston/Lancaster 1985), p. 373.
2. Sahal-Béchot, S., Astron. Astrophys. **1**, 91 (1969).
3. Sahal-Béchot, S., Astron. Astrophys. **2**, 322 (1969).
4. Griem, H. R., "Spectral Line Broadening by Plasmas" (Academic Press, New York 1974).
5. Dimitrijević, M. S. and Konjević, N., J. Quant. Spectrosc. Radiat. Transf. **24**, 451 (1980).
6. Dimitrijević, M. S. and Kršljanin, V., Astron. Astrophys. **165**, 269 (1986).
7. Jacobs, J. M. and Dworetsky, M. M., Nature **299**, 535 (1982).
8. Sadakane, K., Jugaky, J. and Takada-Hidai, M., Astrophys. J. **325**, 776 (1988).
9. Fuhrmann, K., Astron. Astrophys. Suppl. Series **80**, 399 (1989).
10. Danezis, E., Theodossiou, E. and Laskarides, P. G., Astrophys. Space Sci. **179**, 111 (1991).
11. Dimitrijević, M. S., in: "Accuracy of Element Abundance from Stellar Atmospheres" (Lecture Notes in Physics 356) (Edited by R. Wehrse) (Springer, Berlin/Heidelberg 1990), p. 31.
12. Dimitrijević, M. S., in: "Sun and Planetary System" (Astrophysics and Space Library 96) (Edited by W. Fricke and G. Teleki) (Reidel, Dordrecht, Boston/London 1982), p. 101.
13. Dimitrijević, M. S., in: "Physics of Formation of Fe II Lines Outside LTE" (Edited by R. Viotti, A. Vitone and M. Friedjung) (Reidel, Dordrecht 1990), p. 211.

14. Popović, L. Č. and Dimitrijević, M. S., Astron. Astrophys. Suppl. Series **102**, 17 (1993).
15. Dimitrijević, M. S. and Popović, L. Č., Astron. Astrophys. Suppl. Series **101**, 583 (1983).
16. Dimitrijević, M. S., Astrophys. Lett. Commun. **28**, 381 (1993).
17. Dimitrijević, M. S., Djurić, Z. and Mihajlov, A. A., J. Phys. **D27**, 247 (1994).
18. Labat, O., Djeniže, S., Labat, J., Purić, J. and Srećković, A., Phys. Lett. **143**, 9 (1990).
19. Labat, O., Djeniže, S., Purić, J., Labat, J. M. and Srećković, A., J. Phys. **B24**, 1251 (1991).
20. Purić, J., Ćuk, M. and Lakićević, I. S., Phys. Rev. **A32**, 1106 (1985).
21. Djeniže, S., Labat, M. S. and Purić, J., Proc. XXI ICPIG, Bochum, 227 (1993).
22. Bates, D. R. and Damgaard, A., Phyl. Trans. Roy. Soc. Ser. **A242**, 101 (1949).
23. Gruzdev, P. F., Opt. Spectr. **25**, 2 (1968).
24. Warner, B. and Kirkpatrick, R. C., Mon. Not. R. Astron. Soc. **142**, 265 (1969).
25. Gruzdev, P. F., Opt. Spectr. **27**, 877 (1969).
26. Bengtson, R. D. and Miller, M. H., Phys. Rev. **A14**, 1915 (1976).
27. Ostrovich, A. L. and Terzikov, V. V., Opt. Spectr. **44**, 711 (1978).
28. Moore, C. E., "Atomic Energy Levels", Vol. II, III, NSRDS-NBS 35, (U.S. Government Printing Office, Washington, D.C. 1971).
29. Li, H. and Andrew, K. L., J. Opt. Soc. Am. **61**, 96 (1971).
30. Li, H. and Andrew, K. L., J. Opt. Soc. Am. **62**, 255 (1972).
31. Li, H. and Andrew, K. L., J. Opt. Soc. Am. **62**, 1476 (1972).
32. Sobelman, I. I., "Atomic Spectra and Radiative Transitions" (Springer-Verlag, Berlin 1979).
33. Dimitrijević, M. S. and Popović, M. M., Astron. Astrophys, **217**, 201 (1989).
34. Lanz, T., Dimitrijević, M. S. and Artru, M.-C., Astron. Astrophys. **192**, 249 (1988).

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On the S III and S IV Spectral Lines Stark Broadening Parameters

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Abstract

Stark widths of three S III spectral lines belonging to 4p–5p transitions have been measured and calculated. Measurements have been performed in a low pressure linear pulsed arc at $2.1 \cdot 10^{23}\,m^{-3}$ electron density and 40 000 K electron temperature. Calculations for S III lines were performed by using the modified semiempirical approach. For S IV $4s^2S$–$4p^2P^o$ multiplet, calculations were performed within the semiclassical perturbation formalism. The obtained results were compared with other theoretical and experimental data.

1. Introduction

Stark broadening of S III and S IV lines has been considered several times experimentally [1, 2] and theoretically [3–9] due to the increasing significance of the multiply-charged ion lines for research and modelling of hot, dense astrophysical and laboratory plasmas (see e.g. Refs [9] and [10]). The experimental study of S III lines has been performed up to now only for lines from 4s–4p and 4p–4d transitions [1, 2]. Our intention here is to supply Stark broadening data for lines from S III 4p–5s transition, not experimentally investigated up to now. The experimental results will be compared with the theoretical results calculated by using the modified semiempirical approach [4], the approximate semiclassical approach [12] and its modification [4]. Since for S IV, the new atomic energy level data enable application of the full semiclassical perturbation calculation [3, 14], the S IV lines will be considered here as well.

2. Apparatus and procedure

Details of the experimental apparatus were described elsewhere [2]. A pulsed discharge occurred in a Pyrex discharge tube of 5 mm i.d. and had an effective plasma length of 7.4 cm. The tube had end on quartz windows. The working gas was SO_2 at an initial filling pressure of 400 Pa. A capacitor of 0.3 μF was charged up to 14.6 kV and supplied discharge currents up to 6.0 kA. The discharge period was 3.7 μs.

Spectroscopic observations of isolated spectral lines were made end-on along the axis of the discharge tube. Great care was taken to minimize the influence of the selfabsorption on Stark FWHM (fullwidth at half intensity maximum) determination. In order to find existence of selfabsorption of lines, one has to check whether the ratio of their intensities (I) is the same as the ratio of products of spontaneous transition probabilities (A) and statistical weights (g) of their upper level, i.e.: $I_1 : I_2 = A_1 g_1 : A_2 g_2$. In the case of the spectral lines from the S III $4p^3D$–$5s^3P^o$ 17UV multiplet this ratio were found to be the same within the experimental error, proving that no significant selfabsorption exists.

The spectral line profiles were recorded by the step by step method, described elsewhere [2], using spectrograph–photomultiplier combination. The measured profiles were of the Voigt type due to the convolution of the Lorentzian Stark profile and the Gaussian profiles caused by Doppler and instrumental broadening. Van der Waals and resonance broadening were found to be negligible. A standard deconvolution procedure [15] was used. Domination of the Lorentzian part was evident in the Voigt profile.

The electron density was measured using a single wavelength He–Ne laser interferometer for the visible 6328 Å transition with an estimated error of: ±7%. Peak electron density was found to be $2.4 \cdot 10^{23}\,m^{-3}$. The electron temperature was deduced from the relative intensity ratios of 4333.7 Å S III and S II 5646.9 Å lines, assuming the existence of the LTE. It was found to be 40 000 K ± 14% at 5 μs after the beginning of the discharge and decayed slowly during the first 20 μs. The necessary atomic data were used from Ref. [16].

3. Method of calculation

According to the MSE approach [4, 17] the electron impact full width (FHWM) of an ion line is given as

$$W_{MSE} = N\frac{8\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}} \times \left\{\sum_{l_i\pm1} R^2[n_i l_i, n_i(l_i \pm 1)]\tilde{g}\left(\frac{E}{\Delta E_{l_i, l_i\pm1}}\right) + \sum_{l_f\pm1} R^2[n_f l_f, n_f(l_f \pm 1)]\tilde{g}\left(\frac{E}{\Delta E_{l_f, l_f\pm1}}\right) + \left(\sum_{i'} R^2_{ii'}\right)_{\Delta n\neq 0} g(x_{n_i, n_i+1}) + \left(\sum_{f'} R^2_{ff'}\right)_{\Delta n\neq 0} g(x_{n_f, n_f+1})\right\}, \quad (1)$$

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and the corresponding Stark shift as

$$d = N\frac{4\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}} \times \left\{\varepsilon_{l_i,\,l_i+1}R^2[n_i l_i,\, n_i(l_i+1)]\tilde{g}_{\rm sh}\left(\frac{E}{\Delta E_{l_i,\,l_i+1}}\right) - \varepsilon_{l_i,\,l_i-1}R^2[n_i l_i,\, n_i(l_i-1)]\tilde{g}_{\rm sh}\left(\frac{E}{\Delta E_{l_i,\,l_i-1}}\right) - \varepsilon_{l_f,\,l_f+1}R^2[n_f l_f,\, n_f(l_f+1)]\tilde{g}_{\rm sh}\left(\frac{E}{\Delta E_{l_f,\,l_f+1}}\right) + \varepsilon_{l_f,\,l_f-1}R^2[n_f l_f,\, n_f(l_f-1)]\tilde{g}_{\rm sh}\left(\frac{E}{\Delta E_{l_f,\,l_f-1}}\right) + \left(\sum_{i'} R^2_{ii'}\right)_{\Delta n\neq 0} g_{\rm sh}(x_{n_i},\, x_{n_i+1}) - 2\sum_{i'(\Delta E_{ii'}<0)} R^2_{ii',\,\Delta n\neq 0}\, g_{\rm sh}\left(\frac{E}{\Delta E_{n_i l_i,\,n_{i'} l_{i'}}}\right) - \left(\sum_{f'} R^2_{ff'}\right)_{\Delta n\neq 0} g_{\rm sh}(x_{n_f},\, x_{n_f+1}) + 2\sum_{f'(\Delta E_{ff'}<0)} R^2_{ii',\,\Delta n\neq 0}\, g_{\rm sh}\left(\frac{E}{\Delta E_{n_f l_f,\,n_{f'} l_{f'}}}\right) + \sum_k \delta_k\right\} \quad (2)$$

where the initial level is denoted with i and the final one with f and the square of the matrix element $\{R^2[n_k l_k,\, n_k(l_k \pm 1)],\, k = i, f\}$ is

$$R^2[n_k l_k,\, n_k(l_k \pm 1)] = \left(\frac{3n_k^*}{2Z}\right)^2 \frac{l_>}{2l_k+1}(n_k^{*2} - l_k^2)\Phi^2(n_{l_k-1}^{*2},\, n_{l_k}^{*2},\, l_k) \quad (3)$$

and

$$\left(\sum_{k'} R^2_{kk'}\right)_{\Delta n\neq 0} = \left(\frac{3n_k^*}{2Z}\right)^2 \tfrac{1}{9}(n_k^{*2} + 3l_k^2 + 3l_k + 11) \quad (4)$$

where $l_> = \max(l_k,\, l_{k'})$, and with l is denoted the angular momentum quantum number.

In eqs (1–4) N and T are electron density and temperature, respectively, and Φ^2 is the Bates–Damgaard factor tabulated e.g. in Ref. [18]. Here, $g(x)$, $g_{\rm sh}(x)$ and $\tilde{g}(x)$, $\tilde{g}_{\rm sh}(x)$ are the semiempirical [11] and the modified semiempirical [4, 17] Gaunt factors for Stark width and shift, respectively. The factor $\varepsilon_{kk'} = (E_{k'} - E_k)/|E_{k'} - E_k|$, where E_k and $E_{k'}$ are the energy of the considered and its perturbing level. The sum $\sum_k \delta_k$ is different from zero only if perturbing levels strongly violating the assumed approximations exist and may be evaluated as

$$\delta_i = \pm R^2_{ii'}\left[g_{\rm sh}\left(\frac{E}{\Delta E_{i,\,i'}}\right) \mp g_{\rm sh}(x_{n_i,\,n_i+1})\right], \quad (5)$$

for the upper level, and

$$\delta_f = \mp R^2_{ff'}\left[g_{\rm sh}\left(\frac{E}{\Delta E_{f,\,f'}}\right) \mp g_{\rm sh}(x_{n_f,\,n_f+1})\right], \quad (6)$$

for the lower level. In eqs (5) and (6) lower signs correspond to $\Delta E_{jj'} < 0$; $x_{n_k,\,n_k+1} \approx 3kTn_k^{*3}/(2Z^2E_{\rm H})$, where $\Delta E_{kk'} = |E_k - E_{k'}|$, n_k is the principal, n_k^* the effective principal quantum number, $E = 3kT/2$ and $(Z-1)$ is the ionic charge.

In comparison with the semiclassical perturbation approach [4, 17], the modified semiempirical approach needs a considerably smaller number of atomic data. In fact, if there are no perturbing levels strongly violating the assumed approximation, for e.g. the line width calculations, we need only the energy levels with $\Delta n = 0$ and $l_{if} = l_{if} \pm 1$, since all perturbing levels with $\Delta n \neq 0$, needed for a full semiclassical investigation are lumped together and approximately estimated.

Within the frame of the complete semiclassical perturbation theory [3, 14] the full width of a charged particle-impact broadened isolated spectral line, can be expressed in terms of cross sections for elastic and inelastic processes as

$$W = N\int vf(v)\,{\rm d}v\left(\sum_{i'\neq i}\sigma_{ii'}(v) + \sum_{f'\neq f}\sigma_{ff'}(v) + \sigma_{\rm el}\right) + W_{\rm R}, \quad (7)$$

$$d = N\int vf(v)\,{\rm d}v\int_{R_s}^{R_D} 2\pi\rho\,{\rm d}\rho\,\sin 2\phi_{\rm p}. \quad (8)$$

Here, $f(v)$ is the Maxwellian velocity distribution function for electrons and ρ denotes the impact parameter of the incoming electron. The inelastic cross section $\sigma_{jj'}(v)$ can be expressed by an integration over the impact parameter of the transition probability $P_{jj'}(\rho, v)$

$$\sum_{i'\neq i}\sigma_{jj'}(v) = \tfrac{1}{2}\pi R^2 + \int_{R_1}^{R_D}\sum_{j\neq j'} P_{jj'}(\rho, v),\; j = i, f \quad (9)$$

and the elastic cross section is given by

$$\sigma_{\rm el} = 2\pi R_2^2 + \int_{R_2}^{R_D} 8\pi\rho\,{\rm d}\rho\,\sin^2\delta, \quad (10)$$

$$\delta = (\phi_{\rm p}^2 + \phi_{\rm q}^2)^{1/2}. \quad (11)$$

The phase shifts $\phi_{\rm p}$ and $\phi_{\rm q}$ due respectively to the polarisation potential (r^{-4}) and to the quadrupolar potential (r^{-3}) are given in Section 3, of Chapter 2 in Ref. [14]. The contribution of the Feshbach resonances is given by $W_{\rm R}$ [19]. Here, $R_{\rm D}$ is the Debye radius. All the cut-offs R_1, R_2, R_3 are described in Section 1 of Chapter 3 in Ref. [3]. For multiply charged ions (the ionization degree larger than one), the cut-off R_1 can become smaller than the mean atomic radii $\langle r_j\rangle$, $\langle r_{j'}\rangle$. In such a case we have used the cut-off for excitation of ions by electron impacts [20, 21] adapted in Ref. [22] for Stark broadening purposes

$$\sum_{j'\neq j}\sigma_{jj'} = \sum_{j'\neq j}\int_{{\rm Max}\,(\langle r_j\rangle,\,\langle r_{j'}\rangle)}^{R_D} 2\pi\rho\,{\rm d}\rho P_{jj'}(\rho, v) \quad (12)$$

where $R_1 < {\rm Max}\,(\langle r_j\rangle, \langle r_{j'}\rangle)$.

The formulae for the ion-impact broadening parameters are analogous.

4. Results and discussion

In Ref. [4] it is emphasized that "for S III, data on the 4f and 5p levels are unavailable which may affect the results for the multiplets 15 UV–18 UV". This statement concerns as well to the multiplet 19 UV [9]. In spite of the fact that a new comprehensive investigation of S III spectrum [23] exists, as well as a new review of critically selected atomic energy level data [13], the reliable data on 4f and 5p energy level positions are still missing. Since the experimental results obtained here for S III 17 UV multiplet are (in

average) around 3 times larger than calculated [9], we recalculated them with the inclusion of the new energy values for 4d levels [23] and of the estimated [24] positions of $5p^3P$ level (220419 cm^{-1}) and of $5p^3D$ level (219184 cm^{-1}). The present experimental results for line widths within S III $4p^3D$–$5s^3P^o$ (17 UV) and $4p^3S$–$5s^3P^o$ (20 UV) multiplets are compared in Table I with the present calculations by using the modified semiempirical approach [4, 17], the simplified semiclassical approach [12, eq. 526] and its modification [4]. One can see that the results obtained by using the modification [4] of the simplified semiclassical approach [12, eq. (526)] and the modified semiempirical approach [4], agree better with the present experimental results than with the simplified semiclassical approach [12, eq. (526)]. The modified semiempirical approach gives often good agreement with experiment, sometimes even better than more sophisticated approaches, since with the help of the effective Gaunt factor derived from cross section measurements for just singly-, doubly- and triply-charged ions, it is adjusted to provide good average agreement with experiments for a large number of lines of different radiators [4]. In such a way it is convenient for such astrophysical problems like opacity calculations, atmosphere modelling or the numerical simulation of stellar spectra, where a good average accuracy is needed and the accuracy/inaccuracy of a particular value is not critical. If one takes into account that the error bars of the approximate approaches are within 50 per cent [12] and that the positions of 5p levels are approximate, the agreement with experiment is within the error bars of theoretical uncertainties. Moreover, with the existing atomic data the present calculations are only applicable since there is a no sufficiently complete set of accurate S III energy levels to perform more sophisticated semiclassical calculations. In Table II are shown our calculations for S III $4p^3D$–$5s^3P^o$ (17 UV) and $4p^3S$–$5s^3P^o$ (20 UV) multiplets, for a perturber density of 10^{17} cm^{-3} and temperatures $T = 10\,000$ K–160 000 K. When more reliable results for positions of S III, 4f and 5p energy levels become available, data for S III, 15 UV, 16 UV, 18 UV and 19 UV multiplets [9] and presented here data for 17 UV and 20 UV multiplets should be recalculated.

Needed energy levels for S IV have been taken from Ref. [13]. Our results for S IV $4s^2S$–$4p^2P^o$ multiplet Stark broadening parameters due to electron-, proton-, and N II-impacts, are shown in Table III, for a perturber density of 10^{17} cm^{-3} and temperatures $T = 10\,000$–200 000 K. We also specify a parameter C [25], which gives an estimate for the maximum perturber density for which the line may be treated as isolated when it is divided by the corresponding full width at half maximum. For each value given in Table III, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid [3, 14]. The ionized nitrogen was selected as the second perturbing ion, since in the experiment in Ref. [1], the nitrogen was the carrier gas. In Fig. 1, our results for S IV $4s^2S$–$4p^2P^o$ multiplet Stark broadening parameters, are compared with experimental results [1] and other theoretical calculations, i.e. with results obtained by using

Table I. *Stark full widths of S III spectral lines for an electron density of* $2.1 \cdot 10^{17}$ cm^{-3} *and* $T = 40\,000$ *K. With* W_m *is denoted experimental width. Present theoretical results:* W_{MSE} *– by using the modified semiempirical approach [4];* W_{GM} *– by using the modified version [4] of the simplified semiclassical approach [12, eq. (526)];* W_G *– by using the Griem's simplified semiclassical approach [12, eq. (526)]*

	Transition	λ[Å]	W_m[Å]	W_{MSE}[Å]	W_{GM}[Å]	W_G[Å]
S III	$4p^3D$–$5s^3P^o$	2508.15	0.402	0.483	0.466	0.623
	(17 UV)	2499.08	0.360	0.483	0.466	0.623
S III	$4p^3S$–$5s^3P^o$	2785.49	0.380	0.569	0.552	0.752
	(20 UV)					

Table II. *This table shows results for full widths (W) in Å for S III* $4p^3S$–$5s^3P^o$ *and* $4p^3D$–$5s^3P^o$ *multiplets obtained by using:* W_{MSE} *– the modified semiempirical approach [4];* W_G *– the simplified semiclassical approach [12, eq. (526)]; and,* W_{GM} *– its modification [4]. The argument of the Gaunt factor* $x_{jj'} = 3kT/2\Delta E_{jj'}$ *for the closest perturbing level is given too*

	Transition	T[K]	W_{MSE}[Å]	W_{GM}[Å]	W_G[Å]	$3kT/2\Delta E$
S III	$4p^3D$–$5s^3P^o$	10 000	0.395	0.327	0.511	0.46
	Mult. 17 UV	20 000	0.285	0.261	0.383	0.92
	2508.2 Å	40 000	0.230	0.222	0.299	1.8
		80 000	0.206	0.200	0.245	3.7
		160 000	0.189	0.185	0.210	7.4
S III	$4p^3S$–$5s^3P^o$	10 000	0.477	0.395	0.618	0.38
	Mult. 20 UV	20 000	0.339	0.312	0.461	0.77
	2785.5 Å	40 000	0.271	0.263	0.358	1.5
		80 000	0.235	0.235	0.292	3.1
		160 000	0.215	0.217	0.249	6.2

Table III. *This table shows electron-, proton-, and N II-impact broadening parameters for S IV* $4s^2S$–$4p^2P^o$, *for a perturber density of* 10^{17} cm^{-3} *and temperatures from 10 000 up to 200 000 K. By dividing C[25] with the corresponding full width at half maximum, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used*

Perturber density = 1 × E + 17 cm − 3

	Electrons			Protons		N II	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
S IV 4s–4p	10 000	0.323	0.242E-02	0.153E-02	−0.629E-03	0.261E-02	−0.628E-03
3104.9 Å	20 000	0.228	−0.410E-02	0.369E-02	−0.139E-02	0.538E-02	−0.136E-02
$C = 0.31E + 21$	50 000	0.149	−0.448E-02	0.780E-02	−0.306E-02	0.950E-02	−0.279E-02
	100 000	0.113	−0.506E-02	0.110E-01	−0.446E-02	0.118E-01	−0.391E-02
	150 000	0.989E-01	−0.550E-02	0.121E-01	−0.533E-02	0.128E-01	−0.445E-02
	200 000	0.909E-01	−0.489E-02	0.129E-01	−0.574E-02	0.134E-01	−0.482E-02

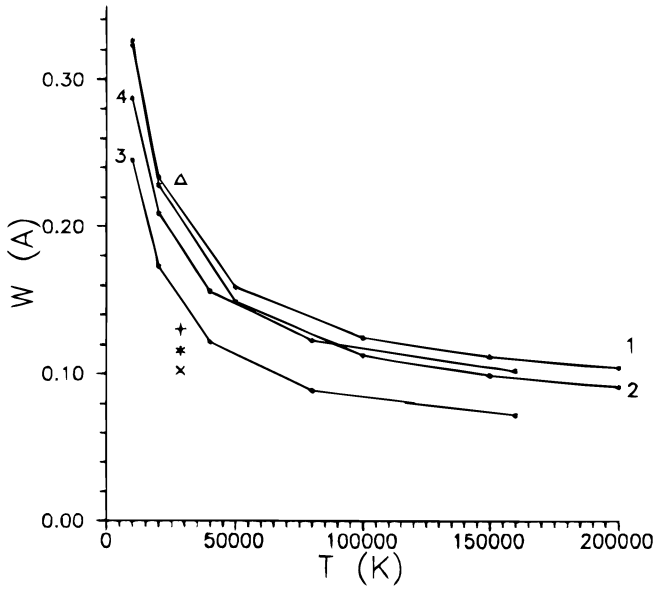

Fig. 1. Full Stark widths for S IV $4s^2S$–$4p^2P^o$ multiplet as a function of temperature for an electron density of $10^{17}\,cm^{-3}$ Experiment: * – Platiša *et al.* (1979) [1]. Theory: 1 – present semiclassical results with the ion broadening contribution included; 2 – present semiclassical results, electron broadening contribution only; 3 – modified semiempirical formula [4]; 4 – calculations [4] by using the simplified semiclassical approximation [12, eq. (526)]; × – Hey and Breger (1980) [5], the method I; + – Hey and Breger (1980) [5], the method II; Δ – semiclassical calculations of Dimitrijević and Konjević (1982) [7].

the modified semiempirical formula [4], calculations by using the simplified semiclassical approximation [12, eq. (526)], approximate approaches from Ref. [5], and semiclassical calculations from Ref. [7]. Experimental results [1] compare better with the approximate approaches of Refs. [5] and [4] than with more sophisticated semiclassical calculations. More experimental data will be useful for a better understanding of these discrepancies.

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References

1. Platiša, M., Popović, M., Dimitrijević, M. and Konjević, N., J. Quant. Spectrosc. Radiat. Transf. **22**, 333 (1979).
2. Djeniže, S. *et al.*, Phys. Rev. A **42**, 2379 (1990).
3. Sahal-Bréchot, S., Astron. Astrophys. **1**, 91 (1969).
4. Dimitrijević, M. S. and Konjević, N., J. Quant. Spectrosc. Radiat. Transf. **24**, 451 (1980).
5. Hey, J. D. and Breger, P., J. Quant. Spectrosc. Radiat. Transf. **24**, 427 (1980).
6. Dimitrijević, M. S. and Konjević, N., in: "Spectral Line Shapes" (Edited by B. Wende) (W. de Gruyter, Berlin, New York 1981), p. 211.
7. Dimitrijević, M. S. and Konjević, N., J. Quant. Spectrosc. Radiat. Transf. **27**, 203 (1982).
8. Dimitrijević, M. S., Bull. Obs. Astron. Belgrade **139**, 31 (1988).
9. Dimitrijević, M. S., Astron. Astrophys. Suppl. Series **76**, 53 (1988).
10. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **96**, 63 (1992).
11. Griem, H. R., Phys. Rev. **165**, 258 (1968).
12. Griem, H. R., "Spectral Line Broadening by Plasmas" (Academic Press, New York 1974).
13. Martin, W. C., Zalubas, R. and Musgrove, A., J. Phys. Chem. Ref. Data **19**, 821 (1990).
14. Sahal-Bréchot, S., Astron. Astrophys. **2**, 322 (1969).
15. Davies, J. T. and Vaughan, J. M., Astrophys. J. **137**, 1302 (1963).
16. Wiese, W. L., Smith, M. W. and Miles, B. M., "Atomic Transition Probabilities" NSRDS-NBS 22, (U.S. Govt. Printing Office, Washington D.C. 1969), Vol. II.
17. Dimitrijević, M. S. and Kršljanin, V., Astron. Astrophys. **165**, 269 (1986).
18. Oertel, G. K. and Shomo, L. P., Astrophys. J. Suppl. Series **16**, 175 (1968).
19. Fleurier, C., Sahal-Bréchot, S. and Chapelle, J., J. Quant. Spectrosc. Radiat. Transf. **17**, 595 (1977).
20. Seaton, M. J., Proc. Phys. Soc. **79**, 1105 (1962).
21. Burges, D., Proceedings of the Symposium on Atomic Collision Processes in Plasmas, Culham, England (1964).
22. Feautrier, N., Ann. d'Astrophys. **31**, 305 (1968).
23. Johansson, L., Magnusson, C. E., Joelsson, I. and Zetterberg, P. O., Physica Scripta **46**, 221 (1992).
24. Breger, P., MSc. Thesis, University of Cape Town (1980).
25. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transf. **31**, 301 (1984).
26. Jones, W. W., Benett, S. M. and Griem, H. R., Calculated Electron Impact Broadening Parameters for Isolated Spectral Lines from the Singly Charged Ions: Lithium through Calcium, Tech. Rep. No 71–128, Univ. of Maryland, College Park, Maryland (1971)

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Stark Broadening of Li II Spectral Lines

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Abstract

Using a semiclassical approach, we have calculated electron-, proton-, and ionized helium-impact line widths and shifts for 29 Li II multiplets. The resulting data have been compared with existing theoretical values.

1. Introduction

Stark-broadening parameters for singly charged lithium lines are of interest for Stark broadening theory investigations since the He-like Li II spectrum is suitable for theoretical research. Stark broadening parameters for Li II lines have been investigated theoretically [1] (see as well Ref. [2]). They are of interest for the examinations of regularities and systematic trends within He isoelectronic sequence as well. For the systematic study of such regularities within the isoelectronic sequence we need the corresponding data for an as large number of successive ions as possible and Li II is the first He-like ion of the series. Moreover, Stark broadening parameters of ion lines are of interest for solar and stellar opacities calculations, investigations of subphotospheric layers, stellar plasma modelling and diagnostic, abundance determinations, etc.

In order to provide the corresponding atomic data for stellar envelope opacities calculations, an international "Opacity project" [3], providing essentially data on energy levels and oscillatory strengths for a large number of atoms and ions, and a number of photoionization cross sections and Stark broadening data as well, has been formed in 1984. After the end of this project the subsequent "Iron Project" [4] will provide data on electron impact excitation cross sections for atoms and ions along isoelectronic sequences. In order to complete as much as possible such data needed for astrophysical and laboratory plasma research and stellar opacities calculations, we decided to provide Stark broadening data for a large set of atoms and ions.

By using the semiclassical-perturbation formalism [5, 6], we have provided up to now Stark broadening parameters for 79 neutral helium multiplets [7–11], 62 Na [12–14], 51 K [15, 16], 61 Li [17, 18], 25 Al [19, 20], 24 Rb [21, 22], 3 Pd [23], 19 Be [24, 25], 270 Mg [26–29], 28 Ca II [30, 31], 30 Be II [32, 33], 23 Al III [34–36], 10 Sc III, 10 Ti IV [36], 39 Si IV [38, 39], 90 C IV [40–42], 5 O IV, 19 O V [43–45], 30 N V [46], 30 O VI [47], 21 S VI [48], 10 F VII [49], 20 Ne VIII, 8 Na IX [50, 51], 7 Al XI and 9 Si XII [52, 53] multiplets become available.

Here, electron, proton-, and ionized helium-impact line widths and shifts for 29 Li II multiplets have been calculated. We present and discuss in this article, the results for Li II, along with a comparison with other theoretical results [1].

2. Theory

A detailed description of the formalism is given in Refs [5, 6] and a summary together with adopted modifications has been repeated several times (see, e.g. Ref. [40]. Consequently, only the basic details of calculations will be presented here. Stark full width (W) at the intensity half maximum (FWHM) and shift (d) of an isolated spectral line, may be expressed as [5, 6, 40]

$$W = N \int vf(v)\, \mathrm{d}v \left(\sum_{i' \neq i} \sigma_{ii'}(v) + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_{\mathrm{el}} \right) + W_{\mathrm{R}},$$

$$d = N \int vf(v)\, \mathrm{d}v \int_{R_3}^{R_{\mathrm{D}}} 2\pi\rho\, \mathrm{d}\rho \sin 2\phi_p \qquad (1)$$

where N is the electron density, $f(v)$ the Maxwellian velocity distribution function for electrons, ρ denotes the impact parameter of the incoming electron, i and f denote the initial and final atomic energy levels, and i', f' their corresponding perturber levels, while W_{R} gives the contribution of the Feshbach resonances [5]. The inelastic cross section $\sigma_{j,j'}(v)$ can be expressed by an integral over the impact parameter of the transition probability $P_{jj'}(\rho, v)$ as

$$\sum_{i' \neq i} \sigma_{jj'}(v) = \tfrac{1}{2}\pi R^2 + \int_{R_1}^{R_{\mathrm{D}}} \sum_{j \neq j'} P_{jj'}(\rho, v), \quad j = i, f \qquad (2)$$

and the elastic cross section is given by

$$\sigma_{\mathrm{el}} = 2\pi R_2^2 + \int_{R_2}^{R_{\mathrm{D}}} 8\pi\rho\, \mathrm{d}\rho \sin^2 \delta,$$

$$\delta = (\phi_{\mathrm{p}}^2 + \phi_{\mathrm{q}}^2)^{1/2}. \qquad (3)$$

The phase shifts ϕ_{p} and ϕ_{q} due respectively to the polarization potential (r^{-4}) and to the quadrupolar potential (r^{-3}), are given in Section 3 of Chapter 2 in Ref. [2]. R_{D} is the Debye radius. All the cut-offs R_1, R_2, R_3 are described in Section 1 of Chapter 3 in Ref. [6].

The formulae for the ion-impact widths and shifts are analogous. We note here that the inelastic collision contribution to the ion-impact widths is included as well.

Differences between the present calculations and the calculations in Ref. [1] may be divided into theoretical differences and differences in input data.

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First of all, the lower cut-offs are different in both methods. In Ref. [1] the same cut-off for widths and shifts as well as for both elastic and inelastic collisions has been used. The effect of the change of the set of values for the cut-offs R_1, R_2, and R_3 has been studied and discussed in detail in Ref. [6]: the final choice of the cut-offs was adopted for physical reasons (it allows for the unitarity of the S-matrix) and followed Ref. [54]. It has been used up until now. We will not come back again on this point in the present paper.

Moreover, in the present method, with the help of the symmetrization procedure one takes into account the impact electron velocity change during an inelastic collision, which is not taken into account in Ref. [1]. The importance of the symmetrization has been shown in Ref. [54]. It has been demonstrated there that the symmetrization improves considerably (by a factor of two) semiclassical cross sections for small energies (close to the threshold), which are overestimated without symmetrization.

Also, for the difference from Ref. [1] we take into account explicitly the elastic collision contribution and the contribution of the Feshbach resonances. The importance of the Feshbach resonances for cross sections of ion lines, is well known since the beginning of the 1960s. In Ref. [55], a simple quantum mechanical formula which enables the estimate of their influence is presented. The alternative is to use the full close-coupling method. Petrini [55] demonstrated the importance of these resonances on the example of the excitation of the green Fe XIV line in the solar corona, with the help of Gailitis' formula. Malinovsky [56] has shown as well that the semiclassical limit of the Galitis formula gives very good results for O V UV lines in the transition zone of the solar corona. Within the present method, the semiclassical limit of the Gailitis formula has been used for the first time in Ref. [57], where it has been demonstrated that the inclusion of Feshbach resonances increase the width of the Mg II resonance lines with 30%.

As another difference in comparison with the method used in Ref. [1], where it is only indicated how to include the Debye shielding correction when necessary, the Debye cut-off is included in the present calculations. Also, while in Ref. [1], the ion-broadening contribution is only a correction within the quasistatic theory, the complete semiclassical perturbation calculation has been performed here for the ion-impact broadening. The differences in the input data are first of all the more recent atomic energy level data [58] and the requirements for the more complete energy level data set for each particular transition. The consequence is that for 15 multiplets included in Ref. [1], there is not enough atomic energy levels for the complete semiclassical perturbation calculation according to our requirements.

Both methods have been compared with critically-selected experimental data for 13 He I multiplets [59] and it was found that the agreement between experimental data and both semiclassical calculations is within the limits of 20 percent, which is the predicted accuracy of the semiclassical method. [2].

3. Results and discussion

Energy levels for Li II lines have been taken from Ref. [58]. Oscillator strengths have been calculated by using the method of Bates and Damgaard [60, 61]. For higher levels, the method described in Ref. [62] has been used. In addition to electron-impact full halfwidths and shifts, Stark-broadening parameters due to proton- and ionized-helium impacts have been calculated. Our results are shown in Table I for a perturber density of $10^{17}\,\mathrm{cm}^{-3}$ and temperatures $T = 5000 - 40\,000\,\mathrm{K}$. We also specify a parameter c [40, 63] which, when it is divided by the corresponding electron-impact full width at half maximum, gives an estimate for the maximum perturber density for which the line may be treated as isolated. For each value given in Table I, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid [5, 6]. Values for $0.1 < NV \leqslant 0.5$ are denoted by an asterisk. When the impact approximation is not valid, the ion-broadening contribution may be estimated by using quaistatic estimations [2, 64]. The accuracy of the results obtained decreases when broadening by ion interactions becomes important. At high densities, the results are no longer linear with density due to Debye screening. This effect is more important for the shift than for the width. Stark-broadening parameter tables for high densities will be published elsewhere [65].

In Figs 1 and 2 the electron-impact full half widths and shifts within $2s^3S$–np^3P^o series have been compared with semiclassical results of Jones *et al.* [1, 2]. We can see gradual change of Stark broadening parameters permitting the interpolation of new data or critical evaluation of mutual consistency of existing data, as in our previous analyses (see e.g. Ref. [40]).

We see in Figs 1 and 2 that the agreement between present calculation and calculations of Jones *et al.* [1, 2] is better at higher temperatures, when the inelastic contribution to the width dominates, than at lower ones, when differences in cut-off procedure and the symmetrization influence are more significant.

Generally, the disagreement of present calculations with the calculations from Ref. [1] is larger than for He I [59]. When we have transitions involving highly excited levels, when a close perturbing energy level exists (e.g. 5p), the

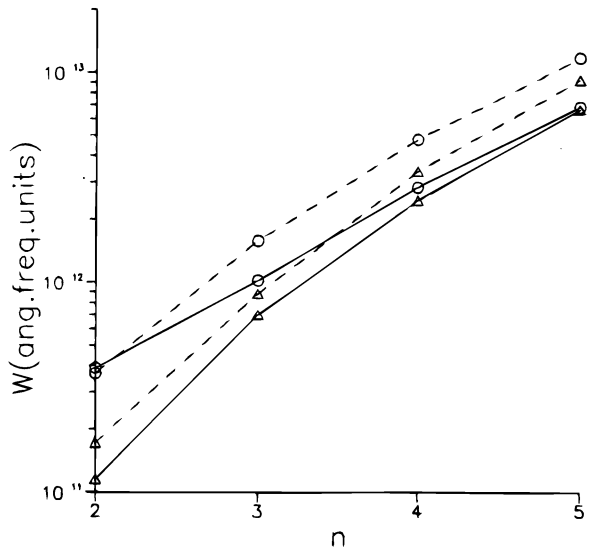

Fig. 1. Electron-impact full half-widths (in angular frequency units) for Li II $2s^3S$–np^3P^o lines as a function of n for $T = 5000\,\mathrm{K}$ (○) and $40\,000\,\mathrm{K}$ (△) at $N_e = 10^{17}\,\mathrm{cm}^{-3}$. With (———) are noted present calculations and with (– – – –) semiclassical calculations of Jones *et al.* [1, 2].

Table I. *This table shows electron-, proton- and ionized helium-impact broadening parameters for Li II for a perturber density of 10^{17} cm^{-3} and temperatures from 5000 up to 40 000 K*

Perburber density = 10^{17} cm^{-3}							
Perturbers are:	Electrons		Protons		Ionized helium		
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
Singlets							
Li II 1S–2P	5000.0	0.557E−03	0.391E−04	0.502E−05	−0.214E−05	0.846E−05	−0.358E−05
199.3 Å	10000.0	0.395E−03	0.401E−04	0.107E−04	−0.449E−05	0.194E−04	−0.849E−05
c = 0.41E+18	20000.0	0.286E−03	0.274E−04	0.172E−04	−0.773E−05	0.328E−04	−0.154E−04
	40000.0	0.211E−03	0.175E−04	0.237E−04	−0.109E−04	0.465E−04	−0.223E−05
Li II 1S–3P	5000.0	0.282E−02	−0.308E−03	*0.227E−03	−0.187E−03		
178.0 Å	10000.0	0.228E−02	−0.246E−03	*0.334E−03	−0.270E−03		
c = 0.15E+17	20000.0	0.189E−02	−0.236E−03	*0.424E−03	−0.374E−03		
	40000.0	0.161E−02	−0.197E−03	*0.531E−03	−0.466E−03		
Li II 1S–4P	5000.0	*0.801E−02	−0.129E−02				
171.6 Å	10000.0	0.704E−02	−0.118E−02				
c = 0.59E+16	20000.0	0.625E−02	−0.995E−03				
	40000.0	0.555E−02	−0.806E−03				
Li II 1S–5P	5000.0	*0.161E−01	−0.303E−02				
168.7 Å	10000.0	*0.155E−01	−0.289E−02				
c = 0.34E+16	20000.0	*0.146E−01	−0.238E−02				
	40000.0	0.134E−01	−0.194E−02				
Li II 2S–2P	5000.0	2.37	−0.141	0.168E−01	−0.268E−01	0.295E−01	−0.447E−01
9584.1 Å	10000.0	1.69	−0.134	0.404E−01	−0.486E−01	0.768E−01	−0.923E−01
c = 0.96E+21	20000.0	1.25	−0.111	0.679E−01	−0.716E−01	0.134	−0.141
	40000.0	0.974	−0.121	0.974E−01	−0.906E−01	0.198	−0.185
Li II 2S–3P	5000.0	0.196	−0.265E−01	*0.147E−01	−0.120E−01		
1420.9 Å	10000.0	0.158	−0.209E−01	*0.216E−01	−0.173E−01		
c = 0.97E+18	20000.0	0.131	−0.182E−01	*0.273E−01	−0.241E−01		
	40000.0	0.112	−0.165E−01	*0.348E−01	−0.300E−01		
Li II 2S–4P	5000.0	*0.336	−0.521E−01				
1093.4 Å	10000.0	0.294	−0.470E−01				
c = 0.24E+18	20000.0	0.260	−0.429E−01				
	40000.0	0.231	−0.354E−01				
Li II 2S–5P	5000.0	*0.562	−0.101				
987.6 Å	10000.0	*0.537	−0.952E−01				
c = 0.12E+18	20000.0	*0.505	−0.811E−01				
	40000.0	0.465	−0.712E−01				
Li II 3S–4P	5000.0	*5.21	−1.21				
4157.6 Å	10000.0	4.62	−1.06				
c = 0.34E+19	20000.0	4.16	−0.888				
	40000.0	3.76	−0.735				
Li II 3S–5P	5000.0	*5.16	−1.07				
2953.6 Å	10000.0	*4.97	−1.03				
c = 0.11E+19	20000.0	*4.70	−0.859				
	40000.0	4.36	−0.744				
Li II 2P–3S	5000.0	0.188	0.810E−01	0.747E−02	0.888E−02	*0.150E−01	*0.130E−01
1755.3 Å	10000.0	0.147	0.633E−01	0.137E−01	0.134E−01	*0.281E−01	*0.238E−01
c = 0.92E+19	20000.0	0.127	0.521E−01	0.185E−01	0.180E−01	*0.380E−01	*0.340E−01
	40000.0	0.114	0.414E−01	0.233E−01	0.223E−01	*0.488E−01	*0.447E−01
Li II 2P–3D	5000.0	0.171	0.360E−01	0.117E−01	0.113E−01	*0.225E−01	*0.159E−01
1681.7 Å	10000.0	0.133	0.300E−01	0.188E−01	0.166E−01	*0.382E−01	*0.282E−01
c = 0.14E+19	20000.0	0.107	0.246E−01	0.248E−01	0.226E−01	*0.503E−01	*0.418E−01
	40000.0	0.876E−01	0.198E−01	0.320E−01	0.276E−01	*0.625E−01	*0.558E−01
Li II 3D–4P	5000.0	*6.70	−1.08				
4639.0 Å	10000.0	5.82	−0.958				
c = 0.43E+19	20000.0	5.13	−0.883				
	40000.0	4.54	−0.726				
Li II 3D–5P	5000.0	*6.16	−1.16				
3188.6 Å	10000.0	*5.86	−1.11				
c = 0.12E+19	20000.0	*5.47	−0.897				
	40000.0	5.02	−0.815				
Triplets							
Li II 2S–2P	5000.0	0.623	−0.455E−01	0.326E−02	−0.414E−02	0.557E−02	−0.693E−02
5486.1 Å	10000.0	0.441	−0.267E−01	0.766E−02	−0.800E−02	0.142E−01	−0.152E−01
c = 0.55E+21	20000.0	0.319	−0.231E−01	0.134E−01	−0.124E−01	0.260E−01	−0.247E−01
	40000.0	0.240	−0.247E−01	0.202E−01	−0.169E−01	0.408E−01	−0.349E−01

Table I. *Continued*

Perburber density = $10^{17}\,cm^{-3}$

Perturbers are:	Electrons		Protons		Ionized helium		
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
Li II 2S–3P	5000.0	0.780E−01	0.226E−02	0.355E−02	0.266E−02	*0.660E−02	*0.421E−02
1198.1 Å	10000.0	0.667E−01	0.436E−02	0.559E−02	0.417E−02	*0.109E−01	*0.754E−02
c = 0.25E+19	20000.0	0.590E−01	0.362E−02	0.709E−02	0.549E−02	*0.142E−01	*0.105E−01
	40000.0	0.535E−01	0.353E−02	0.860E−02	0.675E−02	*0.177E−01	*0.138E−01
Li II 2S–4P	5000.0	0.134	0.199E−01	*0.139E−01	*0.784E−02		
944.7 Å	10000.0	0.126	0.176E−01	*0.181E−01	*0.119E−01		
c = 0.65E+18	20000.0	0.121	0.156E−01	*0.224E−01	*0.172E−01		
	40000.0	0.116	0.146E−01	*0.261E−01	*0.210E−01		
Li II 2S–5P	5000.0	*0.269	*0.396E−01				
861.3 Å	10000.0	*0.266	*0.372E−01				
c = 0.27E+18	20000.0	0.266	0.371E−01				
	40000.0	0.261	0.309E−01				
Li II 3S–4P	5000.0	2.40	0.144	*0.202	*0.114		
3685.8 Å	10000.0	2.19	0.130	*0.261	*0.171		
c = 0.99E+19	20000.0	2.09	0.107	*0.322	*0.248		
	40000.0	2.01	0.112	*0.383	*0.299		
Li II 3S–5P	5000.0	*2.75	*0.214				
2675.3 Å	10000.0	*2.69	*0.239				
c = 0.26E+19	20000.0	2.68	0.260				
	40000.0	2.64	0.223				
Li II 2P–3S	5000.0	0.137	0.624E−01	0.395E−02	0.512E−02	0.777E−02	0.809E−02
1653.1 Å	10000.0	0.101	0.472E−01	0.707E−02	0.803E−02	*0.142E−01	*0.145E−01
c = 0.13E+20	20000.0	0.844E−01	0.388E−01	0.104E−01	0.106E−01	*0.217E−01	*0.202E−01
	40000.0	0.749E−01	0.308E−01	0.132E−01	0.130E−01	*0.281E−01	*0.264E−01
Li II 2P–4S	5000.0	0.168	0.107	*0.143E−01	*0.107E−01		
1166.6 Å	10000.0	0.143	0.886E−01	*0.196E−01	*0.157E−01		
c = 0.26E+19	20000.0	0.129	0.715E−01	*0.253E−01	*0.228E−01		
	40000.0	0.122	0.573E−01	*0.303E−01	*0.278E−01		
Li II 3P–4S	5000.0	3.41	1.73	*0.233	*0.176		
4882.8 Å	10000.0	3.04	1.43	*0.319	*0.257		
c = 0.42E+20	20000.0	2.86	1.15	*0.409	*0.365		
	40000.0	2.75	0.912	*0.500	*0.442		
Li II 2P–3D	5000.0	0.124	0.871E−02	0.352E−02	−0.313E−02	0.647E−02	−0.503E−02
1493.0 Å	10000.0	0.926E−01	0.473E−02	0.573E−02	−0.489E−02	*0.111E−01	−0.891E−02
c = 0.39E+19	20000.0	0.709E−01	0.270E−02	0.782E−02	−0.655E−02	*0.158E−01	−0.127E−01
	40000.0	0.565E−01	0.137E−02	0.976E−02	−0.805E−02	*0.197E−01	−0.163E−01
Li II 2P–4D	5000.0	*0.302	−0.199E−01				
1131.9 Å	10000.0	0.268	−0.109E−01				
c = 0.38E+17	20000.0	0.234	−0.588E−02				
	40000.0	0.204	−0.469E−02				
Li II 3P–3D	5000.0	274.0	−12.6	12.1	−9.03	22.0	−13.3
57388.8 Å	10000.0	226.0	−16.0	18.4	−13.7	36.8	−24.6
c = 0.57E+22	20000.0	195.0	−13.6	23.2	−18.5	46.9	−34.7
	40000.0	172.0	−12.6	28.2	−22.8	57.8	−46.0
Li II 3P–4D	5000.0	*4.91	−0.442				
4326.7 Å	10000.0	4.40	−0.309				
c = 0.55E+18	20000.0	3.91	−0.217				
	40000.0	3.45	−0.138				
Li II 3D–4P	5000.0	4.07	0.553	*0.383	*0.213		
4844.4 Å	10000.0	3.76	0.508	*0.498	*0.326		
c = 0.17E+20	20000.0	3.56	0.429	*0.617	*0.475		
	40000.0	3.38	0.408	*0.702	*0.579		
Li II 3D–5P	5000.0	*4.01	*0.608				
3237.3 Å	10000.0	*3.94	*0.554				
c = 0.39E+19	20000.0	3.91	0.537				
	40000.0	3.82	0.448				

Transitions and averaged wavelengths for the multiplet (in Å) are also given. If one divides c values with the Stark width value, we obtain an estimate for the maximum perturber density (in cm^{-3}) for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the collision volume multiplied by the perturber density (the condition for validity of the impact approximation) lies between 0.1 and 0.5.

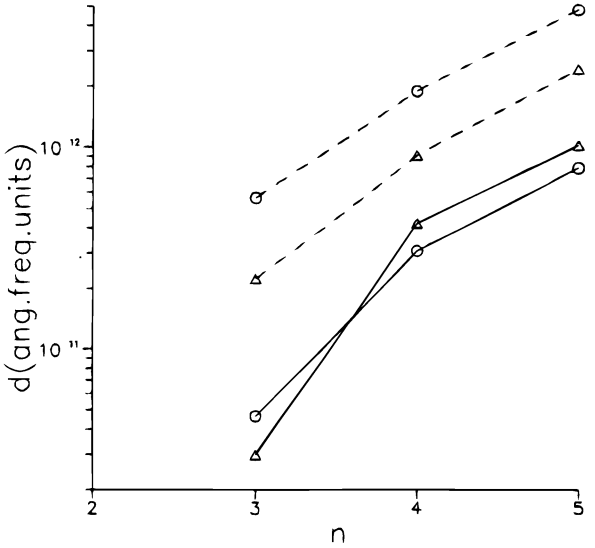

Fig. 2. As in Fig. 1 but for the electron-impact shift.

Debye screening (not explicitly taken into account in Ref. [1], but the corresponding correction is indicated) reduces present widths and shifts. Namely, for transitions involving highly excited levels (n, l), the closest perturbing levels are $(n, l+1)$ and $(n, l-1)$. The difference of energy between (n, l) and $(n, l+1)$ or $(n, l-1)$, which decreases when n increases becomes small. The dominant contribution to the widths and shifts come from the transitions $[(n, l) - (n, l+1)]$ and $[(n, l) - (n, l-1)]$. Typical impact parameters increase for the width and for the shift as well. This is a well-known result of the theory of electron–atom collisions for the S-matrix calculation. Therefore the effect of the Debye shielding cannot be negligible and reduces the widths and shifts. Likewise, at high densities the Debye length decreases and the width and shift linear behaviour with the density is no longer valid. In the case when shifts are much smaller than widths, cancellations between important contributions with different signs may occur, and the accuracy is smaller. It is of interest to determine Li II Stark broadening parameters experimentally at different temperatures in order to test the theoretical improvements and various theoretical aspects of the applied theoretical model.

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References

1. Jones, W. W., Benett, S. M. and Griem, H. R., "Calculated Electron Impact Broadening Parameters for Isolated Spectral Lines from the Singly Charged Ions: Lithium through Calcium", Tech. Rep. No. 71-128, University of Maryland, College Park, Maryland (1971).
2. Griem, H. R., "Spectral Line Broadening by Plasmas" (Academic Press, New York 1974).
3. Seaton, M. J., J. Phys. **B20**, 6363 (1987).
4. Hummer, D. G. *et al.*, Astron. Astrophys. **279**, 298 (1993).
5. Sahal-Bréchot, S., Astron. Astrophys. **1**, 91 (1969).
6. Sahal-Bréchot, S., Astron. Astrophys. **2**, 322 (1969).
7. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transf. **31**, 301 (1984).
8. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. **136**, 289 (1984).
9. Dimitrijević, M. S. and Sahal-Bréchot, S., Phys. Rev. **A31**, 316 (1985).
10. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **82**, 519 (1990).
11. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **141**, 57 (1989).
12. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transf. **34**, 149 (1985).
13. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transf. **44**, 421 (1990).
14. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **142**, 59 (1990).
15. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transf. **38**, 37 (1987).
16. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **142**, 29 (1990).
17. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transf. **46**, 41 (1991).
18. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **143**, 29 (1991).
19. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **146**, 83 (1992).
20. Dimitrijević, M. S. and Sahal-Bréchot, S., Physica Scripta **49**, 34 (1994).
21. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **146**, 97 (1992).
22. Dimitrijević, M. S. and Sahal-Bréchot, S., Physica Scripta **49**, 661 (1994).
23. Dimitrijević, M. S., Astron. Astrophys. Suppl. Series **100**, 593 (1993).
24. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **146**, 73 (1992).
25. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron Astrophys. Suppl. Series **105**, 243 (1994).
26. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **149**, 31 (1994) [errata in: Bull. Obs. Astron. Belgrade **150**, 121 (1994)].
27. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **150**, 47 (1994).
28. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series (1996) in press.
29. Dimitrijević, M. S. and Sahal-Bréchot, S., Physica Scripta **52**, 41 (1995).
30. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **145**, 81 (1992).
31. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transf. **49**, 157 (1993).
32. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transf. **48**, 397 (1992).
33. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **145**, 65 (1992).
34. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Obs. Astron. Belgrade **147**, 35 (1993).
35. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **99**, 585 (1993).
36. Dimitrijević, M. S., Djurić, Z. and Mihajlov, A. A., J. Phys. D: Appl. Phys. **27**, 247 (1994).
37. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **95**, 121 (1992).
38. Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V., Astron. Astrophys. Suppl. Series **89**, 591 (1991).
39. Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V., Bull. Obs. Astron. Belgrade **144**, 81 (1991).
40. Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V., Astron. Astrophys. Suppl. Series **89**, 581 (1991).
41. Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V., Bull. Obs. Astron. Belgrade **144**, 65 (1991).
42. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **96**, 613 (1992).
43. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **109**, 551 (1995).
44. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Astron. Belgrade **150**, 95 (1995).
45. Blagojević, M., Popović, M. V., Konjević, N. and Dimitrijević, M. S., Phys. Rev. **E50**, 2986 (1994).
46. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **95**, 109 (1992).

47. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **93**, 359 (1992).
48. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **100**, 91 (1993).
49. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **101**, 587 (1993).
50. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **107**, 349 (1994).
51. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Astron. Belgrade **148**, 29 (1993).
52. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **105**, 245 (1994).
53. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Astron. Belgrade **148**, 21 (1993).
54. Seaton, M. J., Proc. Phys. Soc. **79**, 1105 (1962).
55. Petrini, D., Astron. Astrophys. **9**, 392 (1970).
56. Malinovsky, M., Astron. Astrophys. **43**, 101 (1975).
57. Fleurier, C., Sahal-Bréchot, S. and Chapelle, J., J. Quant. Spectrosc. Radiat. Transf. **17**, 595 (1977).
58. Bashkin, S. and Stoner, J. J. Jr., "Atomic Energy Levels and Grotian Diagrams", Vol. 1 (North Holland Amsterdam 1975).
59. Dimitrijević, M. S. and Sahal-Bréchot, S., Phys. Rev. **A31**, 316 (1985).
60. Bates, D. R. and Damgaard, A., Trans. Roy. Soc. London, Ser. A. **242**, 101 (1949).
61. Oertel, G. K. and Shomo, L. P., Astrophys. J. Suppl. Series **16**, 175 (1968).
62. Van Regemorter, H., Hoang Binh Dy and Prud'homme, M., J. Phys. **B12**, 1073 (1979).
63. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transf. **31**, 301 (1984).
64. Sahal-Brechot, S., Astron. Astrophys. **245**, 322 (1991).
65. Dimitrijeveić, M. S. and Sahal-Bréchot, S., Bull. Astron. Belgrade **151** (1985) submitted.

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Collisional He – He*(n) Chemi-ionization and Dielectronic He – He^+ – e and He_2^+ – e Recombination: Differential and Total Reaction Rate Coefficients

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Abstract

From the semi-classical theory, the differential and total rate coefficients of collisional He – He*(n) chemi-ionization and dielectronic He – He^+ – e and He_2^+ – e recombination, are determined in this paper. With the help of the calculated differential rate coefficient, the emitted/absorbed electron energy distributions were considered. The calculations were carried out in the case of non-equilibrium helium plasma with atomic temperature T_a and electronic temperature T_e, within the ranges $500\,K \leqslant T_a \leqslant 10\,000\,K$ and $2000\,K \leqslant T_e \leqslant 40\,000\,K$, with the principal quantum number $3 \leqslant n \leqslant 10$. We have determined here, as well, the conditions under which the considered processes are important for the kinetics of weakly ionized helium plasma.

1. Introduction

In partly ionized plasmas, apart from other ionization-recombination processes, possible are chemi-ionization processes due to collisions of an $A^*(n)$ atom in Rydberg state (with the principal quantum number n), with an atom A in the ground state, as well as the inverse chemi-recombination processes. As chemi-recombination ones, we treat the dielectronic recombination processes at the scattering of free electrons e on the collisional quasi-molecular complexes $A + A^+$, as well as on molecular ions A_2^+ in weakly bound vibrational-rotational states. Here, A^+ and A_2^+ denote atomic and molecular ions in the corresponding ground electronic states.

It was shown recently [1, 2], that these processes, not taken into account up to now from the aspect of the influence over the highly excited atomic state populations in weakly ionized plasmas [3], may be very important (and sometimes dominant), whenever the plasma ionization degree is lower than, or of the order of, the magnitude of 10^{-3}. We have in view here, the relative influence of the above mentioned processes (over the excited atomic state populations), in comparison with the influence of the well known processes of the electron-impact ionization of excited atoms and triple electron-electron-ion recombination [4–6].

We follow here Refs [1] and [2], where the influence of the chemi-ionization and chemi-recombination processes was considered on the example of helium and hydrogen plasma, respectively. The hydrogen case has been analysed quite completely in Ref. [2]. In the first considered helium case, however, the relative influence of the chemi-ionization processes in comparison with the processes of the electron-impact ionization and electron–electron–ion recombination was illustrated only, on several examples. Moreover, the chemi-recombination rate coefficients were given for several temperatures for an equilibrium plasma. However, different non equilibrium cases, which are manifested first of all, in differences of the electron temperature (T_e) and atomic particle temperatures (T_a) may be realized in helium plasmas more easily than in hydrogen plasma. Such nonequilibrium cases may be manifested in differences of the electron distribution function from Maxwellian one, as well. The helium plasmas, where such differences are realized, have been experimentally investigated earlier and are quite intensively investigated now [7–11]. It follows that the influence of the chemi-ionization and the chemi-recombination processes in helium plasma should be considered even with higher degree of complexity than it has been done in Ref. [2] for the hydrogen case.

Consequently, we will consider here the chemi-ionization processes during He*(n) and He slow collisions

$$He^*(n) + He \Rightarrow e + He_2^+, \tag{1a}$$

$$He^*(n) + He \Rightarrow e + \begin{cases} He^+ + He \\ He + He^+ \end{cases} \tag{1b}$$

and the inverse He – He^+ – e and He_2^+ – e recombination processes,

$$He_2^+ + e \Rightarrow He^*(n) + He, \tag{2a}$$

$$He^+ + He + e \Rightarrow He^*(n) + He \tag{2b}$$

where $He = He(1s^2)$, $He^+ = He^+(1s)$ and He_2^+ is molecular ion in the ground electronic state $^2\Sigma_u^+$. The principal objective of this paper is to determine the (1a,b) processes rate coefficients within a quite large temperature, T_a, range, for $3 \leqslant n \leqslant 10$. The second objective is determination of the chemi-ionization processes rate coefficients within a quite large range of temperatures, T_a and T_e, where $T_e \geqslant T_a$, and within the same n range. With the respect of Refs [1] and [2], we will not consider here the influence of the chemi-ionization processes (one) and the chemi-recombination processes (2) on the He*(n) atom populations.

Finally, in this paper will be considered the behavior of the differential rate coefficients, describing the energy distribution for electrons ejected in the (1a), (1b), and absorbed in the (2a), (2b) reactions.

Rate coefficients of the processes (1), (2) are determined within the framework of the existing semi-classical theory,

based on the mechanism of resonant energy conversion within the electronic component of the observed atomic system. This theory describes ionization in the case of an atom–Rydberg atom symmetrical collision [12, 13], and recombination in the case of electron scattering on the corresponding ion–atomic complexes and molecular ions [14, 15], under conditions similar to those in weakly ionized plasma. For the processes (1), (2) rate coefficients determination, we will consider that the same assumptions concerning the plasma conditions as in Refs [1] and [2] are valid.

2. Differential rate coefficients

2.1. *Ionization processes*

The processes (1a) and (1b) will be treated here as the results of such energy exchange (within the electronic component of the atom–Rydberg atom collisional system), which is initiated by the dipole interaction between the weakly bound outer electron and the ion–atom subsystem. Since the considered theory was developed on the basis of the dipole approximation, it is correct for internuclear distances R which are much less than the characteristic Rydberg atom radius.

In order to determine the ionization processes rate coefficients we will follow Refs [12, 13]. The relative motion of He*(n) and He atoms will be treated in a classical trajectory approximation, in the center of mass' system; the core of the Rydberg atom He*(n) will be marked as He^+, as well as the corresponding atomic ion; E and ρ will denote the initial kinetic energy of the atoms and initial impact parameter, respectively. Reactions (1a), (1b) will be considered for such R values that the subsystem He + He^+ can be treated as a quasi-molecular complex. The electronic state of this complex is then described by the ground ($^2\Sigma_u^+$) and first excited ($^2\Sigma_g^+$) electronic states of the molecular ion He_2^+. We will denote these states with $|1\rangle$ and $|2\rangle$, and their adiabatic energies with $U_1(R)$ and $U_2(R)$, respectively. We take that this complex can be found in an excited state $|2\rangle$ with a probability of 1/2, which means that the whole atom–atomic system is found in a doubly excited quasi-stationary state with the same probability.

In the general case of excited atom–ground state atom collision, the subsystem of the atom in the ground state and the excited atom core should be described taking into account more of the molecular ion electronic states. Consequently, more sophisticated methods should be used in general. However, for the He*(n) – He slow collisions actual are only electronic states of the He_2^+ molecular ion adiabatically correlated with the He($1s^2$) + He^+(1s) system electronic states at infinite internuclear distance, i.e., just the two above mentioned electronic states ($^2\Sigma_u^+$, $^2\Sigma_g^+$). All other He_2^+ molecular ion electronic states are energetically too high so that for slow He*(n) – He collisions they are not needed for the processes (1) description. When treating the chemi-ionization process (1), as "slow collisions", the He*(n) – He collisions with relative atom–atom velocities within the range from thermal velocity corresponding to room temperature up to a velocity less than or close to the characteristic outer electron velocity for the He*($n = 10$) atom (i.e. around 10% of the atomic velocity unit), are assumed [1, 2, 14, 15]. The same relative velocity range is assumed for the ion–atom collisions in the case of the chemi-recombination process (2). A similar situation is valid as well for other atoms with only s-electrons out of the completed shells (see e.g. Ref. [13]).

We interpreted the observed ionization processes (1a),(1b) as a decay of the described quasi-stationary state. Such decay is conditioned by the non-Coulombic part of the interaction of the electronic component of the ion–atomic complex with weakly bounded outer electron. This non-Coulombic part will be taken here in dipole approximation in accordance with Refs [12] and [13]. The decay takes place according to the scheme: $|2\rangle|\varepsilon_n\rangle \rightarrow |1\rangle|\varepsilon_k\rangle$, where $|\varepsilon_n\rangle$ is the bound state of the outer electron with given n and energy $\varepsilon_n < 0$, and $|\varepsilon_k\rangle$ is the free state of this electron with corresponding energy ε_k. It is now:

$$\epsilon(R) = U_2(R) - U_1(R). \tag{3}$$

In order to realize the ionization process, when R and $\varepsilon_k > 0$ are given, the following condition must be satisfied: $\varepsilon_k = \epsilon(R) - I_n$, where $I_n = |\varepsilon_n|$. The resonant inter-nuclear distance which corresponds to ε_n and ε_k, is denoted with R_{nk}. This distance is determined as the root of the equation

$$\epsilon(R) = I_n + \varepsilon_k. \tag{4}$$

Within the framework of the quasi-static theory applied, it is considered that the transition $|2\rangle|\varepsilon_n\rangle \rightarrow |1\rangle|\varepsilon_k\rangle$ takes place at $R = R_{nk}$. It follows that reactions (1) at a given n are realized in the range $R \leqslant R_n$, where R_n is the root of equation (4), at $\varepsilon_k = 0$.

Because of the energy conservation conditions, channel (1a) of reaction (1) is realized at $R = R_{nk}$ if:

$$U_2(R_{nk}) \leqslant E \leqslant \epsilon(R_{nk}), \tag{5}$$

and channel (1b) is open if

$$E > \epsilon(R_{nk}), \tag{6}$$

where E is the atom kinetic energy within the center of mass reference frame. The channels (1a) and (1b), may be described by differential cross sections $d\sigma_i^{(a,b)}(\varepsilon_k, n, E)$ related to the emission of electrons within the $(\varepsilon_k, \varepsilon_k + d\varepsilon_k)$ energy interval. We will use here the differential cross section values from Ref. [13]. The differential rate coefficients $dk_i^{(a,b,ab)}(\varepsilon_k, n)$, where $dk_i^{(ab)}(\varepsilon_k, n)$ characterizes reaction (1) as a whole, may be obtained with the help of the $d\sigma_i^{(a,b)}(\varepsilon_k, n, E)$:

$$dk_i^{(a,b)}(\varepsilon_k, n) = \int_{E_{min}^{(a,b,ab)}}^{E_{max}^{(a,b,ab)}} v\, d\sigma_i^{(a,b)}(\varepsilon_k, n, E) f_{at}(E) E^{1/2}\, dE,$$

$$dk_i^{(ab)} = dk_i^{(a)} + dk_i^{(b)} \tag{7}$$

where $v = (2E/\mu_{at})^{1/2}$ is the initial relative velocity of atoms, μ_{at} is the reduced atom mass (one half of one helium atom mass), and

$$E_{min}^{(a)} = E_{min}^{(ab)} = U_2(R_{nk}),$$
$$E_{min}^{(b)} = E_{max}^{(a)} = \varepsilon(R_{nk}),$$
$$E_{max}^{(b)} = E_{max}^{(ab)} = \infty. \tag{8}$$

By $f_{at}(E)$ is denoted the corresponding atom–atom energy distribution function, normalized by the condition

$$\int_0^\infty f_{at}(E) E^{1/2}\, dE = 1.$$

In a general case, this function may be a non Maxwellian distribution function at given T [16, 17]. This fact has been discussed in relation with radiative processes at He – He$^+$ collisions within a weakly ionized helium plasma [18]. In the quasi-static theory, differential cross-sections are expressed by the appropriate velocity of decay of the initial electronic state of the system (at given R), which is denoted here as $W(R)$. This velocity can be expressed through the photo-ionization cross-section, and in accordance with Refs [12] and [13] it is taken as $W(R) = g_n R^2/3\sqrt{3}n^5$, where it is taken that the Gaunt factor (g_n) is equal to one within the considered range. Molecular ion parameters entering in the expressions for $d\sigma_i^{(a,\,b,\,ab)}$ for the (1a), (1b) processes may be taken from Ref. [19]. In a general case, differential rate coefficients $dk_i^{(a,\,b,\,ab)}$ must be determined by using eq. (7) with the concrete atom distribution function. The importance of the differential rate coefficients is related to the fact that the quantity $dk_i^{(ab)}/d\varepsilon_k$ determines the energy distribution of electrons emitted during (1a) and (1b) reactions together. The knowledge of the shape of such a distribution may be very important for plasma with a nonequilibrium electron distribution function [9, 10].

When the condition (*i*) from Ref. (15) is satisfied, and the atom distribution function is Maxwellian, i.e. $f_{at}(E) = f_{at}(E, T_a) = (2\pi^{-1/2})(kT_a)^{-3/2}\exp(-E/kT_a)$, on the basis of Ref. [13], we get the differential rate coefficients of the processes (1a), (1b) as:

$$dk_i^{(ab)}(\varepsilon_k, n, T_a) = \frac{2\pi}{3\sqrt{3}}\frac{1}{n^5}a_0^2 v_0 \times \exp\left[-\frac{U_2(R_{nk})}{kT_a}\right]R_{nk}^4\left(\frac{dR_{nk}}{d\varepsilon_k}\right)d\varepsilon_k,$$

$$dk_i^{(a,\,b)}(\varepsilon_k, n, T_a) = dk_i^{(ab)}(\varepsilon_k, n, T_a)\cdot X^{(a,\,b)}(R_{nk}, T_a), \quad (9)$$

where a_0 and v_0 are length and velocity atomic units respectively. By $X^{(a,\,b)}$ are denoted the brunch coefficients describing the relative contribution of channels (a) and (b). They satisfy the condition $X^{(a)} + X^{(b)} = 1$, and are given as:

$$X^{(a)}(R, T_a) = \begin{cases}\gamma\left(\frac{3}{2}; -\frac{U_1(R)}{kT_a}\right)\Big/\Gamma\left(\frac{3}{2}\right), & \text{if } U_1(R) < 0,\\ 0, & \text{if } U_1(R) \geqslant 0,\end{cases} \quad (10a)$$

$$X^{(b)}(R, T_a) = \begin{cases}\Gamma\left(\frac{3}{2}; -\frac{U_1(R)}{kT_a}\right)\Big/\Gamma\left(\frac{3}{2}\right), & \text{if } U_1(R) < 0,\\ 1, & \text{if } U_1(R) \geqslant 0,\end{cases} \quad (10b)$$

where $\gamma(3/2;\ -U_1(R)/kT_a)$ and $\Gamma(3/2;\ -U_1(R)/kT_a)$ are incomplete gamma functions. The values of $U_1(R)$ and $U_2(R)$ are taken here from the Ref. [19].

2.2. *Recombination processes*

The recombination channels (2a) and (2b) as well as reaction (2) as a whole one, we will characterize here with the help of the differential recombination rate coefficients $dk_r^{(a,\,b,\,ab)}(\varepsilon_k, n, T_a)$. Following the previous paper [15], we have taken here that

$$dk_r^{(a,\,b)} = z_r^{(a,\,b)}(\varepsilon_k, n, T_a) f_e(\varepsilon_k)\, d\varepsilon_k,$$

$$dk_r^{(ab)} = dk_r^{(a)} + dk_r^{(b)} \quad (11)$$

where the coefficients $z_r^{(a,\,b)}$ are determined from conditions of thermodynamic balance [6] of ionization and recombination processes, for a given interval $d\varepsilon_k$, in the case of LTE with a temperature equal to T_a. In this balance equation, ionization processes are described by differential rate coefficients $dk_i^{(a,b)}(\varepsilon_k, n, T_a)$ that are given by equations (6)–(7). By $f_e(\varepsilon_k)$ is denoted the electron energy distribution function normalized by the condition

$$\int_0^\infty f_e(\varepsilon_k)(\varepsilon_k)^{1/2}\, d\varepsilon_k = 1. \quad (12)$$

In general, the function $f_e(\varepsilon_k)$ is non-Maxwellian, which is illustrated by Refs [9] and [10].

When the electron energy distribution function is Maxwellian, i.e. $f_e(\varepsilon_k) = f_e(\varepsilon_k, T_e) = (2\pi^{-1/2})(kT_e)^{-3/2}\exp(-\varepsilon_k/kT_e)$, in accordance with Ref. [15], after the necessary transformations, we get:

$$dk_r^{(ab)}(\varepsilon_k, n, T_a, T_e) = C_n(T_e)\exp\left[-\frac{\epsilon(R_{nk})}{kT_e} - \frac{U_1(R_{nk})}{kT_a}\right] \times R_{nk}^4\left(\frac{dR_{nk}}{d\varepsilon_k}\right)d\varepsilon_k,$$

$$dk_r^{(a,\,b)}(\varepsilon_k, n, T_a, T_e) = dk_r^{(ab)}(\varepsilon_k, n, T_a, T_e)\cdot X^{(a,\,b)}(R_{nk}, T_a), \quad (13)$$

where

$$C_n(T_e) = \frac{(2\pi)^{5/2}}{3\sqrt{3}}\frac{(\hbar e a_0)^2}{m^{3/2}}\frac{\exp(I_n/kT_e)}{n^3(kT_e)^{3/2}}. \quad (14)$$

In the hydrogen case [2], equations similar to equations (9) and (14) could be applied only within the $n \geqslant 4$ range [2]. In the helium case however, the factor R_{nk}^4 values are considerably smaller than in the hydrogen case. The consequence is that the respective transition rates are three to four times smaller, which enable the application of these equations (having the Born character) up to $n = 3$. At the end of this section attention should be payed to the fact that eqs (13) and (14) for differential recombination rate coefficients may be easily modified for some of cases with non Maxwellian electron distribution function.

3. Total rate coefficients

The expressions for the ionization differential rate coefficients are used later when determining rate coefficients of recombination processes (2). Rate coefficients $K_i^{(a,\,b)}$ and $K_i^{(ab)} = K_i^{(a)} + K_i^{(b)}$ are important for ionization processes and can be used for determining the corresponding (partial and total) ionization fluxes: $I_i^{(a,\,b)} = K_i^{(a,\,b)}N(\text{He}^*(n))N(\text{He})$ and $I_i^{(ab)} = K_i^{(ab)}N(\text{He}^*(n))N(\text{He})$, where $N(\text{He}^*(n))$ and $N(\text{He})$ are the concentrations of atoms He*(n) and He. These coefficients are given as:

$$K_i^{(a,\,b,\,ab)}(n, T_a) = \int_{\varepsilon_k=0}^\infty dk_i^{(a,\,b,\,ab)}(\varepsilon_k, n, T_a), \quad (15)$$

where integrations are carried out to the maximum value of ε_k, which depends on the behaviour of the adiabatic terms $U_{1,\,2}(R)$. With expressions (6)–(9), the total rate coefficients of ionization will be given in a form that will be appropriate

for numerical calculations:

$$K_i^{(a,\,b)}(n,\,T_a) = \frac{2\pi}{3\sqrt{3}}\frac{1}{n^5}a_0^2 v_0 \int_{R_{min}}^{R_n} \exp\left[-\frac{U_2(R)}{kT_a}\right] \times X^{(a,\,b)}(R,\,T_a)\frac{R^4\,dR}{a_0^5}, \tag{16}$$

$$K_i^{(ab)}(n,\,T_a) = \frac{2\pi}{3\sqrt{3}}\frac{1}{n^5}a_0^2 v_0 \int_{R_{min}}^{R_n} \exp\left[-\frac{U_2(R)}{kT_a}\right]\frac{R^4\,dR}{a_0^5}, \tag{17}$$

where R_n is the root of eq. (4) at $\varepsilon_k = 0$, R_{min} corresponds to the above mentioned maximum value of ε_k, and $X^{(a,\,b)}(R,\,T_a)$ are given by eqs (10a), (10b). We have here that

$$R_n = 3.605;\ 4.077;\ 4.441;\ 4.737;\ 4.986;\ 5.201;\ 5.390;\ 5.559$$

for $n = 3;\ 4;\ 5;\ 6;\ 7;\ 8;\ 9$ and 10, respectively. We note that expressions (16) and (17) have been obtained without any additional approximation in the sub-integral functions, compared to the appropriate expressions given in Ref. [15].

The lower limit of R_{min} is determined numerically and depends on the concrete behavior of terms $U_{1,\,2}(R)$, under conditions of saturation of the calculated values of the integral. This implies that further decrease of R_{min} practically does not affect the value of the integral. In our calculations, we have used the value $R_{min} = 1$, for which it was established that it satisfies the given condition. This result is important because it allows the exclusion of small R from further consideration, where the behaviour of the terms $U_1(R)$ and $U_2(R)$ in the case of He_2^+ ion is much more complicated than in the case of H_2^+ ion, which was considered in Ref. [15]. Apart from this, we also used an analytical approximation (polynomial in the range $R \leqslant 2$) for the functions $U_2(R)$ and $\epsilon(R)$, which drop monotonically with the increase of R, everywhere in the $R \geqslant 1$ range. $K_r^{(a,\,b)}(n)$ and $K_r^{(ab)}(n) = K_r^{(a)}(n) + K_r^{(b)}(n)$ are now rate coefficients of recombination processes (2a, b), determining the corresponding (partial and total) recombination fluxes $I_r^{(a,\,b)}$ and $I_r^{(ab)}$. We will consider that the coefficient $K_r^{(1)}$, describing the dissociative recombination, is normalized on the He^+ and He density units, in the same way as the coefficient $K_r^{(b)}$, describing recombination at ion–atomic collisional complexes. In such cases we have $I_r^{(a,\,b)} = K_r^{(a,\,b)}N(He)N(He^+)N(e)$ and $I_r^{(ab)} = K_r^{(ab)}N(He)N(He^+)N(e)$ where $N(He^+)$ and $N(e)$ are He^+ and free electron densities. This means that the coefficient $K_r^{(1)}$ is expressed through the rate coefficient of dissociative recombination and the proportionality factor $\eta = [N(He)N(He^+)/N(He_2^+)]^{-1}$. This type of presentation of process (2a) is justified under the condition (*ii*) from Ref. (15).

Coefficients $K_r^{(a,\,b)}$ and $K_r^{(ab)}$ will be expressed through corresponding differential rate coefficients of recombination $dk_r^{(a,\,b)}$ and $dk_r^{(ab)} = dk_r^{(a)} + dk_r^{(b)}$:

$$K_r^{(a,\,b,\,ab)}(n,\,T_a,\,T_e) = \int_{\varepsilon_k=0}^{\infty} dk_r^{(a,\,b,\,ab)}(\varepsilon_k,\,n,\,T_a,\,T_e). \tag{18}$$

From the relations (13)–(14) and (18), it follows that the coefficients $K_r^{(a,\,b)}$ and $K_r^{(ab)}$ are given as:

$$K_r^{(a,\,b)}(n,\,T_a,\,T_e) = C_n(T_e)\int_{R_{min}}^{R_n} \exp\left[-\frac{\epsilon(R)}{kT_e} - \frac{U_1(R)}{kT_a}\right] \times X^{(a,\,b)}(R,\,T_a)\frac{R^4\,dR}{a_0^5}, \tag{19}$$

$$K_r^{(ab)}(n,\,T_a,\,T_e) = C_n(T_e)\int_{R_{min}}^{R_n} \exp\left[-\frac{\epsilon(R)}{kT_e} - \frac{U_1(R)}{kT_a}\right]\frac{R^4\,dR}{a_0^5}, \tag{20}$$

where $C_n(T_e)$ are given by expression (14).

4. Results and discussion

Calculated values of the coefficients K_i as a function of n and T_a, are shown in Table I and coefficients K_r as a function of n, T_a and T_e are presented in Tables II.1–II.8. The relative importance of channels "(a)" and "(b)" of the processes (1), (2), are characterized by the ratios $K_i^{(b)}/K_i$ and $K_r^{(b)}/K_r$, which are shown in Tables III and IV.1–IV.8, respectively. These tables allow the direct inclusion of processes (1), (2) in kinetic calculations of gas plasmas, with an atomic temperature within the range $500\,K \leqslant T_a \leqslant 10\,000\,K$ and electron temperature within the range $2000\,K \leqslant T_e \leqslant 40\,000\,K$.

Properties of the energy distribution of electrons emitted in the (1a), (1b) reactions, for $3 \leqslant n \leqslant 8$, are illustrated in Fig. 1 for $T_a = 4000\,K$. In this figure the behavior of the corresponding quantity $dk_i^{(ab)}(\varepsilon_k,\,n,\,T_a)/d\varepsilon_k$ (which has the meaning of the emitted electron spectral intensity, normalized on the excited atom- and the atom in the ground state-density), determined by using eqs (9), (10), is shown as a function of ε_k. Properties of the energy distribution of electrons absorbed in the (2a), (2b) reactions, for $3 \leqslant n \leqslant 8$ are illustrated in Figs 2.1 and 2.2 for $T_a = 4000\,K$, and $T_e = 4000$ and $16\,000\,K$. In these figures the behavior of the corresponding quantity $dk_r^{(ab)}(\varepsilon_k,\,n,\,T_a,\,T_e)/d\varepsilon_k$ (which has the meaning of the absorbed electron spectral intensity, normalized on the free electron-, ion- and atom-density), determined by using eqs (13), (14), is shown as a function of ε_k. Figures 1 and 2 show that due to the (1), (2) reactions electrons are emitted/absorbed within an interval of several eV

Table I. *Calculated values of coefficients* $K_i^{(ab)}$ $[cm^3\ s^{-1}]$ *as a function of* n *and* T_a

	n							
$T_a/[K]$	3	4	5	6	7	8	9	10
500	0.1117 – 17	0.7834 – 14	0.2355 – 12	0.1164 – 11	0.2613 – 11	0.3959 – 11	0.4838 – 11	0.5212 – 11
1000	0.2591 – 13	0.1784 – 11	0.7908 – 11	0.1435 – 10	0.1778 – 10	0.1833 – 10	0.1717 – 10	0.1527 – 10
2000	0.5089 – 11	0.3341 – 10	0.5515 – 10	0.5920 – 10	0.5344 – 10	0.4474 – 10	0.3625 – 10	0.2898 – 10
4000	0.8789 – 10	0.1708 – 09	0.1671 – 09	0.1350 – 09	0.1024 – 09	0.7633 – 10	0.5695 – 10	0.4284 – 10
6000	0.2470 – 09	0.3135 – 09	0.2544 – 09	0.1854 – 09	0.1318 – 09	0.9408 – 10	0.6805 – 10	0.5001 – 10
8000	0.4280 – 09	0.4352 – 09	0.3199 – 09	0.2206 – 09	0.1516 – 09	0.1056 – 09	0.7512 – 10	0.5451 – 10
10000	0.6051 – 09	0.5363 – 09	0.3705 – 09	0.2468 – 09	0.1658 – 09	0.1138 – 09	0.8008 – 10	0.5764 – 10

Table II.1. *Calculated values of coefficients* $K_r^{(ab)}$ [$cm^6\ s^{-1}$] *as function of n,* T_a *and* T_e, *for n = 3*

	T_e/[K] (*n* = 3)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.1072 – 18	0.4956 – 15	0.3492 – 13	0.3660 – 12	0.1563 – 11	0.2594 – 10	0.5540 – 10	0.7240 – 10
1000	0.2734 – 24	0.1126 – 23	0.6846 – 23	0.2713 – 22	0.7142 – 22	0.5762 – 21	0.1046 – 20	0.1280 – 20
2000	0.1842 – 26	0.1736 – 26	0.1985 – 26	0.2445 – 26	0.3048 – 26	0.6364 – 26	0.8213 – 26	0.8724 – 26
4000		0.1207 – 27	0.1012 – 27	0.9025 – 28	0.8321 – 28	0.6606 – 28	0.5628 – 28	0.4852 – 28
6000			0.4072 – 28	0.3434 – 28	0.3002 – 28	0.1935 – 28	0.1452 – 28	0.1156 – 28
8000				0.2152 – 28	0.1843 – 28	0.1097 – 28	0.7823 – 29	0.6025 – 29
10000					0.1384 – 28	0.7908 – 29	0.5491 – 29	0.4154 – 29

Table II.2. *Same as in Table II.1, but for n = 4*

	T_e/[K] (*n* = 4)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.7843 – 21	0.2737 – 16	0.3798 – 14	0.5585 – 13	0.2922 – 12	0.7282 – 11	0.1781 – 10	0.2491 – 10
1000	0.1023 – 25	0.6950 – 25	0.7504 – 24	0.4145 – 23	0.1336 – 22	0.1617 – 21	0.3360 – 21	0.4400 – 21
2000	0.3682 – 27	0.3363 – 27	0.3896 – 27	0.5049 – 27	0.6740 – 27	0.1832 – 26	0.2666 – 26	0.3018 – 26
4000		0.5456 – 28	0.4403 – 28	0.3823 – 28	0.3458 – 28	0.2657 – 28	0.2274 – 28	0.1981 – 28
6000			0.2369 – 28	0.1939 – 28	0.1656 – 28	0.1000 – 28	0.7306 – 29	0.5744 – 29
8000				0.1408 – 28	0.1178 – 28	0.6543 – 29	0.4510 – 29	0.3407 – 29
10000					0.9664 – 29	0.5153 – 29	0.3453 – 29	0.2557 – 29

Table II.3. *Same as in Table II.1, but for n = 5*

	T_e/[K] (*n* = 5)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.6579 – 22	0.5668 – 17	0.1063 – 14	0.1818 – 13	0.1041 – 12	0.3112 – 11	0.8085 – 11	0.1165 – 10
1000	0.1824 – 26	0.1492 – 25	0.2105 – 24	0.1350 – 23	0.4764 – 23	0.6919 – 22	0.1528 – 21	0.2063 – 21
2000	0.1554 – 27	0.1327 – 27	0.1484 – 27	0.1918 – 27	0.2607 – 27	0.7911 – 27	0.1216 – 26	0.1416 – 26
4000		0.3374 – 28	0.2615 – 28	0.2203 – 28	0.1945 – 28	0.1409 – 28	0.1185 – 28	0.1027 – 28
6000			0.1643 – 28	0.1309 – 28	0.1094 – 28	0.6201 – 29	0.4393 – 29	0.3397 – 29
8000				0.1028 – 28	0.8434 – 29	0.4414 – 29	0.2952 – 29	0.2189 – 29
10000					0.7264 – 29	0.3660 – 29	0.2382 – 29	0.1733 – 29

Table II.4. *Same as in Table II.1, but for n = 6*

	T_e/[K] (*n* = 6)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.1429 – 22	0.2010 – 17	0.4437 – 15	0.8221 – 14	0.4936 – 13	0.1617 – 11	0.4337 – 11	0.6355 – 11
1000	0.6290 – 27	0.5392 – 26	0.8793 – 25	0.6113 – 24	0.2263 – 23	0.3605 – 22	0.8215 – 22	0.1127 – 21
2000	0.9020 – 28	0.7168 – 28	0.7637 – 28	0.9660 – 28	0.1312 – 27	0.4168 – 27	0.6581 – 27	0.7781 – 27
4000		0.2406 – 28	0.1799 – 28	0.1474 – 28	0.1274 – 28	0.8677 – 29	0.7132 – 29	0.6121 – 29
6000			0.1244 – 28	0.9684 – 29	0.7951 – 29	0.4268 – 29	0.2942 – 29	0.2238 – 29
8000				0.7994 – 29	0.6451 – 29	0.3217 – 29	0.2098 – 29	0.1532 – 29
10000					0.5727 – 29	0.2759 – 29	0.1755 – 29	0.1258 – 29

Table II.5. *Same as in Table II.1, but for n = 7*

	T_e/[K] (*n* = 7)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.4994 – 23	0.9426 – 18	0.2296 – 15	0.4467 – 14	0.2763 – 13	0.9599 – 12	0.2623 – 11	0.3879 – 11
1000	0.3038 – 27	0.2563 – 26	0.4552 – 25	0.3323 – 24	0.1267 – 23	0.2147 – 22	0.4991 – 22	0.6914 – 22
2000	0.6148 – 28	0.4571 – 28	0.4640 – 28	0.5708 – 28	0.7673 – 28	0.2490 – 27	0.4000 – 27	0.4774 – 27
4000		0.1850 – 28	0.1341 – 28	0.1074 – 28	0.9107 – 29	0.5870 – 29	0.4715 – 29	0.4003 – 29
6000			0.9890 – 29	0.7557 – 29	0.6114 – 29	0.3139 – 29	0.2113 – 29	0.1585 – 29
8000				0.6450 – 29	0.5138 – 29	0.2464 – 29	0.1575 – 29	0.1135 – 29
10000					0.4655 – 29	0.2165 – 29	0.1352 – 29	0.9578 – 30

Table II.6. *Same as in Table II.1, but for n = 8*

	T_e/[K] ($n = 8$)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.2284 − 23	0.5218 − 18	0.1355 − 15	0.2727 − 14	0.1723 − 13	0.6266 − 12	0.1739 − 11	0.2591 − 11
1000	0.1777 − 27	0.1434 − 26	0.2686 − 25	0.2024 − 24	0.7875 − 24	0.1392 − 22	0.3282 − 22	0.4577 − 22
2000	0.4590 − 28	0.3216 − 28	0.3122 − 28	0.3729 − 28	0.4946 − 28	0.1614 − 27	0.2622 − 27	0.3148 − 27
4000		0.1488 − 28	0.1051 − 28	0.8251 − 29	0.6890 − 29	0.4231 − 29	0.3324 − 29	0.2791 − 29
6000			0.8116 − 29	0.6106 − 29	0.4881 − 29	0.2415 − 29	0.1594 − 29	0.1181 − 29
8000				0.5337 − 29	0.4206 − 29	0.1955 − 29	0.1229 − 29	0.8769 − 30
10000					0.3868 − 29	0.1748 − 29	0.1076 − 29	0.7552 − 30

Table II.7. *Same as in Table II.1, but for n = 9*

	T_e/[K] ($n = 9$)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.1235 − 23	0.3215 − 18	0.8729 − 16	0.1797 − 14	0.1151 − 13	0.4309 − 12	0.1207 − 11	0.1805 − 11
1000	0.1172 − 27	0.8916 − 27	0.1730 − 25	0.1332 − 24	0.5251 − 24	0.9527 − 23	0.2266 − 22	0.3173 − 22
2000	0.3624 − 28	0.2411 − 28	0.2248 − 28	0.2610 − 28	0.3409 − 28	0.1108 − 27	0.1811 − 27	0.2183 − 27
4000		0.1233 − 28	0.8521 − 29	0.6580 − 29	0.5421 − 29	0.3192 − 29	0.2456 − 29	0.2040 − 29
6000			0.6810 − 29	0.5057 − 29	0.4002 − 29	0.1920 − 29	0.1247 − 29	0.9143 − 30
8000				0.4500 − 29	0.3515 − 29	0.1592 − 29	0.9874 − 30	0.6984 − 30
10000					0.3268 − 29	0.1443 − 29	0.8774 − 30	0.6113 − 30

Table II.8. *Same as in Table II.1, but for n = 10*

	T_e/[K] ($n = 10$)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.7475 − 24	0.2135 − 18	0.5976 − 16	0.1246 − 14	0.8039 − 14	0.3044 − 12	0.8558 − 12	0.1284 − 11
1000	0.8357 − 28	0.5968 − 27	0.1185 − 25	0.9264 − 25	0.3682 − 24	0.6764 − 23	0.1616 − 22	0.2269 − 22
2000	0.2969 − 28	0.1888 − 28	0.1698 − 28	0.1920 − 28	0.2469 − 28	0.7939 − 28	0.1300 − 27	0.1571 − 27
4000		0.1043 − 28	0.7076 − 29	0.5389 − 29	0.4390 − 29	0.2491 − 29	0.1881 − 29	0.1546 − 29
6000			0.5806 − 29	0.4266 − 29	0.3347 − 29	0.1565 − 29	0.1002 − 29	0.7281 − 30
8000				0.3848 − 29	0.2984 − 29	0.1323 − 29	0.8112 − 30	0.5696 − 30
10000					0.2798 − 29	0.1212 − 29	0.7295 − 30	0.5055 − 30

Table III. *Calculated values of ratio $K_i^{(b)}/K_i^{(ab)}$ as a function of n and T_a*

	n							
T_a/[K]	3	4	5	6	7	8	9	10
500	0.8312 − 07	0.7482 − 04	0.2017 − 02	0.1284 − 01	0.3983 − 01	0.8345 − 01	0.1387 + 00	0.1993 + 00
1000	0.3776 − 03	0.1010 − 01	0.4912 − 01	0.1190 + 00	0.2044 + 00	0.2911 + 00	0.3712 + 00	0.4418 + 00
2000	0.2304 − 01	0.1095 + 00	0.2313 + 00	0.3514 + 00	0.4541 + 00	0.5374 + 00	0.6038 + 00	0.6566 + 00
4000	0.1681 + 00	0.3465 + 00	0.4907 + 00	0.5970 + 00	0.6738 + 00	0.7300 + 00	0.7719 + 00	0.8040 + 00
6000	0.3186 + 00	0.5031 + 00	0.6276 + 00	0.7113 + 00	0.7688 + 00	0.8097 + 00	0.8397 + 00	0.8623 + 00
8000	0.4354 + 00	0.6045 + 00	0.7090 + 00	0.7764 + 00	0.8217 + 00	0.8535 + 00	0.8767 + 00	0.8940 + 00
10000	0.5233 + 00	0.6739 + 00	0.7626 + 00	0.8184 + 00	0.8555 + 00	0.8813 + 00	0.9000 + 00	0.9141 + 00

Table IV.1. *Calculated values of ratio $K_r^{(b)}/K_r^{(ab)}$ as a function of n, T_a and T_e, for n = 3*

	T_e/[K] ($n = 3$)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.7398 − 09	0.1009 − 12	0.1061 − 14	0.8046 − 16	0.1561 − 16	0.4936 − 18	0.1517 − 18	0.8441 − 19
1000	0.2102 − 03	0.3213 − 04	0.3911 − 05	0.7843 − 06	0.2468 − 06	0.1604 − 07	0.5796 − 08	0.3444 − 08
2000	0.2304 − 01	0.1537 − 01	0.9932 − 02	0.6404 − 02	0.4252 − 02	0.1065 − 02	0.5408 − 03	0.3699 − 03
4000		0.1681 + 00	0.1479 + 00	0.1314 + 00	0.1178 + 00	0.7736 − 01	0.5937 − 01	0.4997 − 01
6000			0.3186 + 00	0.2992 + 00	0.2827 + 00	0.2279 + 00	0.1983 + 00	0.1804 + 00
8000				0.4354 + 00	0.4196 + 00	0.3654 + 00	0.3341 + 00	0.3142 + 00
10000					0.5233 + 00	0.4738 + 00	0.4443 + 00	0.4251 + 00

Table IV.2. *Same as in Table IV.1, but for n = 4*

	T_e/[K] ($n = 4$)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.9302 – 07	0.1610 – 11	0.8345 – 14	0.4413 – 15	0.6870 – 16	0.1373 – 17	0.3585 – 18	0.1831 – 18
1000	0.5232 – 02	0.4639 – 03	0.3085 – 04	0.4341 – 05	0.1096 – 05	0.4502 – 07	0.1381 – 07	0.7533 – 08
2000	0.1095 + 00	0.7199 – 01	0.4454 – 01	0.2666 – 01	0.1623 – 01	0.2956 – 02	0.1292 – 02	0.8143 – 03
4000		0.3465 + 00	0.3066 + 00	0.2733 + 00	0.2451 + 00	0.1570 + 00	0.1164 + 00	0.9509 – 01
6000			0.5031 + 00	0.4748 + 00	0.4503 + 00	0.3653 + 00	0.3167 + 00	0.2863 + 00
8000				0.6045 + 00	0.5846 + 00	0.5141 + 00	0.4713 + 00	0.4430 + 00
10000					0.6739 + 00	0.6159 + 00	0.5799 + 00	0.5555 + 00

Table IV.3. *Same as in Table IV.1, but for n = 5*

	T_e/[K] ($n = 5$)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.9575 – 06	0.6462 – 11	0.2418 – 13	0.1081 – 14	0.1517 – 15	0.2434 – 17	0.5866 – 18	0.2873 – 18
1000	0.2564 – 01	0.1817 – 02	0.9021 – 04	0.1074 – 04	0.2442 – 05	0.8036 – 07	0.2274 – 07	0.1189 – 07
2000	0.2313 + 00	0.1561 + 00	0.9751 – 01	0.5745 – 01	0.3385 – 01	0.5302 – 02	0.2151 – 02	0.1300 – 02
4000		0.4907 + 00	0.4401 + 00	0.3966 + 00	0.3589 + 00	0.2338 + 00	0.1726 + 00	0.1398 + 00
6000			0.6276 + 00	0.5966 + 00	0.5695 + 00	0.4716 + 00	0.4123 + 00	0.3739 + 00
8000				0.7090 + 00	0.6889 + 00	0.6156 + 00	0.5691 + 00	0.5374 + 00
10000					0.7626 + 00	0.7058 + 00	0.6692 + 00	0.6438 + 00

Table IV.4. *Same as in Table IV.1, but for n = 6*

	T_e/[K] ($n = 6$)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.3767 – 05	0.1506 – 10	0.4693 – 13	0.1909 – 14	0.2529 – 15	0.3592 – 17	0.8266 – 18	0.3947 – 18
1000	0.6441 – 01	0.4203 – 02	0.1768 – 03	0.1913 – 04	0.4103 – 05	0.1193 – 06	0.3225 – 07	0.1643 – 07
2000	0.3514 + 00	0.2457 + 00	0.1575 + 00	0.9338 – 01	0.5449 – 01	0.7892 – 02	0.3068 – 02	0.1809 – 02
4000		0.5970 + 00	0.5424 + 00	0.4945 + 00	0.4520 + 00	0.3028 + 00	0.2251 + 00	0.1824 + 00
6000			0.7113 + 00	0.6808 + 00	0.6537 + 00	0.5527 + 00	0.4886 + 00	0.4459 + 00
8000				0.7764 + 00	0.7575 + 00	0.6868 + 00	0.6404 + 00	0.6081 + 00
10000					0.8184 + 00	0.7657 + 00	0.7309 + 00	0.7063 + 00

Table IV.5. *Same as in Table IV.1, but for n = 7*

	T_e/[K] ($n = 7$)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.9225 – 05	0.2667 – 10	0.7405 – 13	0.2835 – 14	0.3614 – 15	0.4727 – 17	0.1055 – 17	0.4959 – 18
1000	0.1155 + 00	0.7426 – 02	0.2817 – 03	0.2868 – 04	0.5917 – 05	0.1579 – 06	0.4134 – 07	0.2071 – 07
2000	0.4541 + 00	0.3286 + 00	0.2169 + 00	0.1306 + 00	0.7624 – 01	0.1054 – 01	0.3979 – 02	0.2308 – 02
4000		0.6738 + 00	0.6192 + 00	0.5703 + 00	0.5260 + 00	0.3627 + 00	0.2725 + 00	0.2215 + 00
6000			0.7688 + 00	0.7400 + 00	0.7141 + 00	0.6148 + 00	0.5493 + 00	0.5045 + 00
8000				0.8217 + 00	0.8044 + 00	0.7381 + 00	0.6935 + 00	0.6617 + 00
10000					0.8555 + 00	0.8075 + 00	0.7751 + 00	0.7518 + 00

Table IV.6. *Same as in Table IV.1 but for n = 8*

	T_e/[K] ($n = 8$)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.1734 – 04	0.4036 – 10	0.1036 – 12	0.3795 – 14	0.4703 – 15	0.5764 – 17	0.1256 – 17	0.5826 – 18
1000	0.1718 + 00	0.1124 – 01	0.3980 – 03	0.3884 – 04	0.7799 – 05	0.1956 – 06	0.4999 – 07	0.2473 – 07
2000	0.5374 + 00	0.4009 + 00	0.2724 + 00	0.1671 + 00	0.9800 – 01	0.1321 – 01	0.4881 – 02	0.2798 – 02
4000		0.7300 + 00	0.6772 + 00	0.6292 + 00	0.5848 + 00	0.4143 + 00	0.3150 + 00	0.2574 + 00
6000			0.8097 + 00	0.7829 + 00	0.7586 + 00	0.6632 + 00	0.5982 + 00	0.5528 + 00
8000				0.8535 + 00	0.8377 + 00	0.7763 + 00	0.7340 + 00	0.7035 + 00
10000					0.8813 + 00	0.8377 + 00	0.8078 + 00	0.7860 + 00

Table IV.7. *Same as in Table IV.1, but for n = 9*

	T_e/[K] ($n = 9$)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.2775 − 04	0.5538 − 10	0.1342 − 12	0.4769 − 14	0.5794 − 15	0.6787 − 17	0.1455 − 17	0.6690 − 18
1000	0.2281 + 00	0.1544 − 01	0.5210 − 03	0.4933 − 04	0.9712 − 05	0.2333 − 06	0.5867 − 07	0.2877 − 07
2000	0.6038 + 00	0.4625 + 00	0.3227 + 00	0.2018 + 00	0.1195 + 00	0.1588 − 01	0.5786 − 02	0.3288 − 02
4000		0.7719 + 00	0.7218 + 00	0.6754 + 00	0.6320 + 00	0.4589 + 00	0.3533 + 00	0.2904 + 00
6000			0.8397 + 00	0.8149 + 00	0.7923 + 00	0.7016 + 00	0.6382 + 00	0.5930 + 00
8000				0.8767 + 00	0.8622 + 00	0.8055 + 00	0.7657 + 00	0.7366 + 00
10000					0.9000 + 00	0.8603 + 00	0.8327 + 00	0.8124 + 00

of free electron energies ε_k. They show as well relatively small free electron emission/absorption intensity decrease with ε_k increase, and that the emitted/absorbed electron distribution is practically linear for the considered cases if a logarithmic scale is used for the differential rate coefficients $dk_{i,r}^{(ab)}(\varepsilon_k, n, T_a)/d\varepsilon_k$. Calculations presented in Figs 1 and 2 have been performed with parameters chosen to be in accordance with the experimental conditions in Refs [7] and [8]. These results, with the results of previous papers [1, 2], make it possible to see the significance of the processes (1) and (2), as factors influencing the free electron population, as well as the energy range where this significance is particularly high. Namely, results of the previous papers [1, 2] show that chemi-ionization and chemi-recombination processes of the type (1) and (2) contribute to the total free-electron population, more than, or similarly to, the known electron-atom impact ionization, and electron-electron-ion recombination processes. The results presented here in Figs 1 and 2 illustrate the influence of the processes (1) and (2) on the free electron population for free electron energies from zero up to energies close to 10 eV. Moreover it is shown in these Figs that the influence of the (1) and (2) processes on the free electron population must be especially important within small free-electron energies (less or around 1 eV) range. This should be taken into account particularly, for the weakly ionized plasma kinetics description. The n-dependence difference in Figs 1 and 2 is mostly related to the fact that chemi-ionization processes (1) have a threshold energy close to the ionization energy of the He*(n) atom, while for chemi-recombination processes (2) such threshold does not exist. Moreover the higher chemi-ionization intensity for $n = 4$ than for $n = 3$ is just due to the important threshold energy decrease when n changes from 3 to 4. Further decrease of the chemi-ionization intensity for n

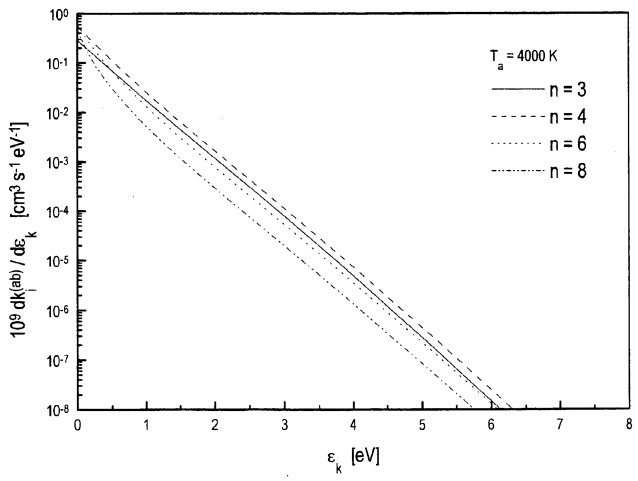

Fig. 1. The total spectral intensity $dk_i^{(ab)}/d\varepsilon_k$ (multiplied with 10^9) of electrons emitted due to (1a), (1b) ionization processes for He and He*(n) atom density unities, as a function of ε_k for $T_a = 4000$ K and $3 \leqslant n \leqslant 8$. Here, ε_k denotes the free electron energy.

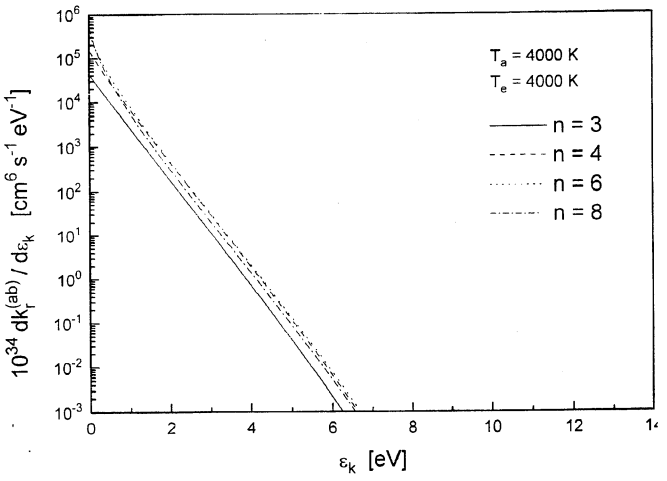

Fig. 2.1. The total spectral intensity $dk_r^{(ab)}/d\varepsilon_k$ (multiplied with 10^{34}) of electrons absorbed due to (2a), (2b) recombination processes for He atom and e − He^+ pair density unities, as a function of ε_k for $T_a = T_e = 4000$ K and $3 \leqslant n \leqslant 8$. Here, ε_k denotes the free electron energy.

Table IV.8. *Same as in Table IV.1, but for n = 10*

	T_e/[K] ($n = 10$)							
T_a/[K]	2000	4000	6000	8000	10000	20000	30000	40000
500	0.3994 − 04	0.7115 − 10	0.1654 − 12	0.5761 − 14	0.6913 − 15	0.7900 − 17	0.1675 − 17	0.7657 − 18
1000	0.2815 + 00	0.1987 − 01	0.6475 − 03	0.5994 − 04	0.1164 − 04	0.2723 − 06	0.6773 − 07	0.3299 − 07
2000	0.6566 + 00	0.5146 + 00	0.3677 + 00	0.2344 + 00	0.1402 + 00	0.1855 − 01	0.6699 − 02	0.3784 − 02
4000		0.8040 + 00	0.7566 + 00	0.7123 + 00	0.6703 + 00	0.4974 + 00	0.3876 + 00	0.3207 + 00
6000			0.8623 + 00	0.8394 + 00	0.8183 + 00	0.7326 + 00	0.6713 + 00	0.6269 + 00
8000				0.8940 + 00	0.8808 + 00	0.8283 + 00	0.7910 + 00	0.7634 + 00
10000					0.9141 + 00	0.8778 + 00	0.8522 + 00	0.8333 + 00

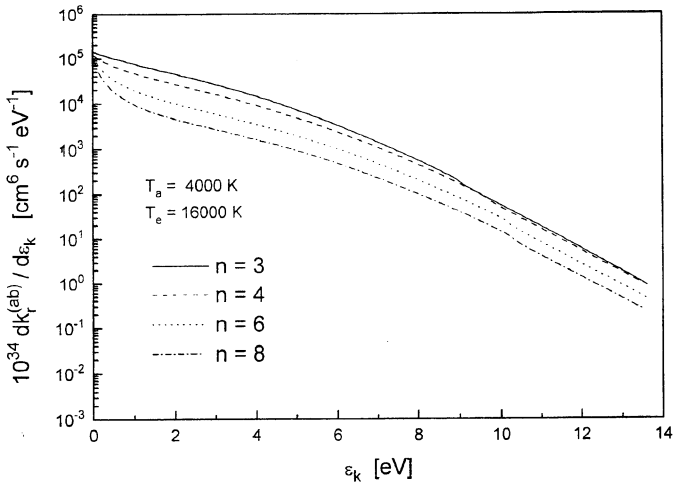

Fig. 2.2. Same as in Fig. 2.1, but for $T_e = 16\,000$ K.

larger than 4 is the consequence of the fact that the ionization rate coefficient decreases as n^{-5}, which is demonstrated by eq. (16). Obtained results may be applied even when there exists relatively small deviation of electron distribution function from Maxwellian one.

Table III shows that the relative contribution of ionization channel (1b) compared to the reaction (1) as a whole, grows quickly and monotonically with the increase of T_a, and at each n it becomes greater than 1/2 for $T_a \geqslant 6000$ K. It must be realized that at greater n this contribution becomes greater than 1/2 at smaller T_a, for e.g. $T_a < 2000$ K at $n = 10$.

Tables IV.1–IV.8 show similar behavior of the relative contribution of recombination channel (2b) compared to the reaction (2) as a whole, when T_a increases. It can also be seen that these relative contributions are a little less than in the case of ionization processes. Finally, it has been noticed that with different n, the lower limits of the domain T_a where these contributions are greater than 1/2 are strongly dependent on the electron temperature T_e. On the whole, Tables IV.1–IV.8 show that within the observed T_a and T_e ranges, channels (2a) and (2b) must be considered together.

Results for processes (1) and (2) rate coefficients shown in Tables I–IV enable completely the inclusion of these processes in the low-temperature helium plasma kinetic calculations. Namely, based on the results in previous papers [1, 2], the states with $n > 10$, may be eliminated from the consideration, in comparison with the concurrent electron processes. On the other hand, the helium states with $n = 2$, i.e. the resonant and the metastable, in each case need a particular treatment.

5. Conclusion

In this paper we have determined the differential and the total rate coefficients for the chemi-ionization processes (1) and chemi-recombination processes (2), within the semiclassical method. It is shown as well that the (1,2) reaction must be treated as a factor influencing simultaneously the He*(*n*) atom populations and the free electron energy distribution for weakly ionized plasmas. The results have been given in such a form that they can be used directly when modeling weakly ionized helium plasma with atomic temperatures in the 500 K $\leqslant T_a \leqslant$ 10 000 K range and electronic temperatures in the 2000 K $\leqslant T_e \leqslant$ 40 000 K range. We will draw attention to some of the possible directions of further investigations in this research field. The first is the modification of the equations obtained here, which will enable the application of the theory at least on some of the cases of non-Maxwellian electron distribution functions. The second is the consideration of some examples of (1) and (2) processes with the atom–atom and ion–atom relative velocity non-Maxwellian distribution functions. Finally, the third direction is taking into account the (1), (2) processes for $n = 2$, when the theoretical approach used here is not applicable. Since each of the processes (1a), (1b) and (2a), (2b), similarly as for the hydrogen case obtains the multichannel character, it is neccessary to apply a more sophisticated method. One such method could be based on the application of an adequate version of the Multichannel Quantum Defect Theory (MQDT). We have in view here that the MQDT methods have been developed for a long time for molecular systems (see e.g. Ref. [20]), and that some preliminary results exist for hydrogen [21, 22].

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References

1. Mihajlov, A. A., Djurić, Z. and Dimitrijević, M. S., J. Quant. Spectrosc. Radiat. Transf. **55**, 141 (1996).
2. Mihajlov, A. A., Dimitrijević, M. S. and Djurić, Z., Physica Scripta **53**, 159 (1996).
3. Vorobiev, V.S., 12th European Sect. Conf. on Atom. Molec. Phys. Ioniz. Gases, Abstracts of Invited Lectures and Contributed Papers, Noordwijkerhout, 9 (1994).
4. Bates, D. R., Kingston, A. E. and McWhirter, W. R. P., Proc. Roy. Soc. **A267**, 297 (1962).
5. Bates, D. R., Kingston, A. E. and McWhirter, R. W. P., Proc. Roy. Soc. **A270**, 155 (1962).
6. Sobelman, I. I., "Atomic Spectra and Radiative Transitions" (Springer-Verlag, Berlin 1979), ch. 11.
7. Aleksandrov, V. Ya., Gurevich, D. B. and Podmoshenskii, I. V., Opt. Spektrosk. **26**, 36 (1969).
8. Aleksandrov, V. Ya., Gurevich, D. B., Mihajlov, A. A. and Podmoshenskii, I. V., Opt. Spektrosk. **37**, 855 (1974).
9. Petrović, Z. Lj. and Crompton, W., Aust. J. Phys. **40**, 347 (1987).
10. Milloy, H. B. and Crompton, R. W., Phys. Rev. **A15**, 1847 (1977).
11. Solov'yanchik, D. A., J. Appl. Spectrosc. **59**, 340 (1993).
12. Janev, R. K. and Mihajlov, A. A., Phys. Rev. **A21**, 819 (1980).
13. Mihajlov, A. A. and Janev, R. K., J. Phys. B: At. Mol. Phys. **14**, 1639 (1981).
14. Mihajlov, A. A. and Ljepojević, N. N., Proc. Symp. on Physics of Ionized Gases (Dubrovnik, 1982) (Zagreb: Institute of Physics of the University of Zagreb) Contributed papers p. 385 (1982).
15. Mihajlov, A. A., Ljepojević, N. N. and Dimitrijević, M. S., J. Phys. B: At. Mol. Opt. Phys. **25**, 5121 (1992).
16. Petrović, Z. Lj., Jelenković, B. M. and Phelps, A. V., Phys. Rev. Lett. **68**, 325 (1992).
17. Vrhovac, S. B., Radovanov, S. B., Petrović, Z. Lj. and Jelenković, B. M., J. Phys. D: Appl. Phys. **25**, 217 (1992).
18. Ermolaev, A. M., Mihajlov, A. A., Dimitrijević, M. S. and Ignjatović, Lj. M., J. Phys. D: Appl. Phys. **28**, 1047 (1995).
19. Gupta, B. M. and Madsen, F. A., J. Chem. Phys. **47**, 48 (1967).
20. Giusti, A., J. Phys. **B13**, 3867 (1980).
21. Giusti, A., Bardsley, J. N. and Derkits, C., Phys. Rev. **A28**, 682 (1983).
22. Giusti-Suzor, A., in "Dissociative Recombination: Theory, Experiment and Applications (Edited by J. B. A. Mitchell and S. L. Guberman) (World Scientific Publishing, Singapore, New Jersey 1989), p. 14.

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Electron-Impact Broadening of Mg II Spectral Lines for Astrophysical and Laboratory Plasma Research

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Abstract

Using a semiclassical approach, we have calculated electron-, proton- and ionized helium-impact line widths and shifts for 66 Mg II multiplets as a function of temperature. The results obtained have been compared with available experimental and theoretical results.

1. Introduction

Spectral lines of ionized magnesium are of importance for the investigation, diagnostics and modelling of laboratory and stellar plasmas. Stark broadening of Mg II lines has been investigated in numerous experiments [1–14] and considered theoretically [2, 4, 5, 8, 11, 15–26]. The reasons for studying Mg II lines are not only based on laboratory plasma research and plasma devices development. Due to the cosmical abundance of magnesium and its ionization potential value, Mg II lines are present in solar and stellar spectra and the corresponding Stark broadening data are of interest for their analysis as well. Of additional interest is the consideration and modelling of subphotospheric layers [27], opacity calculations, radiative transfer research and the development of space astronomy. For such purposes data on a number of spectral lines as large as possible are needed, while existing calculations provide Stark broadening data for a very limited number of Mg II multiplets.

In order to provide the needed Stark broadening data, we have calculated within the semi-classical-perturbation formalism [18, 28] electron-, proton- and ionized helium-impact line widths and shifts for 66 Mg II multiplets. Since for the resonance 3s–3p Mg II line detailed semi-classical-perturbation calculations already exist (Ref. [11] and calculations of Sahal-Bréchot given as private communication in Ref. [13]), as well as detailed comparison with experimental data [11, 13], we will not consider again this line here. We will present and discuss the obtained results for other Mg II lines, along with a comparison with experimental [2, 3, 7, 10] and other theoretical [21, 23–25] data.

2. Theory

A detailed description of the applied semi-classical-perturbation approach used here, is given in Refs [18] and [28]. The original method has been improved and updated several times [11, 29–32] and a summary together with different theoretical improvements has been repeated several times (see e.g. Ref. [32]). Consequently, only the basic details of the used formalism will be presented here. According to Refs [18, 28 and 32], the Stark full width (W) at the intensity half maximum (FWHM) and shift (d) of an isolated spectral line, may be expressed as

$$W = N \int vf(v)\, \mathrm{d}v \left(\sum_{i' \neq i} \sigma_{ii'}(v) + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_{\mathrm{el}} \right) + W_{\mathrm{R}},$$

$$d = N \int vf(v)\, \mathrm{d}v \int_{R_3}^{R_{\mathrm{D}}} 2\pi\rho\, \mathrm{d}\rho\, \sin 2\phi_{\mathrm{p}} \qquad (1)$$

where N is the electron density, $f(v)$ the Maxwellian velocity distribution function for electrons, ρ denotes the impact parameter of the incoming electron, i and f denote the initial and final atomic energy levels, and i', f' their corresponding perturber levels, while W_{R} gives the contribution of the Feshbach resonances [11].

The inclusion of such resonances may be performed in two ways. First of all one calculates the increase $\Delta\Omega$ of the collision strength Ω at an ion X^+ excitation energy threshold E_S, with the help of the Gailitis formula (see Ref. [11] and references therein). Then, below this threshold one may extrapolate the collision strength Ω with $\Delta\Omega = \text{const}$, which is valid when a great number of resonances exists. The second method is to use the relation between Ω, the cross section σ and the electron wave number K ($\Omega = K^2\sigma$) and assume that $\Delta\sigma = \Delta\Omega_S/K^2$ is constant below E_S. This second method is most accurate when there are few resonances. We have used here the first method ($\Delta\Omega = \text{const}$ below an ion excitation energy threshold) since this method is more correct for transitions between higher states. It is more correct as well for multiply charged ions. It is demonstrated however in Ref. [11], that for the Mg II 3s–3p resonance line the second method gives results which are in better agreement with experiment.

The inelastic cross section $\sigma_{j,j'}(v)$ can be expressed by an integral over the impact parameter of the transition probability $P_{jj'}(\rho, v)$ as

$$\sum_{i' \neq i} \sigma_{jj'}(v) = \tfrac{1}{2}\pi R_1^2 + \int_{R_1}^{R_{\mathrm{D}}} 2\pi\rho\, \mathrm{d}\rho \sum_{j \neq j'} P_{jj'}(\rho, v), \quad j = i, f \qquad (2)$$

and the elastic cross section is given by

$$\sigma_{\mathrm{el}} = 2\pi R_2^2 + \int_{R_2}^{R_{\mathrm{D}}} 8\pi\rho\, \mathrm{d}\rho\, \sin^2\delta,$$

$$\delta = (\phi_{\mathrm{p}}^2 + \phi_{\mathrm{q}}^2)^{1/2}. \qquad (3)$$

The phase shifts ϕ_{p} and ϕ_{q} due respectively to the polarization potential (r^{-4}) and to the quadrupolar potential (r^{-3}), are given in Section 3 of Chapter 2 in Ref. [28]. R_{D} is the

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Debye radius. All the cut-offs R_1, R_2, R_3 are described in Section 1 of Chapter 3 in Ref. [18]. The formulae for the ion-impact widths and shifts are analogous.

2. Results and discussion

Energy levels for Mg II lines have been taken from Ref. [33]. Oscillator strengths have been calculated by using the method of Bates and Damgaard [34, 35]. For higher levels, the method described in Ref. [36] has been used. In addition to electron-impact full halfwidths and shifts, Stark-broadening parameters due to proton- and ionized-helium impacts have been calculated. Our results for 66 Mg II multiplets are shown in Table I, for a perturber density of $10^{15}\,\mathrm{cm}^{-3}$ and temperatures $T = 5000$–$150\,000\,\mathrm{K}$. Additional tables for perturber densities 10^{16}–$10^{19}\,\mathrm{cm}^{-3}$, will be published in Ref. [37]. We also specify a parameter c [30], which gives an estimate for the maximum perturber density for which the line may be treated as isolated when it is divided by the corresponding full width at half maximum. For each value given in Table I, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid [18, 28]. Values for $NV > 0.5$ are not given and values for $0.1 < NV < 0.5$ are denoted by an asterisk. When the impact approximation is not valid, the ion broadening contribution may be estimated by using a quasistatic approach [23, 38]. In the region between where neither of these two approximations is valid, a unified type theory should be used. For example in Ref. [39], simple analytical formulas for such a case are given. The accuracy of the results obtained decreases when broadening by ion interactions becomes important.

The most sophisticated strong coupling quantum mechanical results [19, 20] exist only for the Mg II 3s–3p resonance line. This method has never been applied for a large scale calculation like in this article since the difficulties increase with the increase of the principal quantum number n. Moreover, with the increase of the principal quantum number n short-range effects which can be described well only quantum-mechanically decrease rapidly and the semi-classical methods become better and more accurate. We choose the semi-classical method as actually the best and most accurate method enabling such large scale calculations. The general accuracy of the semi-classical method is estimated as $\pm 30\%$ [23] and detailed investigations on neutral helium lines [40], where there is a lot of good and accurate experimental data showed even better agreement. One must take into account however, that for resonance lines the accuracy is smaller due to the influence of effects like strong collisions and resonances, included in the semi-classical formalism in a more approximate way. In approximate, semi-empirical methods [41, 42], the most difficult part, the calculation of cross sections for virtual transitions perturbing the initial and the final level of the corresponding transition for the spectral line considered, is avoided by replacing cross sections with Gaunt factors derived from experiments. Consequently, for such methods only a good average accuracy is expected. They are especially useful for problems like opacity calculations or radiative transfer studies, where the accuracy of each particular line is not critical and a good average accuracy for a large number of lines is needed. Such methods provide often good agreement with experiment just for resonance lines, where the large number of experimental data used for the empirical part of semi-empirical methods and their testing and adjusting, exist.

In Table II our results for Stark widths (full widths at half maximum – FWHM) are compared with experimental results (Fleurier *et al.* (1977) [11]; Chapelle and Sahal-Bréchot (1970) [2]; Helbig and Kusch (1972) [3]; Kusch and Schwiecker (1976) [10]), which have been critically estimated and selected in Ref. [43], as well as with the results of semi-classical calculations of Jones, Benett and Griem (1971) [21, 23] (WJBG) (differences between the present calculations and the calculations in Ref. [21], published also in Ref. [23], have been discussed in detail in Ref. [32]), calculations of Dimitrijević and Konjević (1981) [24] by using the Griem's semi-empirical approach [42] (WGDK). Since the electron densities in experiments change within a small range, experimental data are normalized on an electron density of $10^{17}\,\mathrm{cm}^{-3}$.

We can see in Table II that the differences between different experiments under similar conditions are very large. For example for the full width at half maximum (FWHM) of the Mg II 3d–4f 4481.16 Å line, the values of 2.1 Å [2], 4.26 Å [3] and 10.8 Å [10] for practically the same plasma conditions ($T = 10\,000$–$12\,000\,\mathrm{K}$), have been reported. An attempt is made [43] to critically estimate the accuracy of experimental data and in Table II is given as well the accuracy estimated in Ref. [43], where the uncertainties of experimental data are subdivided into four ranges [44]: A – uncertainties within 15%; B – uncertainties within 30%; C – uncertainties within 50% and D – uncertainties larger than 50% [44]. The plus sign indicates a slightly better piece of data among several similar ones [44]. One can see that the majority of experimental data for non-resonant lines, where semi-classical methods work well is estimated to have uncertainties larger than 50%. Consequently there is not enough reliable experimental data to test the semi-classical theory on the magnesium ion lines. Moreover, all experimental data for non-resonant lines are in a very narrow temperature interval (10 000–14 000 K) and new reliable experiments will be very useful.

We notice a good agreement between semi-empirical calculations performed [24] within the Griem's semi-empirical [42] and the modified semi-empirical approach [41], with the more sophisticated semi-classical calculations. This is promising for the much simpler use of the modified semi-empirical method [41] when there are no sophisticated results, or in the cases when a considerably higher effort to use a more sophisticated method, does not promise a higher accuracy (e.g. lack of reliable atomic data). Our results are in excellent agreement with the experimental results of Chapelle and Sahal-Bréchot (1970) [2] for the Mg II 3d–4f transition, which has the best accuracy for non-resonant lines according to critical reviews of experimental data [43–45].

In Table III, our results for Stark shifts are compared with experiment {Fleurier *et al.* (1977) [11]; Helbig and Kusch (1972) [3]; Kusch and Schwiecker (1976) [10]; Purić and Konjević (1972) [7]} Stark shifts (dm) in Å normalized on an electron density of $10^{17}\,\mathrm{cm}^{-3}$, as well as with the results of semi-classical calculations of Jones, Benett and Griem (1971) [21, 23] (dJBG) and calculations of Dimitrijević and Kršljanin (1986) [25] (dDK) using the modified

semi-empirical approach [25, 41]. One can see that experimental data for the shift are of lower accuracy. It is difficult to come to a final conclusion since even the sign of experimental shifts are different. A new high precision measurement would be very useful.

Under WIon, in Table II and dIon in Table III are shown the present calculations within the impact approximation of the ion broadening contribution. One can see that while for the width the ion broadening contribution remains a small correction, for shifts it may become even the dominant contribution, as for the 3d–4f 4481.6 Å line. The influence of the Debye screening for shifts is also more pronounced, as well as deviations from the linearity with the electron density. Additional tables for perturber densities 10^{16}–$10^{19}\,\mathrm{cm}^{-3}$, will be published in Ref. [37].

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References

1. Aulehla, E. and Herman, L., C.R.H. Acad. Sci. **246**, 1676 (1958).
2. Chapelle, J., Sahal-Bréchot, S., Astron. Astrophys. **6**, 415 (1970).
3. Helbig, V., Kusch, H. J., Astron. Astrophys. **20**, 299 (1972).
4. Jones, W. W., Sanchez, A., Greig, J. R. and Griem, H. R., Phys. Rev. **A5**, 2318 (1972).
5. Jones, W. W., "Measurement and Calculation of the Stark Broadening Parameters of Singly Ionized Calcium and Magnesium" (University of Maryland, Techn. Rep. 72-051 1972).
6. Kunkov, V. V., Il'in, G. G. and Fishman, I. S., Opt. Spectrosc. **32**, 585 (1972).
7. Purić, J. and Konjević, N., Z. Phys. **249**, 440 (1972).
8. Roberts, D. E. and Barnard, A. J., J. Quant. Spectrosc. Radiative Transfer **12**, 1205 (1972).
9. Hadžiomerspahić, D., Platiša, M., Konjević, N. and Popović, M., Z. Phys. **262**, 169 (1973).
10. Kusch, H. J. and Schwiecker, H., Astron. Astrophys. **53**, 59 (1976).
11. Fleurier, C., Sahal-Bréchot, S. and Chapelle, J., J. Quant. Spectrosc. Radiative Transfer **17**, 595 (1977).
12. Larson, G. F. and Fassel, V. A., Appl. Spectrosc. **33**, 592 (1979).
13. Goldbach, C., Nollez, G., Plomdeur, P. and Zimmermann, J. P., Phys. Rev. **A25**, 2596 (1982).
14. Bassyouni, A. H. and Ramadan, A. G., Egypt. J. Phys. **14**, 101 (1983).
15. Dumont, S., C.R.H. Acad. Sci. **B263**, 85 (1966).
16. Davis, J. and Roberts, D. E., Proc. Phys. Soc. **92**, 889 (1967).
17. Sahal-Bréchot, S., Z. Astrophys. **69**, 74 (1968).
18. Sahal-Bréchot, S., Astron. Astrophys. **2**, 322 (1969).
19. Bely, O. and Griem, H. R., Phys. Rev. **A1**, 97 (1970).
20. Barnes, K. S., J. Phys. **B4**, 1377 (1971).
21. Jones, W. W., Benett, S. M. and Griem, H. R., "Calculated Electron Impact Broadening Parameters for Isolated Spectral lines from the Singly Charged Ions: Lithium through Calcium" (University of Maryland, College Park, Maryland, Techn. Rep. 71-128 1971).
22. Jones, W. W. Phys. Rev. **A7**, 1826 (1973).
23. Griem, H. R., "Spectral Line Broadening by Plasmas" (Academic Press, New York 1974).
24. Dimitrijević, M. S. and Konjević, N., Astron. Astrophys. **102**, 93 (1981).
25. Dimitrijević, M. S. and Kršljanin, V., Astron. Astrophys. **165**, 269 (1986).
26. Dimitrijević, M. S. and Konjević, N., Astron. Astrophys. **172**, 345 (1987).
27. Seaton, M. J., J. Phys. **B20**, 6363 (1987).
28. Sahal-Bréchot, S., Astron. Astrophys. **1**, 91 (1969).
29. Sahal-Bréchot, S., Astron. Astrophys. **35**, 321 (1974).
30. Dimitrijević, M. S. and Sahal-Bréchot, S., JQSRT **31**, 301 (1984).
31. Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V., Astron. Astrophys. Suppl. Series **89**, 581 (1991).
32. Dimitrijević, M. S. and Saha-Bréchot, S., Physica Scripta **52**, 41 (1995).
33. Bashkin, S. and Stoner, J. Jr., "Atomic Energy Levels and Grotrian Diagrams", Vol. 1 (North-Holland, Amsterdam 1975).
34. Bates, D. R. and Damgaard, A., Trans. Roy. Soc. London, Ser. **A242**, 101 (1949).
35. Oertel, G. K. and Shomo, L. P., Astrophys. J. Suppl. Series **16**, 175 (1968).
36. Van Regemorter, H., Hoang Binh Dy and Prud'homme, M., J. Phys. **B12**, 1073 (1979).
37. Dimitrijević, M. S. and Sahal-Bréchot, S., Bull. Astron. Belgrade **151**, 101 (1995).
38. Sahal-Bréchot, S., Astron. Astrophys. **245**, 322 (1991).
39. Barnard, A. J., Cooper, J. and Smith, E. W., J. Quant. Spectrosc. Radiative Transfer **14**, 1025 (1974).
40. Dimitrijević, M. S. and Sahal-Bréchot, S., Phys. Rev. **A31**, 316 (1985).
41. Dimitrijević, M. S. and Konjević, N., J. Quant. Spectrosc. Radiative Transfer **24**, 451 (1980).
42. Griem, H. R., Phys. Rev. **165**, 268 (1968).
43. Konjević, N., Dimitrijević, M. S. and Wiese, W. L., J. Phys. Chem. Ref. Data **13**, 649 (1984).
44. Konjević, N. and Wiese, W. L., J. Phys. Chem. Ref. Data **5**, 259 (1976).
45. Konjević, N. and Wiese, W. L., J. Phys. Chem. Ref. Data **19**, 1307 (1990).

Table I. *This table shows electron-, proton- and He II-impact broadening parameters for Mg II, for a perturber density of 10^{15} cm^{-3} and temperatures from 5000 up to 150 000 K. Transitions and averaged wavelengths for the multiplet (in Å) are also given. By dividing c with the full width at half maximum, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the collision volume multiplied by the perturber density (the conditions for validity of the impact approximation) lies between 0.1 and 0.5*

Perturber density = 1 × E + 15 cm^{-3} Perturbers are:		Electrons		Protons		Ionized helium	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
Mg II 3s–4p	5000	0.726E−03	0.623E−04	0.567E−04	0.332E−05	0.695E−04	0.319E−05
1240.1 Å	10000	0.561E−03	0.391E−04	0.752E−04	0.570E−05	0.813E−04	0.515E−05
c=0.14E + 18	20000	0.460E−03	0.289E−04	0.851E−04	0.819E−05	0.910E−04	0.714E−05
	50000	0.416E−03	0.249E−04	0.968E−04	0.112E−04	0.993E−04	0.927E−05
	100000	0.410E−03	0.204E−04	0.101E−03	0.134E−04	0.103E−03	0.110E−04
	150000	0.405E−03	0.179E−04	0.103E−03	0.148E−04	0.103E−03	0.120E−04
Mg II 3s–5p	5000	0.103E−02	0.860E−04	0.158E−03	−0.993E−05	0.170E−03	−0.904E−05
1026.0 Å	10000	0.861E−03	0.651E−04	0.178E−03	−0.145E−04	0.191E−03	−0.127E−04
c = 0.44E + 17	20000	0.795E−03	0.444E−04	0.198E−03	−0.188E−04	0.204E−03	−0.157E−04
	50000	0.822E−03	0.336E−04	0.210E−03	−0.240E−04	0.214E−03	−0.198E−04
	100000	0.860E−03	0.226E−04	0.216E−03	−0.282E−04	0.218E−03	−0.228E−04
	150000	0.867E−03	0.220E−04	0.219E−03	−0.305E−04	0.220E−03	−0.248E−04
Mg II 3s–6p	5000	0.165E−02	−0.877E−04	0.352E−03	−0.619E−04	0.376E−03	−0.522E−04
946.7 Å	10000	0.151E−02	−0.676E−04	0.393E−03	−0.770E−04	0.409E−03	−0.635E−04
c = 0.20E + 17	20000	0.153E−02	−0.482E−04	0.418E−03	−0.920E−04	0.424E−03	−0.757E−04
	50000	0.171E−02	−0.216E−04	0.436E−03	−0.113E−03	0.439E−03	−0.916E−04
	100000	0.184E−02	−0.138E−04	0.441E−03	−0.131E−03	0.443E−03	−0.103E−03
	150000	0.186E−02	−0.847E−05	0.442E−03	−0.138E−03	0.444E−03	−0.113E−03
Mg II 3s–7p	5000	0.282E−02	−0.577E−03	0.711E−03	−0.176E−03	*0.745E−03	*−0.145E−03
907.4 Å	10000	0.271E−02	−0.441E−03	0.771E−03	−0.214E−03	*0.785E−03	*−0.176E−03
c = 0.11E + 17	20000	0.289E−02	−0.286E−03	0.804E−03	−0.253E−03	0.810E−03	−0.205E−03
	50000	0.338E−02	−0.219E−03	0.847E−03	−0.298E−03	0.834E−03	−0.246E−03
	100000	0.365E−02	−0.128E−03	0.888E−03	−0.345E−03	0.836E−03	−0.289E−03
	150000	0.369E−02	−0.107E−03	0.879E−03	−0.365E−03	0.807E−03	−0.295E−03
Mg II 4s–4p	5000	0.514E−01	−0.124E−01	0.319E−02	−0.955E−03	0.388E−02	−0.856E−03
9229.4 Å	10000	0.393E−01	−0.921E−02	0.426E−02	−0.137E−02	0.456E−02	−0.119E−02
c = 0.78E + 19	20000	0.327E−01	−0.671E−02	0.487E−02	−0.174E−02	0.514E−02	−0.146E−02
	50000	0.313E−01	−0.502E−02	0.564E−02	−0.222E−02	0.563E−02	−0.183E−02
	100000	0.318E−01	−0.397E−02	0.592E−02	−0.261E−02	0.596E−02	−0.210E−02
	150000	0.318E−01	−0.353E−02	0.626E−02	−0.278E−02	0.611E−02	−0.227E−02
Mg II 4s–5p	5000	0.136E−01	−0.102E−02	0.196E−02	−0.258E−03	0.212E−02	−0.223E−03
3615.4 Å	10000	0.114E−01	−0.807E−03	0.222E−02	−0.359E−03	0.237E−02	−0.302E−03
c = 0.54E + 18	20000	0.107E−01	−0.701E−03	0.247E−02	−0.436E−03	0.254E−02	−0.361E−03
	50000	0.113E−01	−0.567E−03	0.262E−02	−0.554E−03	0.267E−02	−0.452E−03
	100000	0.120E−01	−0.521E−03	0.272E−02	−0.635E−03	0.270E−02	−0.509E−03
	150000	0.121E−01	−0.418E−03	0.269E−02	−0.678E−03	0.271E−02	−0.560E−03
Mg II 4s–6p	5000	0.150E−01	−0.105E−02	0.306E−02	−0.585E−03	0.327E−02	−0.491E−03
2791.6 Å	10000	0.136E−01	−0.129E−02	0.343E−02	−0.722E−03	0.356E−02	−0.597E−03
c = 0.17E + 18	20000	0.138E−01	−0.860E−03	0.365E−02	−0.868E−03	0.372E−02	−0.712E−03
	50000	0.155E−01	−0.818E−03	0.376E−02	−0.105E−02	0.386E−02	−0.850E−03
	100000	0.168E−01	−0.608E−03	0.390E−02	−0.119E−02	0.381E−02	−0.968E−03
	150000	0.170E−01	−0.511E−03	0.397E−02	−0.128E−02	0.393E−02	−0.102E−02
Mg II 4s–7p	5000	0.216E−01	−0.400E−02	0.529E−02	−0.133E−02	*0.555E−02	*−0.109E−02
2475.2 Å	10000	0.206E−01	−0.337E−02	0.575E−02	−0.162E−02	*0.584E−02	*−0.133E−02
c = 0.80E + 17	20000	0.219E−01	−0.273E−02	0.598E−02	−0.191E−02	0.602E−02	−0.156E−02
	50000	0.257E−01	−0.197E−02	0.633E−02	−0.227E−02	0.620E−02	−0.186E−02
	100000	0.278E−01	−0.136E−02	0.654E−02	−0.259E−02	0.631E−02	−0.218E−02
	150000	0.281E−01	−0.114E−02	0.646E−02	−0.274E−02	0.606E−02	−0.226E−02
Mg II 5s–5p	5000	0.674	−0.242	0.718E−01	−0.303E−01	0.762E−01	−0.257E−01
21395.8 Å	10000	0.546	−0.203	0.830E−01	−0.379E−01	0.862E−01	−0.313E−01
c = 0.19E + 20	20000	0.521	−0.178	0.943E−01	−0.451E−01	0.937E−01	−0.374E−01
	50000	0.549	−0.130	0.105	−0.552E−01	0.102	−0.457E−01
	100000	0.584	−0.103	0.112	−0.638E−01	0.106	−0.506E−01
	150000	0.588	−0.889E−01	0.115	−0.670E−01	0.110	−0.551E−01

Table I. (Continued)

Perturber density = 1 × E + 15 cm^{-3} Perturbers are:		Electrons		Protons		Ionized helium	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
Mg II 5s–6p	5000	0.130	−0.423E−01	0.241E−01	−0.661E−02	0.256E−01	−0.541E−02
7790.1 Å	10000	0.120	−0.354E−01	0.270E−01	−0.804E−02	0.279E−01	−0.667E−02
c = 0.13E + 19	20000	0.123	−0.278E−01	0.288E−01	−0.957E−02	0.291E−01	−0.794E−02
	50000	0.140	−0.205E−01	0.301E−01	−0.117E−01	0.297E−01	−0.954E−02
	100000	0.151	−0.159E−01	0.313E−01	−0.131E−01	0.315E−01	−0.103E−01
	150000	0.153	−0.137E−01	0.327E−01	−0.144E−01	0.312E−01	−0.120E−01
Mg II 5s–7p	5000	0.120	−0.341E−01	0.286E−01	−0.789E−02	*0.299E−01	*−0.647E−02
5741.8 Å	10000	0.117	−0.294E−01	0.311E−01	−0.965E−02	*0.316E−01	*−0.794E−02
c = 0.43E + 18	20000	0.125	−0.233E−01	0.326E−01	−0.113E−01	0.324E−01	−0.917E−02
	50000	0.148	−0.180E−01	0.343E−01	−0.138E−01	0.334E−01	−0.108E−01
	100000	0.161	−0.134E−01	0.348E−01	−0.149E−01	0.344E−01	−0.123E−01
	150000	0.162	−0.114E−01	0.356E−01	−0.159E−01	0.335E−01	−0.128E−01
Mg II 6s–6p	5000	5.36	−2.20	0.725	−0.359	0.747	−0.295
41143.6 Å	10000	4.86	−2.08	0.833	−0.437	0.826	−0.360
c = 0.37E + 20	20000	4.78	−1.73	0.911	−0.514	0.883	−0.418
	50000	5.37	−1.35	0.983	−0.607	0.955	−0.506
	100000	5.71	−1.07	1.11	−0.702	1.03	−0.591
	150000	5.74	−0.898	1.16	−0.736	1.04	−0.604
Mg II 6s–7p	5000	0.910	−0.384	0.180	−0.650E−01	*0.188	*−0.534E−01
14265.8 Å	10000	0.873	−0.324	0.198	−0.797E−01	*0.199	*−0.655E−01
c = 0.27E + 19	20000	0.924	−0.283	0.209	−0.923E−01	0.209	−0.763E−01
	50000	1.08	−0.206	0.228	−0.112	0.210	−0.899E−01
	100000	1.17	−0.159	0.240	−0.129	0.219	−0.984E−01
	150000	1.18	−0.133	0.249	−0.136	0.234	−0.113
Mg II 7s–7p	5000	30.9	−13.5	4.84	−2.58	*4.83	*−2.11
70314.1 Å	10000	29.5	−13.7	5.37	−3.15	*5.14	*−2.56
c = 0.65E + 20	20000	30.1	−11.6	6.02	−3.69	5.66	−3.02
	50000	34.9	−9.14	6.56	−4.24	6.02	−3.42
	100000	37.1	−6.97	7.15	−4.85	5.80	−3.78
	150000	37.2	−5.82	7.78	−5.40	6.41	−4.08
Mg II 3p–4s	5000	0.419E−02	0.173E−02	0.671E−04	0.110E−03	0.783E−04	0.975E−04
2934.7 Å	10000	0.295E−02	0.133E−02	0.125E−03	0.157E−03	0.129E−03	0.135E−03
c = 0.93E + 18	20000	0.214E−02	0.994E−03	0.193E−03	0.197E−03	0.175E−03	0.163E−03
	50000	0.177E−02	0.747E−03	0.270E−03	0.251E−03	0.233E−03	0.205E−03
	100000	0.163E−02	0.584E−03	0.321E−03	0.290E−03	0.281E−03	0.240E−03
	150000	0.158E−02	0.510E−03	0.368E−03	0.319E−03	0.309E−03	0.261E−03
Mg II 3p–5s	5000	0.326E−02	0.156E−02	0.134E−03	0.189E−03	0.134E−03	0.161E−03
1752.5 Å	10000	0.234E−02	0.146E−02	0.217E−03	0.238E−03	0.189E−03	0.196E−03
c = 0.14E + 18	20000	0.199E−02	0.122E−02	0.282E−03	0.283E−03	0.241E−03	0.233E−03
	50000	0.175E−02	0.981E−03	0.371E−03	0.345E−03	0.298E−03	0.284E−03
	100000	0.173E−02	0.772E−03	0.427E−03	0.393E−03	0.370E−03	0.325E−03
	150000	0.169E−02	0.675E−03	0.470E−03	0.428E−03	0.397E−03	0.354E−03
Mg II 3p–6s	5000	0.463E−02	0.254E−02	0.360E−03	0.393E−03	0.315E−03	0.325E−03
1482.2 Å	10000	0.387E−02	0.233E−02	0.475E−03	0.483E−03	0.400E−03	0.398E−03
c = 0.53E + 17	20000	0.324E−02	0.211E−02	0.615E−03	0.570E−03	0.504E−03	0.470E−03
	50000	0.322E−02	0.163E−02	0.778E−03	0.673E−03	0.617E−03	0.546E−03
	100000	0.317E−02	0.135E−02	0.842E−03	0.776E−03	0.688E−03	0.600E−03
	150000	0.312E−02	0.114E−02	0.989E−03	0.834E−03	0.742E−03	0.667E−03
Mg II 3p–7s	5000	0.737E−02	0.432E−02	0.779E−03	0.786E−03	0.669E−03	0.647E−03
1368.9 Å	10000	0.628E−02	0.437E−02	0.984E−03	0.960E−03	0.826E−03	0.787E−03
c = 0.27E + 17	20000	0.565E−02	0.375E−02	0.124E−02	0.112E−02	0.985E−03	0.908E−03
	50000	0.593E−02	0.300E−02	0.146E−02	0.132E−02	0.122E−02	0.110E−02
	100000	0.599E−02	0.232E−02	0.178E−02	0.148E−02	0.141E−02	0.123E−02
	150000	0.589E−02	0.194E−02	0.168E−02	0.158E−02	0.163E−02	0.127E−02
Mg II 4p–5s	5000	0.774E−01	0.333E−01	0.410E−02	0.410E−02	0.431E−02	0.350E−02
8230.0 Å	10000	0.577E−01	0.307E−01	0.575E−02	0.516E−02	0.537E−02	0.427E−02
c = 0.32 + 19	20000	0.513E−01	0.253E−01	0.714E−02	0.617E−02	0.648E−02	0.508E−02
	50000	0.488E−01	0.201E−01	0.898E−02	0.748E−02	0.758E−02	0.611E−02
	100000	0.502E−01	0.157E−01	0.101E−01	0.851E−02	0.896E−02	0.712E−02
	150000	0.497E−01	0.137E−01	0.111E−01	0.928E−02	0.959E−02	0.766E−02

Table I. (Continued)

Perturber density = 1 × E + 15 cm^{-3} Perturbers are:		Electrons		Protons		Ionized helium	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
Mg II 4p–6s	5000	0.431E−01	0.228E−01	0.333E−02	0.350E−02	0.296E−02	0.289E−02
4433.2 Å	10000	0.363E−01	0.207E−01	0.435E−02	0.431E−02	0.372E−02	0.355E−02
c = 0.48E + 18	20000	0.311E−01	0.186E−01	0.560E−02	0.510E−02	0.462E−02	0.420E−02
	50000	0.311E−01	0.147E−01	0.705E−02	0.601E−02	0.563E−02	0.486E−02
	100000	0.318E−01	0.117E−01	0.757E−02	0.695E−02	0.627E−02	0.534E−02
	150000	0.315E−01	0.994E−02	0.894E−02	0.746E−02	0.671E−02	0.594E−02
Mg II 4p–7s	5000	0.507E−01	0.291E−01	0.528E−02	0.529E−02	0.455E−02	0.436E−02
3553.1 Å	10000	0.434E−01	0.294E−01	0.666E−02	0.646E−02	0.561E−02	0.530E−02
c = 0.18E + 18	20000	0.394E−01	0.251E−01	0.838E−02	0.752E−02	0.668E−02	0.611E−02
	50000	0.419E−01	0.200E−01	0.984E−02	0.890E−02	0.820E−02	0.739E−02
	100000	0.425E−01	0.154E−01	0.120E−01	0.995E−02	0.946E−02	0.829E−02
	150000	0.421E−01	0.129E−01	0.113E−01	0.106E−01	0.110E−01	0.856E−02
Mg II 5p–6s	5000	0.755	0.354	0.678E−01	0.553E−01	0.651E−01	0.457E−01
17444.6 Å	10000	0.653	0.320	0.834E−01	0.678E−01	0.777E−01	0.561E−01
c = 0.74E + 19	20000	0.593	0.287	0.101	0.797E−01	0.897E−01	0.655E−01
	50000	0.632	0.218	0.121	0.945E−01	0.103	0.768E−01
	100000	0.656	0.180	0.131	0.110	0.108	0.843E−01
	150000	0.655	0.152	0.149	0.116	0.119	0.942E−01
Mg II 5p–7s	5000	0.335	0.180	0.348E−01	0.329E−01	0.308E−01	0.270E−01
8833.9 Å	10000	0.293	0.182	0.434E−01	0.402E−01	0.372E−01	0.330E−01
c = 0.11E + 19	20000	0.272	0.155	0.538E−01	0.465E−01	0.437E−01	0.381E−01
	50000	0.296	0.119	0.629E−01	0.553E−01	0.531E−01	0.458E−01
	100000	0.305	0.952E−01	0.758E−01	0.614E−01	0.610E−01	0.510E−01
	150000	0.303	0.795E−01	0.716E−01	0.660E−01	0.694E−01	0.526E−01
Mg II 6p–7s	5000	4.96	2.40	0.587	0.444	0.552	0.363
31674.9 Å	10000	4.55	2.44	0.704	0.546	0.633	0.443
c = 0.14E + 20	20000	4.37	2.06	0.799	0.620	0.701	0.506
	50000	4.91	1.64	0.954	0.750	0.830	0.611
	100000	5.15	1.27	1.10	0.828	0.918	0.679
	150000	5.14	1.06	1.05	0.906	0.977	0.699
Mg II 3p–3d	5000	0.267E−02	0.447E−03	0.999E−04	0.348E−04	0.127E−03	0.322E−04
2796.3 Å	10000	0.199E−02	0.321E−03	0.149E−03	0.552E−04	0.174E−03	0.477E−04
c = 0.72E + 18	20000	0.151E−02	0.218E−03	0.187E−03	0.760E−04	0.199E−03	0.639E−04
	50000	0.120E−02	0.186E−03	0.225E−03	0.980E−04	0.231E−03	0.809E−04
	100000	0.109E−02	0.149E−03	0.248E−03	0.117E−03	0.244E−03	0.957E−04
	150000	0.105E−02	0.132E−03	0.260E−03	0.127E−03	0.251E−03	0.103E−03
Mg II 3p–4d	5000	0.423E−02	0.148E−02	0.465E−03	0.452E−03	0.428E−03	0.376E−03
1736.7 Å	10000	0.356E−02	0.118E−02	0.598E−03	0.555E−03	0.528E−03	0.459E−03
c = 0.15E + 17	20000	0.312E−02	0.981E−03	0.751E−03	0.662E−03	0.643E−03	0.539E−03
	50000	0.272E−02	0.720E−03	0.948E−03	0.787E−03	0.774E−03	0.656E−03
	100000	0.246E−02	0.558E−03	0.113E−02	0.885E−03	0.919E−03	0.711E−03
	150000	0.231E−02	0.482E−03	0.110E−02	0.945E−03	0.945E−03	0.761E−03
Mg II 3p–5d	5000	0.780E−02	0.345E−02	0.129E−02	0.118E−02	0.112E−02	0.962E−03
1477.3 Å	10000	0.713E−02	0.284E−02	0.159E−02	0.143E−02	0.137E−02	0.116E−02
c = 0.59E + 16	20000	0.662E−02	0.237E−02	0.197E−02	0.167E−02	0.163E−02	0.136E−02
	50000	0.599E−02	0.168E−02	0.236E−02	0.192E−02	0.194E−02	0.153E−02
	100000	0.547E−02	0.130E−02	0.273E−02	0.217E−02	0.195E−02	0.175E−02
	150000	0.511E−02	0.109E−02	0.317E−02	0.245E−02	0.222E−02	0.185E−02
Mg II 3p–6d	5000	0.147E−01	0.722E−02	*0.299E−02	*0.259E−02	*0.257E−02	*0.211E−02
1366.7 Å	10000	0.139E−01	0.602E−02	*0.370E−02	*0.313E−02	*0.302E−02	*0.257E−02
c = 0.30E + 16	20000	0.132E−01	0.485E−02	0.419E−02	0.356E−02	*0.351E−02	*0.292E−02
	50000	0.121E−01	0.345E−02	0.523E−02	0.417E−02	*0.420E−02	*0.346E−02
	100000	0.111E−01	0.260E−02	0.624E−02	0.459E−02	0.402E−02	0.379E−02
	150000	0.103E−01	0.215E−02	0.724E−02	0.551E−02	0.486E−02	0.376E−02
Mg II 3p–7d	5000	0.264E−01	0.135E−01				
1307.8 Å	10000	0.256E−01	0.112E−01	*0.721E−02	*0.604E−02		
c = 0.18E + 16	20000	0.244E−01	0.884E−02	*0.808E−02	*0.718E−02	*0.621E−02	*0.557E−02
	50000	0.226E−01	0.637E−02	*0.913E−02	*0.858E−02	*0.826E−02	*0.640E−02
	100000	0.206E−01	0.468E−02	*0.128E−01	*0.937E−02	*0.841E−02	*0.699E−02
	150000	0.191E−01	0.386E−02	*0.114E−01	*0.105E−01	*0.980E−02	*0.813E−02

Table I. (Continued)

Perturber density = 1 × E + 15 cm^{-3} Perturbers are:		Electrons		Protons		Ionized helium	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
Mg II 4p–4d	5000	0.951E−01	0.281E−01	0.102E−01	0.930E−02	0.954E−02	0.773E−02
7892.1 Å	10000	0.807E−01	0.220E−01	0.129E−01	0.114E−01	0.116E−01	0.943E−02
c = 0.30E + 18	20000	0.718E−01	0.181E−01	0.160E−01	0.136E−01	0.139E−01	0.111E−01
	50000	0.649E−01	0.131E−01	0.200E−01	0.162E−01	0.166E−01	0.135E−01
	100000	0.607E−01	0.103E−01	0.236E−01	0.182E−01	0.194E−01	0.146E−01
	150000	0.578E−01	0.901E−02	0.232E−01	0.194E−01	0.200E−01	0.156E−01
Mg II 4p–5d	5000	0.708E−01	0.304E−01	0.115E−01	0.104E−01	0.100E−01	0.849E−02
4389.8 Å	10000	0.648E−01	0.248E−01	0.141E−01	0.126E−01	0.122E−01	0.102E−01
c = 0.52E + 17	20000	0.604E−01	0.206E−01	0.175E−01	0.147E−01	0.144E−01	0.120E−01
	50000	0.553E−01	0.144E−01	0.209E−01	0.169E−01	0.172E−01	0.135E−01
	100000	0.511E−01	0.112E−01	0.242E−01	0.192E−01	0.172E−01	0.154E−01
	150000	0.480E−01	0.938E−02	0.280E−01	0.216E−01	0.196E−01	0.163E−01
Mg II 4p–6d	5000	0.994E−01	0.483E−01	*0.201E−01	*0.173E−01	*0.172E−01	*0.142E−01
3538.4 Å	10000	0.945E−01	0.403E−01	*0.248E−01	*0.210E−01	*0.203E−01	*0.172E−01
c = 0.20E + 17	20000	0.897E−01	0.323E−01	0.281E−01	0.238E−01	*0.236E−01	*0.196E−01
	50000	0.829E−01	0.229E−01	0.351E−01	0.279E−01	*0.282E−01	*0.232E−01
	100000	0.762E−01	0.172E−01	0.419E−01	0.307E−01	0.270E−01	0.254E−01
	150000	0.711E−01	0.143E−01	0.485E−01	0.369E−01	0.326E−01	0.252E−01
Mg II 4p–7d	5000	0.156	0.749E−01				
3168.8 Å	10000	0.151	0.659E−01	*0.424E−01	*0.354E−01		
c = 0.10E + 17	20000	0.144	0.518E−01	*0.475E−01	*0.422E−01	*0.365E−01	*0.327E−01
	50000	0.134	0.372E−01	*0.536E−01	*0.504E−01	*0.485E−01	*0.376E−01
	100000	0.122	0.273E−01	*0.750E−01	*0.550E−01	*0.494E−01	*0.410E−01
	150000	0.114	0.226E−01	*0.671E−01	*0.614E−01	*0.575E−01	*0.477E−01
Mg II 5p–5d	5000	1.13	0.458	0.176	0.153	0.156	0.125
16791.0 Å	10000	1.04	0.366	0.213	0.186	0.186	0.149
c = 0.76E + 18	20000	0.984	0.302	0.263	0.215	0.220	0.176
	50000	0.931	0.210	0.310	0.248	0.256	0.198
	100000	0.883	0.163	0.358	0.281	0.260	0.228
	150000	0.841	0.135	0.417	0.317	0.293	0.240
Mg II 5p–6d	5000	0.629	0.298	*0.124	*0.106	*0.107	*0.866E−01
8743.8 Å	10000	0.599	0.248	*0.153	*0.128	*0.125	*0.105
c = 0.12E + 18	20000	0.572	0.198	0.173	0.146	*0.145	*0.120
	50000	0.537	0.140	0.215	0.171	*0.173	*0.142
	100000	0.500	0.105	0.256	0.188	0.164	0.155
	150000	0.470	0.868E−01	0.297	0.226	0.199	0.154
Mg II 5p–7d	5000	0.728	0.366				
6787.6 Å	10000	0.706	0.303	*0.195	*0.163		
c = 0.48E + 17	20000	0.676	0.238	*0.218	*0.194	*0.168	*0.150
	50000	0.632	0.171	*0.246	*0.231	*0.223	*0.172
	100000	0.582	0.125	*0.345	*0.252	*0.227	*0.188
	150000	0.544	0.103	*0.309	*0.282	*0.264	*0.219
Mg II 6p–6d	5000	8.35	3.83	*1.57	*1.31	*1.39	*1.06
30546.7 Å	10000	8.02	3.18	*1.91	*1.57	*1.61	*1.29
c = 0.15E + 19	20000	7.76	2.52	2.16	1.79	*1.81	*1.47
	50000	7.50	1.77	2.65	2.12	*2.16	*1.73
	100000	7.14	1.33	3.15	2.31	2.05	1.95
	150000	6.80	1.09	3.72	2.78	2.47	1.93
Mg II 6p–7d	5000	3.81	1.89				
15221.2 Å	10000	3.71	1.56	*0.988	*0.821		
c = 0.24E + 18	20000	3.58	1.22	*1.11	*0.975	*0.855	*0.760
	50000	3.40	0.874	*1.25	*1.17	*1.12	*0.867
	100000	3.17	0.640	*1.75	*1.28	*1.14	*0.954
	150000	2.99	0.528	*1.58	*1.43	*1.32	*1.11
Mg II 7p–7d	5000	45.5	22.0				
50237.6 Å	10000	44.3	18.3	*11.0	*9.04		
c = 0.26E+19	20000	43.2	14.2	*12.4	*10.9		
	50000	42.2	10.1	*14.4	*13.0	*12.7	*9.54
	100000	40.2	7.35	*19.3	*14.0	*12.9	*10.5
	150000	38.1	6.07	*18.1	*15.7	*14.9	*12.3

Table I. (Continued)

Perturber density = 1 × E + 15 cm^{-3} Perturbers are:		Electrons		Protons		Ionized helium	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
Mg II 3d–4p	5000	0.620E−01	−0.503E−04	0.515E−02	−0.290E−03	0.624E−02	−0.277E−03
10931.0 Å	10000	0.487E−01	−0.448E−03	0.666E−02	−0.493E−03	0.720E−02	−0.441E−03
c = 0.11E + 20	20000	0.411E−01	−0.769E−03	0.753E−02	−0.702E−03	0.804E−02	−0.608E−03
	50000	0.382E−01	−0.427E−03	0.850E−02	−0.949E−03	0.873E−02	−0.783E−03
	100000	0.382E−01	−0.451E−03	0.885E−02	−0.113E−02	0.892E−02	−0.935E−03
	150000	0.380E−01	−0.526E−03	0.897E−02	−0.125E−02	0.912E−02	−0.102E−02
Mg II 3d–5p	5000	0.151E−01	−0.224E−04	0.229E−02	−0.190E−03	0.247E−02	−0.168E−03
3850.2 Å	10000	0.126E−01	−0.611E−04	0.259E−02	−0.270E−03	0.276E−02	−0.233E−03
c=0.62E+18	20000	0.117E−01	−0.347E−04	0.286E−02	−0.339E−03	0.296E−02	−0.282E−03
	50000	0.122E−01	−0.242E−04	0.304E−02	−0.433E−03	0.307E−02	−0.353E−03
	100000	0.128E−01	−0.364E−04	0.311E−02	−0.499E−03	0.316E−02	−0.413E−03
	150000	0.129E−01	−0.471E−04	0.316E−02	−0.549E−03	0.318E−02	−0.448E−03
Mg II 3d–6p	5000	0.162E−01	−0.100E−02	0.341E−02	−0.608E−03	0.364E−02	−0.512E−03
2929.5 Å	10000	0.148E−01	−0.979E−03	0.381E−02	−0.756E−03	0.396E−02	−0.623E−03
c = 0.19E + 18	20000	0.150E−01	−0.724E−03	0.405E−02	−0.901E−03	0.411E−02	−0.744E−03
	50000	0.168E−01	−0.460E−03	0.421E−02	−0.109E−02	0.426E−02	−0.891E−03
	100000	0.180E−01	−0.332E−03	0.427E−02	−0.128E−02	0.424E−02	−0.100E−02
	150000	0.182E−01	−0.236E−03	0.433E−02	−0.136E−02	0.432E−02	−0.109E−02
Mg II 3d–7p	5000	0.232E−01	−0.452E−02	0.578E−02	−0.143E−02	*0.607E−02	*−0.118E−02
2583.0 Å	10000	0.223E−01	−0.337E−02	0.628E−02	−0.174E−02	*0.639E−02	*−0.143E−02
c = 0.87E + 17	20000	0.237E−01	−0.238E−02	0.654E−02	−0.206E−02	0.659E−02	−0.167E−02
	50000	0.277E−01	−0.183E−02	0.690E−02	−0.243E−02	0.679E−02	−0.199E−02
	100000	0.299E−01	−0.119E−02	0.720E−02	−0.279E−02	0.684E−02	−0.236E−02
	150000	0.302E−01	−0.985E−03	0.709E−02	−0.296E−02	0.658E−02	−0.241E−02
Mg II 4d–5p	5000	1.13	−0.249	0.130	−0.885E−01	0.130	−0.736E−01
24076.0 Å	10000	0.977	−0.179	0.157	−0.109	0.151	−0.900E−01
c = 0.28E + 19	20000	0.902	−0.158	0.184	−0.129	0.171	−0.106
	50000	0.877	−0.113	0.216	−0.153	0.197	−0.128
	100000	0.865	−0.917E−01	0.250	−0.174	0.213	−0.139
	150000	0.844	−0.777E−01	0.246	−0.190	0.217	−0.149
Mg II 4d–6p	5000	0.185	−0.357E−01	0.289E−01	−0.121E−01	0.302E−01	−0.100E−01
8119.2 Å	10000	0.168	−0.294E−01	0.331E−01	−0.148E−01	0.332E−01	−0.123E−01
c = 0.32E + 18	20000	0.164	−0.234E−01	0.357E−01	−0.174E−01	0.347E−01	−0.143E−01
	50000	0.173	−0.168E−01	0.392E−01	−0.207E−01	0.364E−01	−0.167E−01
	100000	0.179	−0.130E−01	0.426E−01	−0.240E−01	0.372E−01	−0.186E−01
	150000	0.178	−0.111E−01	0.451E−01	−0.254E−01	0.402E−01	−0.206E−01
Mg II 4d–7p	5000	0.156	−0.356E−01	0.315E−01	−0.104E−01	*0.328E−01	*−0.853E−02
5918.7 Å	10000	0.147	−0.300E−01	0.345E−01	−0.127E−01	*0.345E−01	*−0.105E−01
c = 0.17E + 18	20000	0.151	−0.235E−01	0.364E−01	−0.148E−01	0.362E−01	−0.119E−01
	50000	0.169	−0.169E−01	0.390E−01	−0.173E−01	0.373E−01	−0.141E−01
	100000	0.178	−0.121E−01	0.393E−01	−0.195E−01	0.377E−01	−0.157E−01
	150000	0.179	−0.101E−01	0.430E−01	−0.214E−01	0.415E−01	−0.180E−01
Mg II 5d–6p	5000	9.90	−3.67	1.53	−1.15	*1.44	*−0.943
45302.6 Å	10000	9.26	−2.98	1.83	−1.41	1.61	−1.13
c = 0.55E + 19	20000	8.99	−2.39	2.14	−1.60	1.87	−1.31
	50000	8.97	−1.65	2.37	−1.83	2.05	−1.49
	100000	8.84	−1.28	2.74	−2.12	2.15	−1.75
	150000	8.57	−1.05	3.27	−2.32	2.43	−1.83
Mg II 5d—7p	5000	1.41	−0.499	0.241	−0.138	*0.237	*−0.112
14734.8 Å	10000	1.33	−0.406	0.267	−0.166	*0.254	*−0.136
c = 0.59E + 18	20000	1.34	−0.317	0.298	−0.193	0.267	−0.154
	50000	1.42	−0.226	0.336	−0.231	0.282	−0.180
	100000	1.45	−0.167	0.377	−0.260	0.338	−0.219
	150000	1.42	−0.137	0.431	−0.275	0.311	−0.214
Mg II 6d–7p	5000	62.1	−27.4	*11.2	*−8.54	*10.0	*−6.83
76594.3 Å	10000	59.8	−22.4	*13.0	*−10.2	*11.2	*−8.30
c = 0.95E + 19	20000	58.9	−17.6	*14.4	*−11.7	*12.6	*−9.62
	50000	59.5	−12.4	18.3	−13.7	*14.9	*−11.3
	100000	58.4	−9.21	20.6	−14.8	13.5	−13.2
	150000	56.3	−7.57	25.2	−17.1	16.9	−12.6

Table I. (Continued)

Perturber density = 1 × E + 15 cm^{-3} Perturbers are:		Electrons		Protons		Ionized helium	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
Mg II 3d–4f	5000	0.269E−01	−0.854E−03	0.214E−02	−0.216E−02	0.198E−02	−0.177E−02
4482.7 Å	10000	0.213E−01	−0.100E−02	0.283E−02	−0.263E−02	0.251E−02	−0.218E−02
c = 0.98E + 17	20000	0.173E−01	−0.123E−02	0.354E−02	−0.315E−02	0.306E−02	−0.260E−02
	50000	0.144E−01	−0.838E−03	0.463E−02	−0.382E−02	0.378E−02	−0.313E−02
	100000	0.128E−01	−0.647E−03	0.544E−02	−0.432E−02	0.416E−02	−0.335E−02
	150000	0.120E−01	−0.521E−03	0.609E−02	−0.466E−02	0.470E−02	−0.390E−02
Mg II 3d–5f	5000	0.655E−01	−0.987E−03	*0.258E−01	*0.209E−01		
3105.8 Å	10000	0.556E−01	−0.641E−04	*0.326E−01	*0.253E−01	*0.234E−01	*0.204E−01
c = 0.15E + 16	20000	0.473E−01	0.269E−03	*0.408E−01	*0.289E−01	*0.298E−01	*0.239E−01
	50000	0.382E−01	0.620E−03	*0.562E−01	*0.341E−01	*0.382E−01	*0.282E−01
	100000	0.322E−01	0.240E−03	*0.641E−01	*0.383E−01	*0.511E−01	*0.301E−01
	150000	0.288E−01	0.345E−04	*0.782E−01	*0.384E−01	*0.502E−01	*0.352E−01
Mg II 3d–6f	5000	0.122	−0.438E−02				
2661.6 Å	10000	0.106	−0.224E−02				
c = 0.69E + 15	20000	0.922E−01	0.407E−03				
	50000	0.749E−01	0.135E−02				
	100000	0.628E−01	0.635E−03				
	150000	0.560E−01	−0.205E−03				
Mg II 3d–7f	5000	0.203	−0.123E−01				
2450.4 Å	10000	0.182	−0.743E−02				
c = 0.38E + 15	20000	0.161	−0.114E−02				
	50000	0.132	0.143E−02				
	100000	0.111	0.195E−03				
	150000	0.986E−01	−0.119E−02				
Mg II 4d–4f	5000	95.3	−21.5	9.09	−8.77	8.29	−7.22
	10000	79.9	−16.0	11.6	−10.7	10.3	−8.82
c = 0.20E + 21	20000	68.9	−14.1	14.4	−12.6	12.1	−10.2
	50000	59.7	−10.2	17.7	−14.8	14.9	−12.4
	100000	53.8	−7.91	22.0	−17.2	16.3	−14.5
	150000	50.2	−6.80	24.7	−17.9	18.8	−14.9
Mg II 4d–5f	5000	0.711	−0.404E−01	*0.241	*0.199		
9634.8 Å	10000	0.608	−0.315E−01	*0.307	*0.242	*0.225	*0.192
c = 0.15E + 17	20000	0.523	−0.139E−01	*0.393	*0.275	*0.283	*0.226
	50000	0.430	−0.135E−01	*0.542	*0.325	*0.368	*0.269
	100000	0.367	−0.124E−01	*0.611	*0.358	*0.493	*0.288
	150000	0.331	−0.127E−01	*0.750	*0.358	*0.473	*0.330
Mg II 4d–6f	5000	0.727	−0.350E−01				
6348.6 Å	10000	0.636	−0.218E−01				
c = 0.39E + 16	20000	0.553	0.620E−02				
	50000	0.453	−0.908E−03				
	100000	0.381	−0.297E−02				
	150000	0.342	−0.695E−02				
Mg II 4d–7f	5000	0.963	−0.612E−01				
5265.7 Å	10000	0.863	−0.363E−01				
c = 0.18E + 16	20000	0.761	−0.112E−01				
	50000	0.626	0.114E−02				
	100000	0.527	−0.362E−02				
	150000	0.471	−0.969E−02				
Mg II 5d–6f	5000	6.31	−0.672				
17722.8 Å	10000	5.56	−0.474				
c = 0.30E + 17	20000	4.89	−0.193				
	50000	4.07	−0.179				
	100000	3.47	−0.151				
	150000	3.12	−0.158				
Mg II 5d–7f	5000	4.66	−0.437				
11259.2 Å	10000	4.18	−0.286				
c = 0.80E + 16	20000	3.17	−0.279E−01				
	50000	3.08	−0.643E−01				
	100000	2.61	−0.676E−01				
	150000	2.34	−0.863E−01				

Table I. (Continued)

Perturber density = 1 × E + 15 cm^{-3} Perturbers are:		Electrons		Protons		Ionized helium	
Transition	T (K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
Mg II 6d–7f	5000	35.4	−5.04				
29407.2 Å	10000	32.0	−3.64				
c = 0.55E + 17	20000	28.6	−2.35				
	50000	24.1	−1.38				
	100000	20.6	−1.15				
	150000	18.6	−1.15				
Mg II 4f–5d	5000	0.478	0.187	0.687E−01	0.619E−01	0.603E−01	0.507E−01
10394.8 Å	10000	0.429	0.150	0.855E−01	0.763E−01	0.705E−01	0.616E−01
c = 0.29E + 18	20000	0.392	0.122	0.101	0.856E−01	0.848E−01	0.699E−01
	50000	0.352	0.851E−01	0.115	0.102	0.981E−01	0.808E−01
	100000	0.320	0.659E−01	0.143	0.116	0.105	0.950E−01
	150000	0.298	0.548E−01	0.165	0.123	0.117	0.968E−01
Mg II 4f–6d	5000	0.382	0.177	*0.713E−01	*0.619E−01	*0.624E−01	*0.503E−01
6622.0 Å	10000	0.358	0.147	*0.873E−01	*0.741E−01	*0.728E−01	*0.608E−01
c = 0.71E + 17	20000	0.336	0.117	0.986E−01	0.844E−01	*0.827E−01	*0.694E−01
	50000	0.307	0.821E−01	0.125	0.101	*0.988E−01	*0.818E−01
	100000	0.280	0.618E−01	0.149	0.109	0.952E−01	0.920E−01
	150000	0.261	0.510E−01	0.177	0.130	0.116	0.922E−01
Mg II 4f–7d	5000	0.482	0.239				
5435.6 Å	10000	0.464	0.198	*0.125	*0.105		
c = 0.31E + 17	20000	0.439	0.155	*0.140	*0.125	*0.109	*0.974E−01
	50000	0.405	0.111	*0.160	*0.151	*0.143	*0.111
	100000	0.369	0.814E−01	*0.224	*0.163	*0.147	*0.123
	150000	0.343	0.672E−01	*0.205	*0.183	*0.168	*0.142
Mg II 5f–6d	5000	5.18	1.51	*0.645	*−0.488	*0.510	*−0.390
19190.0 Å	10000	4.69	1.23	*0.844	*−0.599	*0.612	*−0.483
c = 0.58E + 17	20000	4.26	0.947	*1.11	*−0.681	*0.739	*−0.554
	50000	3.73	0.654	*1.62	*−0.802	*0.989	*−0.656
	100000	3.31	0.500	*2.21	*−0.876	*1.20	*−0.722
	150000	3.04	0.417	*2.55	*−1.08	*1.57	*−0.721
Mg II 5f–7d	5000	3.00	1.13	*0.302	*0.211	*0.247	*0.170
11754.8 Å	10000	2.80	0.931	*0.374	*0.253	*0.295	*0.209
c = 0.22E + 17	20000	2.59	0.716	*0.484	*0.301	*0.353	*0.239
	50000	2.32	0.506	*0.688	*0.339	*0.458	*0.276
	100000	2.08	0.374	*0.917	*0.373	*0.535	*0.341
	150000	1.92	0.310	*1.12	*0.417	*0.631	*0.315
Mg II 6f–7d	5000	32.6	8.84				
31900.8 Å	10000	29.9	7.08				
c = 0.99E + 17	20000	27.2	5.26				
	50000	23.6	3.61				
	100000	20.8	2.73				
	150000	19.0	2.31				

Table II. *Experimental Stark full widths at half maximum (Wm) in Å normalized on an electron density of 10^{17} cm^{-3} compared with theory. The WDSB are present semi-classical calculations; WJBG are semi-classical calculations of Jones, Benett and Griem (1971); WDK are calculations of Dimitrijević and Konjević (1981) [24] by using the modified semi-empirical approach [41]; WGDK are calculations of Dimitrijević and Konjević (1981) [24] by using the Griem's semi-empirical approach [43]; WIon are present calculations within the impact approximation of ion broadening contribution. The asterisk denotes cases when the impact approximation is not applicable. Experimental data are: (a) Fleurier et al. (1977) [11]; (b) Helbig and Kusch (1972) [3]; (c) Kusch and Schwiecker (1976) [10]; (d) Chapelle and Sahal-Bréchot (1970) [2]; (e) Purić and Konjević (1972) [7]. In the Table are given also the transition, the line wavelength, the principal perturbing ion, and the critically estimated accuracy according to Refs [43–45], where the uncertainties of experimental data are subdivided into four ranges [44]: A – uncertainties within 15%; B – uncertainties within 30%; C – uncertainties within 50% and D – uncertainties larger than 50% [45]. The plus sign indicates a slightly better piece of data among several similar ones [44]*

Tr	Wavelength	T (K)	Wm (Å)	WDSB (Å)	WJBG (Å)	WDK (Å)	WGDK (Å)	WIon (Å)	Pert.	Acc.	Ref.
3p–3d	2790.79	14300	0.18	0.17	0.16	0.13	0.13	0.02	Ar	D	a
3p–4s	2928.75	10000	0.70	0.30	0.32	0.26	0.23	0.012	Ar	D	b
		10000	1.10	0.30	0.32	0.26	0.23	0.012	H	D	c
		14400	0.31	0.24	0.31	0.22	0.19	0.014	Ar	D	a
	2936.54	10000	0.72	0.30	0.32	0.26	0.23	0.012	Ar	D	b
		10000	0.56	0.30	0.32	0.26	0.23	0.012	H	D	c
		14400	0.31	0.24	0.31	0.22	0.19	0.014	Ar	D	a
3d–4f	4481.16	10000	4.26	2.1	2.7	2.1	3.6	*	Ar	D	b
		10000	10.8	2.1	2.7	2.1	3.6	0.28	H	D	c
		12000	2.1	2.0	2.6	2.0	3.6	*	Ar	C+	d

Table III. *Experimental Stark shifts (dm) in Å normalized on an electron density of 10^{17} cm^{-3} compared with theory. The dDSB are present semi-classical calculations; dJBG are semi-classical calculations of Jones, Benett and Griem (1971) [21, 23]; dDK are calculations of Dimitrijević and Kršljanin (1986) [25] by using the modified semiempirical approach [25, 41]; dIon are present calculations within the impact approximation of ion broadening contribution. The asterisk denotes cases when the impact approximation is not applicable. References for experimental data are the same as in Table I. In the Table are given also well the transition, the line wavelength, the principal perturbing ion and the critically estimated accuracy according to Refs [43–45] (see the explanation for Table II)*

Tr	Wavelength	T (K)	dm (Å)	dDSB (Å)	dJBG (Å)	dMSE (Å)	dIon (Å)	Pert.	Acc.	Ref.
3p–3d	2790.79	14300	0.061	0.028	0.074	—	0.004	Ar	C	a
3p–4s	2928.75	10000	0.06	0.13	0.16	0.11	0.009	Ar	D	b
		10000	0.28	0.13	0.16	0.11	0.014	H	D	c
		14400	0.18	0.11	0.15	0.10	0.011	Ar	C	a
		16800	0.08	0.11	0.14	0.10	0.012	Ar	C	e
	2936.54	10000	0.08	0.13	0.16	—	0.009	Ar	D	b
		10000	0.49	0.13	0.16	—	0.014	H	D	c
		14400	0.18	0.11	0.15	—	0.011	Ar	C	a
		16800	0.08	0.11	0.14	—	0.012	Ar	C	e
3d–4f	4481.16	10000	0.32	−0.040	−0.96	—	*	Ar	D	b
		10000	−1.89	−0.040	−0.96	—	−0.21	H	D	c

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Stark Broadening Parameters for Spectral Lines of Singly-, Doubly- and Triply-Charged Vanadium Ions

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Abstract

In this paper we present Stark broadening parameters for 52 transitions of singly-, doubly-, and triply-charged vanadium ions calculated by using the modified semiempirical method. The Stark widths and shifts have been calculated for an electron density 10^{23}m^{-3} and presented as a function of electron temperature.

1. Introduction

With the development of space born techniques, the interest for atomic data and spectral line parameters of many emitters in various ionization stages increases. Vanadium is present in stellar and solar plasmas, and atomic and spectroscopic data for its ions, including Stark broadening parameters are of interest for the investigation and modeling of such plasmas. The Stark broadening mechanism is the main pressure broadening mechanism in stellar plasma conditions with $T_{\rm eff} \geq 10000$ K, i.e. for plasma present in A and B-type stars photospheres. Moreover, it has been found that vanadium is overabundant in some A-type stars. For example van't Veer- Mennert *et al*. [1] have found vanadium overabundance in the Am star HR178, and Sadakane and Ueta [2] an overabundance in Sirius, also an A-type star. Kocer *et al*. [3] have compared V I and V II spectral lines in θ Cyg, ι Psc, 15 Vul, 32 Aqr, and the Sun and they found the similar vanadium abundance in all stars considered.

Stark broadening of spectral lines for emitter/absorber higher ionization stages are also of interest. Lines of triply charged ions are present for example in PG 1159 star atmospheres [4]. Moreover, for the modeling of subphotospheric layers, higher ionization stages are of interest as well [5]. Consequently, Stark broadening parameters for singly and multiply charged vanadium ion lines are of interest not only for the laboratory plasma research and for the testing and developing of the Stark broadening theory for shapes of multicharged ion lines, but also for the consideration of stellar plasma.

Recently, the electron-, proton-, and He III-impact line widths and shifts for 33 vanadium V and 26 vanadium XIII multiplets have been calculated [6] within the semiclassical perturbation formalism [7–10]. In the case of singly-, doubly-, and triply-ionized vanadium it is not possible to use the semiclassical method for the calculation of Stark broadening parameters in an adequate manner and with the accuracy usually expected, due to the lack of the reliable atomic data required. Consequently, it is justified to apply simpler methods. One such method is the modified semiemprical method – MSE [11,12]. This method has been tested several times, and it has been shown (see e.g. Refs. [13–16]) that for emitters with complex spectra, such as spectra of V II, V III and V IV, the MSE approach gives a good average accuracy. Here we use the MSE method for the calculation of Stark broadening parameters for 14 transitions of singly-ionized vanadium (widths and shifts), 8 of doubly-ionized (widths) and 30 transition of triply-ionized vanadium (widths).

2. The modified semiempirical approach

Within the modified semiemprical approach [11,12], as well as in the semiempirical one [17] the most complicated part of the calculations within the semiclassical method [7–10], the calculation of the cross sections for the corrensponding dipol transitions, perturbing initial (i) and final (f) level of transtion, is replaced by empirical Gaunt factors derrived from experiment [18–20]. Moreover, the set of atomic data has been minimized by lumping together transitions with $\Delta n \neq 0$. The expression for the electron impact full width (FHWM) in the MSE formalism of an ion line is given as

$$W_{\rm MSE} = N\frac{8\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}\cdot$$

$$\left\{\sum_{\ell_i\pm1}\sum_{L_{i'}J_{i'}}\Re^2[n_i\ell_iL_iJ_i, n_i(\ell_i\pm1)L_{i'}J_{f'}]\tilde{g}\left(\frac{E}{\Delta E_{\ell i,\ell_i\pm1}}\right)+\right.$$

$$+\sum_{\ell_f\pm1}\sum_{L_{f'}J_{f'}}\Re^2[n_f\ell_fL_fJ_f, n_f(\ell_f\pm1)L_{f'}J_{f'}]\tilde{g}\left(\frac{E}{\Delta E_{\ell_f,\ell_f\pm1}}\right)+$$

$$\left.\left(\sum_{i'}\Re^2_{ii'}\right)_{\Delta n\neq0}g(x_{n_i,n_i+1})+\left(\sum_{f'}\Re^2_{\rm ff'}\right)_{\Delta n\neq0}g(x_{n_f,n_f+1})\right\},$$

and the corresponding Stark shift as

$$d = N\frac{4\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}\cdot\left\{\sum_{L_{i'}J_{i'}}\sigma J_iJ_{i'}\Re^2[n_i\ell_iL_iJ_i, n_i(\ell_i+1)\right.$$

$$\left.L_{i'}J_{i'}]\tilde{g}_{\rm sh}\left(\frac{E}{\Delta E_{\ell_i,\ell_{i+1}}}\right)-\right.$$

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$$\sum_{L_{i'}J_{i'}} \sigma_{J_iJ_{i'}} \Re^2[n_i\ell_iL_iJ_i, n_i(\ell_i-1)L_{i'}J_{i'}]\tilde{g}_{\rm sh}\left(\frac{E}{\Delta E_{\ell_i,\ell_{i-1}}}\right) -$$

$$\sum_{L_{f'}J_{f'}} \sigma_{J_fJ_{f'}} \Re^2[n_f\ell_fL_fJ_f, n_f(\ell_f+1)L_{f'}J_{f'}]\tilde{g}_{\rm sh}\left(\frac{E}{\Delta E_{\ell_f,\ell_{f+1}}}\right) +$$

$$\sum_{L_{f'}J_{f'}} \sigma_{J_fJ_{f'}} \Re^2[n_f\ell_fL_fJ_f, n_f(\ell_f-1)L_{f'}J_{f'}]\tilde{g}_{\rm sh}\left(\frac{E}{\Delta E_{\ell_f,\ell_{f-1}}}\right) +$$

$$+\left(\sum_{i'}\Re^2_{ii'}\right)_{\Delta n\neq 0} g_{\rm sh}(x_{n_i}, x_{n_{i+1}})$$

$$-\left(\sum_{f'}\Re^2_{ff'}\right)_{\Delta n\neq 0} g_{\rm sh}(x_{n_f}, x_{n_{f+1}})$$

$$-2\sum_{i'(\Delta E_{ii'}<0)}\sum_{L_{i'}J_{i'}}\Re^2(n_i\ell_iL_iJ_i, n_i\ell_{i'}L_{i'}J_{i'})g_{\rm sh}\left(\frac{E}{\Delta E_{\ell_i,\ell_{i'}}}\right)$$

$$+2\sum_{f'(\Delta E_{ff'}<0)}\sum_{L_{f'}J_{f'}}\Re^2(n_f\ell_fL_fJ_f, n_f\ell_{f'}L_{f'}J_{f'})g_{\rm sh}\left(\frac{E}{\Delta E_{\ell_f,\ell_{f'}}}\right)$$

$$+\sum_k \delta_k\} \tag{2}$$

where the square of the matrix element $\Re^2[n_k\ell_kL_kJ_k, (\ell_k\pm 1)L'_kJ'_k]$, $k=i,f\}$ is

$$\Re^2[n_k\ell_kL_kJ_k, n_k(\ell_k\pm 1)L'_kJ'_k] = \frac{\ell_>}{2J_k+1} R^2_{\rm line}\cdot R^2_{\rm mult}\cdot [R^{n_k(\ell_k\pm 1)}_{n_k\ell_k}]^2 \tag{3}$$

and

$$\left(\sum_{k'}\Re^2_{kk'}\right)_{\Delta n\neq 0} = \left(\frac{3n_k}{2Z}\right)^2\frac{1}{9}(n_k^2+3\ell_k^2+3\ell_k+11) \tag{4}$$

where $\ell_> = \max(\ell_k, \ell_k\pm 1)$.

In Eqs. (1–4), N and T are electron density and temperature, respectively. $R_{\rm line}$ and $R_{\rm mult}$ are line and multiplet factors. The $[R^{n_k\ell_k\pm 1}_{n\ell}]$ is the radial integral, $g(x), g_{\rm sh}(x)$ and $\tilde{g}(x), \tilde{g}_{\rm sh}(x)$ are the semiempirical [17] and the modified semiempirical [11,12] Gaunt factors for Stark width and shift, respectively. The factor $\sigma_{kk'} = (E_{k'}-E_k)/|E_{k'}-E_k|$, where E_k and $E_{k'}$ are the energy of the considered and its pertubing level. The sum $\Sigma_k\delta_k$ is different from zero only if perturbing levels strongly violating the assumed approximations exist and may be evaluated as

$$\delta_i = \pm\Re^2_{ii'}[g_{\rm sh}\left(\frac{E}{\Delta E_{i,i'}}\right) \mp g_{\rm sh}(x_{n_i,n_{i+1}})], \tag{5}$$

for the upper level, and

$$\delta_f = \mp\Re^2_{ff'}[g_{\rm sh}\left(\frac{E}{\Delta E_{f,f'}}\right) \mp g_{\rm sh}(x_{n_f,n_{f+1}})], \tag{6}$$

for the lower level. In eqs. (5) and (6) lower signs correspond to $\Delta E_{jj'}<0$. Also, $x_{n_k,n_k+1}\approx 3kTn_k^{*3}/(2Z^2E_H)$, where $\Delta E_{kk'} = |E_k-E_{k'}|$, n_k^* is the effective principal quantum number and $(Z-1)$ is the ionic charge.

In comparison with the semiclassical perturbation approach [9,10], the modified semiempirical approach needs a considerably smaller number of atomic data. In fact, if there are no perturbing levels strongly violating the assumed approximation, for e.g. the line width calculations, we need only the energy levels with $\Delta n=0$ and $\ell=\ell_{i_f}\pm 1$, since all perturbing levels with $\Delta n\neq 0$, needed for a full semiclassical investigation are lumped together and approximately estimated. The accuracy of the method is about $\pm 50\%$ in average [11].

From Eqs. (1) and (2) one can see that for temperatures corresponding to energies below the excitation threshold, when the Gaunt factor is extrapolated toward lower energies as a constant having the threshold value [17,18], W and d depend on T as $T^{-1/2}$. However, since there are several Gaunt factors involved, and since for the energies above the excitation threshold the temperature dependence is more complicated, extrapolations by using $T^{-1/2}$ dependence should be done very carefully, especially toward higher temperatures.

3. Results and discussion

The atomic energy levels needed for the calculations were taken from [21,22]. Oscillator strengths have been calculated by using the method of Bates and Damgaard [23] and the tables of Oertel and Shomo [24].

Results obtained using the MSE approach for electron – impact line widths and shifts for 14 V II and line widths for 8 V III and 30 V IV multiplets as a function of temperature are presented in Tables I–III. Since the ionization potential increase with the increase of the degree of ionization, the upper and lower limit of the temperature range considered increase as well, taking into account the corresponding ionization degree values.

The calculations have been performed for a perturber density of $10^{23}\mathrm{m}^{-3}$, since within the MSE formalism, the results for the electron-impact broadening parameters are linear with electron density. For the first three UV transitions we have calculated Stark widths and shifts taking into account the influence of z^5D^0 and z^5F^0 levels as particular contributions and not lumping them together with other $\Delta n\neq 0$ transitions, in order to improve the accuracy. Stark widths and shifts are expected to be nearly the same within a multiplet [25,26] if one has not irregularities of energy level structure or the influence of the intercombination or forbidden perturbing transitions to the particular members within a multiplet [27]. Consequently, an averaged wavelength for the multiplet as a whole, has been used in the tables. If the wavelengths of the particular lines within the multiplet are close, the tabulated values may be used for any member of the multiplet. If differences may not be neglected, one may obtain Stark broadening parameters W_1, and d_1 for a line with the wavelength λ_1 within the considered multiplet, by using the following expression

$$W_1 = W(\lambda/\lambda_1)^2,$$
$$d_1 = d(\lambda/\lambda_1)^2, \tag{7}$$

where W, d and λ are tabulated values for the multiplet as a whole. Generally, the accuracy of theoretically calculated Stark broadening parameter values is smaller for shifts than for widths [28,29]. Namely, for widths contributions involved in the calculation have positive signs, while for shifts the signs of particular contributions are different

Table I. *Stark widths (FWHM) and shifts of V II spectral lines at an electron density of $10^{23} m^{-3}$ as a function of temperature. The average wavelength of the multiplet is denoted by $\bar{\lambda}$.*

Transition	T (K)	W (nm)	d (nm)
	5000.	0.181E-01	–0.397E-02
$a^3F - z^3\ D^0$	10000.	0.126E-01	–0.284E-02
	30000.	0.704E-02	–0.173E-02
$\bar{\lambda} = 354.65$ nm	50000.	0.557E-02	–0.144E-02
	100000.	0.472E-02	–0.121E-02
	150000.	0.468E-02	–0.105E-02
	5000.	0.160E-01	–0.324E-02
$a^3\ F - z^3\ F^0$	10000.	0.111E-01	–0.232E-02
	30000.	0.625E-02	–0.139E-02
$\bar{\lambda} = 319.02$ nm	50000.	0.496E-02	–0.113E-02
	100000.	0.420E-02	–0.871E-03
	150000.	0.415E-02	–0.780E-03
	5000.	0.166E-01	–0.351E-02
$a^3\ F - z^3G^0$	10000.	0.116E-01	–0.251E-02
	30000.	0.648E-02	–0.152E-02
$\bar{\lambda} = 327.42$ nm	50000.	0.514E-02	–0.124E-02
	100000.	0.435E-02	–0.980E-03
	150000.	0.429E-02	–0.876E-03
	5000.	0.183E-01	0.115E-01
$z^3\ D^0 - e^3\ P$	10000.	0.126E-01	0.862E-02
	30000.	0.789E-02	0.641E-02
$\bar{\lambda} = 262.42$ nm	50000.	0.737E-02	0.681E-02
	100000.	0.721E-02	0.659E-02
	150000.	0.701E-02	0.621E-02
	5000.	0.213E-01	0.132E-01
$z^3G^0 - e^3\ H$	10000.	0.147E-01	0.987E-02
	30000.	0.918E-02	0.735E-02
$\bar{\lambda} = 278.23$ nm	50000.	0.857E-02	0.780E-02
	100000.	0.918E-02*	0.750E-02
	150000.	0.901E-02*	0.746E-02
	5000.	0.101E-01	0.339E-03
$a^5\ D - z^5\ F^0$	10000.	0.700E-02	0.257E-03
(lUV)	30000.	0.390E-02	0.195E-03
$\bar{\lambda} = 271.47$ nm	50000.	0.305E-02	0.195E-03
	100000.	0.247E-02	0.305E-03
	150000.	0,242E-02	0.333E-03
	5000.	0.928E-02	–0.132E-03
$a^5D - z^5\ D^0$	10000.	0.645E-02	–0.839E-04
(2UV)	30000.	0.359E-02	–0.230E-04
$\bar{\lambda} = 271.05$ nm	50000.	0.282E-02	0.338E-05
	100000.	0.232E-02	0.882E-04
	150000.	0.229E-02	0.155E-03
	5000.	0.979E-02	–0.130E-03
$a^5\ D - z^5\ D^0$	10000.	0.681E-02	–0.792E-04
(3UV)	30000.	0.380E-02	–0.113E-04
$\bar{\lambda} = 268.50$ nm	50000.	0.297E-02	0.263E-04
	100000.	0.242E-02	0.138E-03
	150000.	0.236E-02	0.188E-03
	5000.	0.124E-01	–0.241E-02
$a^5\ F - z^5\ D^0$	10000.	0.863E-02	–0.172E-02
$\bar{\lambda} = 289.66$ nm	30000.	0.483E-02	–0.102E-02
	50000.	0.380E-02	–0.811E-03
	100000.	0.316E-02	–0.618E-03
	150000.	0.309E-02	–0.534E-03
	5000.	0.128E-01	–0.192E-02
$a^5\ F - z^5\ F^0$	10000.	0.889E-02	–0.136E-02
$\bar{\lambda} = 293.11$ nm	30000.	0.498E-02	–0.806E-03
	50000.	0.392E-02	–0.634E-03
	100000.	0.325E-02	–0.466E-03
	150000.	0.318E-02	–0.383E-03

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Table I. *Continued*

Transition	T (K)	W (nm)	d (nm)
$a^5F - z^5\ G^0$	5000.	0.131E-01	–0.300E-02
	10000.	0.914E-02	–0.214E-02
$\bar{\lambda} = 310.89$ nm	30000.	0.511E-02	–0.129E-02
	50000.	0.402E-02	–0.104E-02
	100000.	0.334E-02	–0.859E-03
	150000.	0.328E-02	–0.736E-03
	5000.	0.198E-01	0.106E-01
$z^5\ ^5F^0 - e^5\ G$	10000.	0.136E-01	0.789E-02
	30000.	0.831E-02	0.579E-02
$\bar{\lambda} = 276.64$ nm	50000.	0.760E-02	0.619E-02
	100000.	0.798E-02*	0.608E-02
	150000.	0.842E-02*	0.561E-02
	5000.	0.171E-01	0.104E-01
$z^5\ G^0 - e^5\ G$	10000.	0.118E-01	0.774E-02
	30000.	0.719E-02	0.561E-02
$\bar{\lambda} = 262.47$ nm	50000.	0.661E-02	0.591E-02
	100000.	0.699E-02*	0.580E-02
	150000.	0.739E-02*	0.535E-02
	5000.	0.164E-01	0.109E-01
$z^5\ G^0 - e^5\ H$	10000.	0.113E-01	0.811E-02
	30000,	0.689E-02	0.583E-02
$\bar{\lambda} = 265.47$ nm	50000.	0.636E-02	0.608E-02
	100000.	0.677E-02*	0.595E-02
	150000.	0.721E-02*	0.552E-02

Table II. *Stark widths (FWHM) of V III spectral lines at an electron density of $10^{23}m^{-3}$ as a function of temperature. With an asterisk are denoted values calculated by using the high temperature limit so that a jump due to the change of the calculation procedure exists.*

Transition	T (K)	W (nm)
	10000.	0.681E-02
$a^2F - z^2\ D^0$	20000.	0.474E-02
	50000.	0.296E-02
$\bar{\lambda} = 255.17$ nm	100000.	0.223E-02
	200000.	0.195E-02
	300000.	0.193E-02
	10000.	0.690E-02
$b^2\ F - z^2\ F^0$	20000.	0.481E-02
	50000.	0.301E-02
$\bar{\lambda} = 259.50$ nm	100000.	0.226E-02
	200000.	0.199E-02
	300000.	0.196E-02
	10000.	0.569E-02
$b^2\ F - z^2G^0$	20000.	0.396E-02
	50000.	0.247E-02
$\bar{\lambda} = 236.41$ nm	100000.	0.186E-02
	200000.	0.165E-02*
	300000.	0.162E-02*
	10000.	0.552E-02
$z^2\ G^0 - e^2\ H$	20000.	0.383E-02
	50000.	0.248E-02
$\bar{\lambda} = 184.35$ nm	100000.	0.207E-02
	200000.	0.207E-02
	300000.	0.206E-02
	10000.	0.480E-02
$b^4F - z^4\ D^0$	20000.	0.335E-02
	50000.	0.209E-02
$\bar{\lambda} = 222.21$ nm	100000.	0.155E-02
	200000.	0.136E-02
	300000.	0.131E-02

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Table II. *Continued*

Transition	T (K)	W (nm)
	10000.	0.536E-02
$b^4\ F - z^4\ F^0$	20000.	0.374E-02
	50000.	0.233E-02
$\bar{\lambda} = 233.33$ nm	100000.	0.173E-02
	200000.	0.149E-02
	300000.	0.144E-02
	10000.	0.613E-02
$b^4F - z^4\ G^0$	20000.	0.428E-02
	50000.	0.267E-02
$\bar{\lambda} = 238.65$ nm	100000.	0.198E-02
	200000.	0.169E-02
	300000.	0.164E-02
	10000.	0.465E-02
$z^4\,G^0 - e^4\ H$	20000.	0.323E-02
	50000.	0.207E-02
$\bar{\lambda} = 180.41$ nm	100000.	0.170E-02
	200000.	0.170E-02
	300000.	0.170E-02*

Table III. *Same as in Table II, but for V IV transitions.*

Transition	T (K)	W (nm)
$b^1D - z^1\ P^0$	30000.	0.200E-02
	50000.	0.154E-02
$\bar{\lambda} = 180.62$ nm	100000.	0.111E-02
	250000.	0.854E-03
	500000.	0.812E-03
$b^1\,D - z^1\ D^0$	30000.	0.292E-02
	50000.	0.225E-02
$\bar{\lambda} = 226.90$ nm	100000.	0.163E-02
	250000.	0.126E-02
	500000.	0.119E-02
$b^1\,D - z^1G^0$	30000.	0.206E-02
	50000.	0.158E-02
$\bar{\lambda} = 186.16$ nm	100000.	0.114E-02
	250000.	0.881E-03
	500000.	0.839E-03
$z^1\ P^0 - 4d^1\ D$	30000.	0.161E-02
	50000.	0.125E-02
$\bar{\lambda} = 142.37$ nm	100000.	0.933E-02
	250000.	0.795E-02
	500000.	0.789E-02
$z^1\,P^0 - 5s^1\ D$	30000.	0.243E-02
	50000.	0.195E-02
$\bar{\lambda} = 121.84$ nm	100000.	0.160E-02
	250000.	0.140E-02
	500000.	0.129E-02
$z^1\,D^0 - 4d^1\ P$	30000.	0.124E-02
	50000.	0.953E-03
$\bar{\lambda} = 135.65$ nm	100000.	0.708E-03
	250000.	0.600E-03
	500000.	0.605E-03*
$z^1\,D^0 - 4d^1\,F$	30000.	0.135E-02
	50000.	0.104E-02
$\bar{\lambda} = 139.50$ nm	100000.	0.770E-03
	250000.	0.646E-03
	500000.	0.649E-03*
$z^1D^0 - 5s^1\ D$	30000.	0.183E-02
	50000.	0.146E-02
$\bar{\lambda} = 107.11$ nm	100000.	0.121E-02
	250000.	0.106E-02
	500000.	0.979E-03

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Table III. *Continued.*

Transition	T (K)	W (nm)
$z^1\,F^0 - 4d^1\,D$	30000.	0.150E-02
	50000.	0.116E-02
$\bar{\lambda} = 139.11$ nm	100000.	0.870E-03
	250000.	0.744E-03
	500000.	0.740E-03
$z^1\,F^0 - 4d^1\,F$	30000.	0.188E-02
	50000.	0.144E-02
$\bar{\lambda} = 161.19$ nm	100000.	0.106E-02
	250000.	0.888E-03
	500000.	0.895E-03*
$z^1\,F^0 - 4d^1\,G$	30000.	0.139E-02
	50000.	0.108E-02
$\bar{\lambda} = 135.51$ nm	100000.	0.811E-03
	250000.	0.701E-03
	500000.	0.698E-03
$z^1\,F^0 - 5s^1\,D$	30000.	0.232E-02
	50000.	0.185E-02
$\bar{\lambda} = 119.44$ nm	100000.	0.152E-02
	250000.	0.133E-02
	500000.	0.123E-02
$5s^1\,D - 5p^1\,P^0$	30000.	0.583E-01
	50000.	0.472E-01
$\bar{\lambda} = 484.26$ nm	100000.	0.395E-01
	250000.	0.359E-01
	500000.	0.329E-01
$5s^1\,D - 5p^1\,D^0$	30000.	0.824E-01
	50000.	0.670E-01
$\bar{\lambda} = 594.17$ nm	100000.	0.566E-01
	250000.	0.512E-01
	500000.	0.473E-01
$5s^1D - 5p^1\,F^0$	30000.	0.624E-01
	50000.	0.506E-01
$\bar{\lambda} = 498.70$ nm	100000.	0.424E-01
	250000.	0.384E-01
	500000.	0.317E-01
$a^3\,D - z^3\,P^0$	30000.	0.193E-02
	50000.	0.148E-02
$\bar{\lambda} = 182.13$ nm	100000.	0.106E-02
	250000.	0.816E-03
	500000.	0.778E-03
$a^3\,D - z^3\,D^0$	30000.	0.223E-02
	50000.	0.171E-02
$\bar{\lambda} = 200.15$ nm	100000.	0.124E-02
	250000.	0.951E-03
	500000.	0.905E-03
$a^3\,D - z^3\,F^0$	30000.	0.219E-02
	50000.	0.168E-02
$\bar{\lambda} = 195.18$ nm	100000.	0.121E-02
	250000.	0.931E-03
	500000.	0.887E-03
$z^3P^0 - e^3\,D$	30000.	0.162E-02
	50000.	0.125E-02
$\bar{\lambda} = 152.27$ nm	100000.	0.922E-03
	250000.	0.773E-03
	500000.	0.781E-03*
$z^3\,P^0 - 5s^3\,D$	30000.	0.217E-02
	50000.	0.176E-02
$\bar{\lambda} = 117.66$ nm	100000.	0.144E-02
	250000.	0.126E-02
	500000.	0.116E-02
$z^3\,D^0 - e^3\,D$	30000.	0.136E-02
	50000.	0.104E-02
$\bar{\lambda} = 141.61$ nm	100000.	0.773E-03
	250000.	0.651E-03
	500000.	0.658E-03*

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Table III. *Continued.*

Transition	T (K)	W (nm)
$z^3\,D^0 - e^3\,F$	30000.	0.117E-02
	50000.	0.903E-03
$\bar{\lambda} = 130.67$ nm	100000.	0.677E-03
	250000.	0.583E-03
	500000.	0.585E-03*
$z^3\,D^0 - 5s^3\,D$	30000.	0.191E-02
	50000.	0.155E-02
$\bar{\lambda} = 111.20$ nm	100000.	0.127E-02
	250000.	0.112E-02
	500000.	0.103E-02
$z^3\,F^0 - e^3\,D$	30000.	0.145E-02
	50000.	0.111E-02
$\bar{\lambda} = 144.21$ nm	100000.	0.823E-03
	250000.	0.690E-03
	500000.	0.697E-03*
$z^3\,F^0 - e^3\,F$	30000.	0.124E-02
	50000.	0.959E-03
$\bar{\lambda} = 132.88$ nm	100000.	0.718E-03
	250000.	0.615E-03
	500000.	0.617E-03*
$z^3F^{\,0} - e^3\,G$	30000.	0.144E-02
	50000.	0.111E-02
$\bar{\lambda} = 142.16$ nm	100000.	0.818E-03
	250000.	0.686E-03
	500000.	0.691E-03*
$z^3\,F^0 - 5s^3\,D$	30000.	0.199E-02
	50000.	0.161E-02
$\bar{\lambda} = 112.79$ nm	100000.	0.132E-02
	250000.	0.116E-02
	500000.	0.107E-02
$5s^3\,D - 5p^3\,P^0$	30000.	0.533E-01
	50000.	0.450E-01
$\bar{\lambda} = 487.50$ nm	100000.	0.377E-01
	250000.	0.344E-01
	500000.	0.316E-01
$5s^3\,D - 5p^3\,D^0$	30000.	0.681E-01
	50000.	0.554E-01
$\bar{\lambda} = 534.00$ nm	100000.	0.464E-01
	250000.	0.421E-01
	500000.	0.387E-01
$5s^3\,D - 5p^3\,F^0$	30000.	0.674E-01
	50000.	0.547E-01
$\bar{\lambda} = 515.44$ nm	100000.	0.457E-01
	250000.	0.414E-01
	500000.	0.379E-01

and mutual cancelations may lower the accuracy. Since shifts are smaller for doubly and triply ionized emitters than for singly ionized emitters, here are presented Stark shifts only for V II transitions. However, Stark shifts for V III and V IV transitions are available from the authors upon request.

There are no experimental data for the Stark broadening parameters of V II, V III and V IV spectral lines. However, the Stark width and shift for V II $a^5D - z^5F^0$ transition estimated on the basis of regularities and systematic trends have been published in Ref. [30]. In Fig. 1 a comparison between our calculated Stark width for the 1 UV multiplet and the width taken from [30] is shown. As one can see in Fig. 1, the estimation given in [30] is in good agreement with our results. For the shift however, the estimate in Ref. [30] gives value of 0.0046 nm for $T = 20000$ K and a perturber density of $10^{23}\mathrm{m}^{-3}$, while the result of our calculations is 0.000208 nm.

4. Conclusion

Stark broadening parameters for 14 transitions of V II, 8 of V III and 30 of V IV have been calculated by using the modified semiempirical method. The presented results are the first results for Stark broadening of V II, V III and V IV spectral lines, which are not an estimate based on regularities and systematic trends. We hope that they will be of interest for modelling and investigation of trace element lines in stellar spectra, for laboratory plasma research as well as for the theoretical considerations of heavy element spectra

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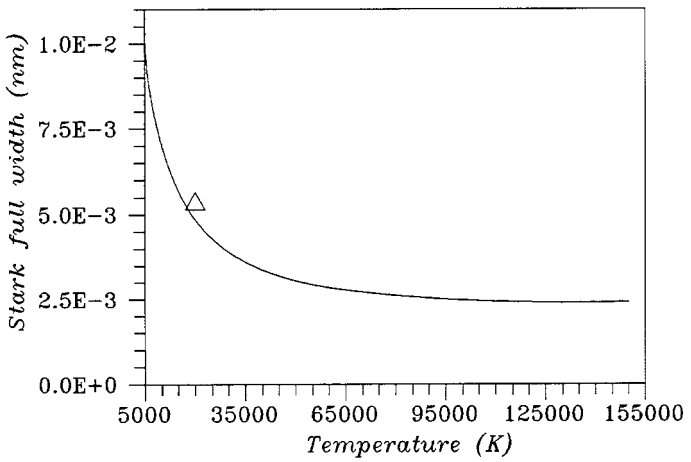

Fig. 1. Stark full widths for the V II $a^5\,D - z^5\,F^0$ as a function of temperature, at an electron density of $10^{23}m^{-3}$. The used notations are: (—) – our calculation (see the text), (Δ) – the estimated Stark width on the basis of regularities and systematic trends (Ref. [13]).

and investigations of systematic trends along isoelectronic sequences.

The obtained results have been compared with simple estimates for V II $a^5D - z^5\,F^0$ transition based on regularities and systematic trends [30]. The agreement is good for the width, indicating that such estimates may be of interest for the Stark width estimates when more sophisticated calculations do not exist. For the shift however, the disagreement is considerable.

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References

1. van't Veer-Mennert, C., Coupry, M. F. and Burkhart, C., Astron. Astrophys. **146**, 139 (1985).
2. Sadakane, K. and Ueta, M., Publ. Astron. Soc. Japan **41**, 279 (1989).
3. Kocer, D., Adelman, S. J., Bolcal, C. and Mill, G., In: "Peculiar Versus Normal Phenomena in A-Type and Related Stars," (eds. M. M. Dworetski, F. Castelli, R. Faraggiama), ASP Conf. Series **44**, 213 (1993).
4. Werner, K., Heber, U. and Hunger, K., Astron. Astrophys. **244**, 437 (1991).
5. Seaton, M. J., J. Phys. B **20**, 6363 (1987).
6. Dimitrijević, M. S. and Sahal-Bréchot, S., At. Data Nucl. Data Tables **68**, 241(1998).
7. Dimitrijević, M. S. Sahal-Bréchot, S. and Bommier, V., Astron. Astrophys. Suppl. Series **89**, 581 (1991).
8. Dimitrijević, M. S. and Sahal-Bréchot, S., Physica Sripta **52**, 41 (1995).
9. Sahal-Bréchot, S., Astron. Astrophys. **1**, 91 (1969).
10. Sahal-Bréchot, S., Astron. Astrophys. **2**, 322 (1969).
11. Dimitriiević, M. S. and Konjević, N., J. Quant. Spectrosc. Radiat. Transfer **24**, 451 (1980).
12. Dimitriiević, M. S. and Kršljanin, V., Astron. Astrophys. **165**, 269 (1986).
13. Popović, L. Č. and Dimitrijević, M. S., Physica Scripta **53**, 325 (1996).
14. Popović, L. Č. and Dimitrijević, M. S., Astron. Astrophys. Suppl. Series **116**, 359 (1996).
15. Popović, L. Č. and Dimitrijević, M. S., Astron. Astrophys. Suppl. Series **120**, 373 (1996).
16. Popović, L. Č. and Dimitrijević, M. S., Astron. Astrophys. Suppl. Series **127**, 295 (1998)
17. Griem, H. R., Phys. Rev. **165**, 258 (1968)
18. Seaton, M. J., in "Atomic and Molecular Processes" (ed. D. R. Bates) ch. 11, (Academic Press, New York, 1962).
19. van Regemorter, H., Astrophys. J. **136**, 906 (1962).
20. Kobzev, G. A., Opt. Spektrosk. **30**, 106 (1971).
21. Bashkin, S. and Stoner, J. O. Jr., "Atomic Energy Levels and Grotrian Diagrams, Vanadium I – Chromium XXIV", Vol. 3, (North Holland, Amsterdam, 1981).
22. Sugar, J. and Corliss, C., Atomic Energy Levels of the Iron Period Elements: Potassium. through Nickel, J. Phys. Chem. Ref. Data **14**, Suppl. No 2 (1985).
23. Bates, D. R. and Damgaard, A., Trans. Roy. Soc. London, Ser. A **242**, 101 (1949).
24. Oertel, G. K. and Shomo, L. P., Astrophys. J. Suppl. Series **16**, 175 (1968).
25. Wiese, W. L. and Konjević, N., J. Quant. Spectrosc. Radiat. Transfer **28**, 185 (1982).
26. Wiese, W. L. and Konjević, N., J. Quant. Spectrosc. Radiat. Transfer **47**, 185 (1992).
27. Dimitrijević, M. S. and Tankosić, D., Physica Scripta submitted (1999).
28. Dimitrijević, M. S., Feautrier, N. and Sahal-Bréchot, S., J. Phys. B**14**, 2559 (1981).
29. Popović, L. Č., Vince, I., Dimitrijević, M. S., Astron. Astrophys. Suppl. Series **102**, 17 (1993).
30. Lakićevć, I. S., Astron. Astrophys. **127**, 37 (1983).

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Stark Broadening of F VI, Cl VII and Kr VIII Spectral Lines

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Abstract

Using a semiclassical approach, we have calculated electron-, proton-, and He III-impact line widths and shifts for 2 F VI, 10 Cl VII and 6 Kr VIII multiplets, as a function of temperature.

1. Introduction

In a series of papers we have performed large scale calculations of Stark broadening parameters for a number of spectral lines of various emitters from neutrals up to twelve time charged ions. The results of such calculations are of interest for a number of different problems in physics, astrophysics and plasma technology. Our calculations are performed within the semiclassical – perturbation formalism [1–4] for a number of radiators (See *e.g.* Ref. [5] and references therein).

As the continuation of our project, we will consider here Stark broadening within F VI, Cl VII and Kr VIII spectra. Chlorine and fluorine spectral lines have been observed in Solar [6], as well as in stellar spectra [7]. In Ref. [8] has been reported that chlorine and fluorine have been found in the ejecta of SN 1987 A supernova. With the development of space-borne spectroscopy, spectral line parameters even for trace elements become of increasing interest for astrophysics. By using the Goddard High Resolution Spectrograph on the Hubble Space Telescope, elements such as krypton, have been detected for the first time [9]. Fluorine is a product of hydrogen burning in stellar interiors and envelopes, chlorine a product of alpha processes – neutron capture on slow time scale (slow means slower than typical beta decay times) where the first step would be photostripping of alpha particles from some Ne^{20} nuclei and their subsequent capture by others, and krypton a product of s (neutron capture in slow time scale orderly evolution of stellar interiors) and r (neutron capture in fast time scale in type I supernovae) processes. Consequently, the data on the spectral line broadening parameters of these elements in various ionization stages are of interest for the consideration and modelling of stellar plasma, particularly subphotospheric layers and radiative transfer in stellar interiors. For investigating and developing soft X-ray lasers, such data may be useful as well (see *e.g.* Refs. [10] and [11]). Also, line broadening data for multiply charged ions are of significance for fusion plasmas and laser-produced plasma research, and for the investigation of Stark broadening parameter systematic trends along isoelectronic sequences.

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2. Theory

A detailed description of the formalism is given in Refs. [1,2,12,13], and only the basic details of calculations will be presented here. The Stark full width (W) at the intensity half maximum (FWHM) and shift (d) of an isolated spectral line may be expressed as [1,2]

$$\begin{aligned} W &= N\int vf(v)\mathrm{d}v\Big(\sum_{i'\neq i}\sigma_{ii'}(v)+\sum_{f'\neq f}\sigma_{ff'}(v)+\sigma_{\mathrm{el}}\Big)+W_{\mathrm{R}},\\ d &= N\int vf(v)\mathrm{d}v\int_{R_3}^{R_{\mathrm{D}}}2\pi\rho\mathrm{d}\rho\sin 2\phi_{\mathrm{p}} \end{aligned} \tag{1}$$

where N is the electron density, $f(v)$ the Maxwellian velocity distribution function for electrons, ρ denotes the impact parameter of the incoming electron, i and f denote the initial and final atomic energy levels, and i', f' their corresponding perturber levels, while W_{R} gives the contribution of the Feshbach resonances [13]. The inelastic cross section $\sigma_{j,j'}(v)$ can be expressed by an integral over the impact parameter of the transition probability $P_{jj'}(\rho, v)$ as

$$\sum_{i'\neq i}\sigma_{jj'}(v)=\frac{1}{2}\pi {R_1}^2+\int_{R_1}^{R_{\mathrm{D}}}\sum_{j\neq j'}P_{jj'}(\rho,v), j=i,f \tag{2}$$

and the elastic cross section is given by

$$\begin{aligned} \sigma_{\mathrm{el}} &= 2\pi R_2^2+\int_{R_2}^{R_{\mathrm{D}}}8\pi\rho\mathrm{d}\rho\sin^2\delta,\\ \delta &= (\phi_{\mathrm{p}}^2+\phi_{\mathrm{q}}^2)^{1/2}. \end{aligned} \tag{3}$$

The phase shifts ϕ_{p} and ϕ_{q} due respectively to the polarisation potential (r^{-4}) and to the quadrupolar potential (r^{-3}), are given in Section 3 of Chapter 2 in Ref. [1]. R_{D} is the Debye radius. All the cut-offs R_1, R_2, R_3 are described in Section 1 of Chapter 3 in Ref. [2].

For electrons hyperbolic paths due to the attractive Coulomb force were used, while for perturbing ions the paths are different since the force is repulsive. The formulae for the ion-impact widths and shifts are analogous to Eqs. (1–3), without the resonance contribution to the width. The difference in calculation of the corresponding transition probabilities and phase shifts as functions of the impact parameter in Eqs. (2) and (3) is in the ion perturber trajectories which are influenced by the repulsive Coulomb force instead of an attractive one as for electrons.

The results obtained within the semiclassical perturbation approach [1,2,12,13] have been compared with critically selected experimental data for 13 He I multiplets [14] and it was found that the agreement between experimental data

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Table I. *This table shows electron-, proton-, and He III-impact broadening parameters for F VI, Cl VII and Kr VIII for perturber densities of $10^{17} cm^{-3}$ and temperatures from 100 000 up to 2 000 000 K for F VI and Cl VII and for 200 000 up to 3 000 000 K for Kr VIII. Stark broadening parameters for densities lower than tabulated, are linear with perturber density. Transitions and averaged wavelengths for the multiplet (in Å) are also given in the table. By dividing C by the corresponding full width at half maximum [4], we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used.*

PERTURBER DENSITY = 1.E + 17 cm^{-3}				
PERTURBERS ARE:		ELECTRONS	PROTONS	He III
TRANSITION	T(K)	Width (Å) Shift (Å)	Width (Å) Shift (Å)	Width (Å) Shift (Å)
F VI 2S 2P	100000.	0.321E-03-0.422E-05	0.117E-05-0.192E-05	0.219E-05-0.381E-05
535.2 Å	200000.	0.228E-03-0.575E-05	0.322E-05-0.377E-05	0.610E-05-0.754E-05
C=0.54E+20	500000.	0.149E-03-0.599E-05	0.899E-05-0.781E-05	0.174E-04-0.157E-04
	1000000.	0.111E-03-0.608E-05	0.142E-04-0.112E-04	0.280E-04-0.227E-04
	1500000.	0.953E-04-0.574E-05	0.175E-04-0.133E-04	0.349E-04-0.271E-04
	2000000.	0.859E-04-0.568E-05	0.190E-04-0.142E-04	0.379E-04-0.291E-04
F VI 2P 3S	100000.	0.928E-04 0.703E-05	0.279E-05 0.736E-05	0.552E-05 0.147E-04
173.1 Å	200000.	0.697E-04 0.856E-05	0.667E-05 0.107E-04	0.134E-04 0.217E-04
C=0.70E+18	500000.	0.500E-04 0.791E-05	0.136E-04 0.149E-04	0.274E-04 0.305E-04
	1000000.	0.397E-04 0.750E-05	0.185E-04 0.180E-04	0.360E-04 0.366E-04
	1500000.	0.349E-04 0.672E-05	0.218E-04 0.199E-04	0.412E-04 0.405E-04
	2000000.	0.319E-04 0.619E-05	0.238E-04 0.210E-04	0.460E-04 0.427E-04
Cl VII 3S 3P	100000.	0.183E-02-0.168E-04	0.150E-04-0.960E-05	0.290E-04-0.191E-04
804.8 Å	200000.	0.131E-02-0.222E-04	0.351E-04-0.186E-04	0.683E-04-0.373E-04
C = 0.80E+20	500000.	0.879E-03-0.263E-04	0.711E-04-0.367E-04	0.141E-03-0.739E-04
	1000000.	0.674E-03-0.237E-04	0.997E-04-0.510E-04	0.198E-03-0.103E-03
	1500000.	0.586E-03-0.234E-04	0.110E-03-0.585E-04	0.218E-03-0.119E-03
	2000000.	0.534E-03-0.227E-04	0.117E-03-0.633E-04	0.234E-03-0.128E-03
Cl VII 3S 4P	100000.	0.277E-03 0.281E-05	0.103E-04 0.145E-05	0.201E-04 0.288E-05
196.2 Å	200000.	0.204E-03 0.225E-05	0.165E-04 0.266E-05	0.326E-04 0.534E-05
C = 0.18E+19	500000.	0.143E-03 0.302E-05	0.235E-04 0.456E-05	0.468E-04 0.919E-05
	1000000.	0.114E-03 0.283E-05	0.267E-04 0.609E-05	0.531E-04 0.123E-04
	1500000.	0.102E-03 0.269E-05	0.286E-04 0.678E-05	0.567E-04 0.137E-04
	2000000.	0.942E-04 0.272E-05	0.299E-04 0.727E-05	0.589E-04 0.147E-04
Cl VII 4S 4P	100000.	0.435E-01-0.943E-03	0.134E-02-0.726E-03	0.261E-02-0.145E-02
2190.4 Å	200000.	0.324E-01-0.103E-02	0.217E-02-0.117E-02	0.430E-02-0.236E-02
C = 0.22E+21	500000.	0.233E-01-0.999E-03	0.320E-02-0.177E-02	0.639E-02-0.357E-02
	1000000.	0.188E-01-0.963E-03	0.377E-02-0.212E-02	0.750E-02-0.428E-02
	1500000.	0.168E-01-0.941E-03	0.413E-02-0.234E-02	0.820E-02-0.474E-02
	2000000.	0.156E-01-0.863E-03	0.441E-02-0.251E-02	0.862E-02-0.507E-02
Cl VII 3P 4S	100000.	0.416E-03 0.259E-04	0.639E-05 0.169E-04	0.125E-04 0.337E-04
294.3 Å	200000.	0.307E-03 0.269E-04	0.170E-04 0.264E-04	0.338E-04 0.533E-04
C = 0.40E+19	500000.	0.218E-03 0.284E-04	0.352E-04 0.389E-04	0.706E-04 0.787E-04
	1000000.	0.174E-03 0.270E-04	0.466E-04 0.464E-04	0.942E-04 0.940E-04
	1500000.	0.154E-03 0.262E-04	0.536E-04 0.515E-04	0.108E-03 0.104E-03
	2000000.	0.141E-03 0.248E-04	0.598E-04 0.549E-04	0.119E-03 0.112E-03
Cl VII 3P 3D	100000.	0.114E-02-0.501E-05	0.173E-04-0.164E-05	0.334E-04-0.327E-05
602.6 Å	200000.	0.814E-03-0.482E-05	0.359E-04-0.328E-05	0.703E-04-0.657E-05
C = 0.45E+20	500000.	0.543E-03-0.493E-05	0.641E-04-0.732E-05	0.126E-03-0.147E-04
	1000000.	0.416E-03-0.384E-05	0.807E-04-0.112E-04	0.161E-03-0.225E-04
	1500000.	0.363E-03-0.405E-05	0.872E-04-0.136E-04	0.174E-03-0.274E-04
	2000000.	0.332E-03-0.396E-05	0.915E-04-0.153E-04	0.182E-03-0.310E-04
Cl VII 3P 4D	100000.	0.403E-03 0.851E-05	0.160E-04 0.127E-04	0.313E-04 0.254E-04
224.8 Å	200000.	0.302E-03 0.991E-05	0.263E-04 0.192E-04	0.519E-04 0.388E-04
C = 0.75E+18	500000.	0.214E-03 0.871E-05	0.402E-04 0.276E-04	0.791E-04 0.560E-04
	1000000.	0.172E-03 0.777E-05	0.499E-04 0.333E-04	0.960E-04 0.674E-04
	1500000.	0.153E-03 0.666E-05	0.564E-04 0.369E-04	0.105E-03 0.742E-04
	2000000.	0.141E-03 0.581E-05	0.620E-04 0.395E-04	0.112E-03 0.797E-04
Cl VII 4P 4D	100000.	0.311E-0l 0.197E-03	0.145E-02 0.595E-03	0.284E-02 0.119E-02
1680.4 Å	200000.	0.234E-01 0.292E-03	0.2l7E-02 0.920E-03	0.428E-02 0.186E-02
C = 0.42E+ 20	500000.	0.169E-01 0.150E-03	0.293E-02 0.115E-02	0.576E-02 0.272E-02
	1000000.	0.137E-01 0.123E-03	0.345E-02 0.162E-02	0.665E-02 0.327E-02
	1500000.	0.123E-01 0.731E-04	0.379E-02 0.179E-02	0.715E-02 0.363E-02
	2000000.	0.114E-01 0.262E-04	0.404E-02 0.192E-02	0.743E-02 0.387E-02

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Table I. *Continued.*

PPERTURBER DENSITY = 1.E + 17 cm^{-3}							
PERTURBERS ARE:		ELECTRONS		PROTONS		He III	
TRANSITION	T(K)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)	Width (Å)	Shift (Å)
Cl VII 3D 4P	100000.	0.149E-02	0.235E-04	0.611E-04	0.117E-04	0.119E-03	0.232E-04
455.7 Å	200000.	0.110E-02	0.221E-04	0.966E-04	0.206E-04	0.191E-03	0.414E-04
C = 0.95E+19	500000.	0.772E-03	0.276E-04	0.136E-03	0.344E-04	0.271E-03	0.694E-04
	1000000.	0.617E-03	0.251E-04	0.155E-03	0.436E-04	0.309E-03	0.881E-04
	1500000.	0.550E-03	0.243E-04	0.166E-03	0.487E-04	0.330E-03	0.988E-04
	2000000.	0.510E-03	0.242E-04	0.173E-03	0.526E-04	0.342E-03	0.106E-03
Cl VII 3D 4F	100000.	0.717E-03	-0.933E-05	0.244E-04	-0.208E-04	0.477E-04	-0.415E-04
340.3 Å	20000.0.	0.529E-03	-0.838E-05	0.429E-04	-0.529E-04	0.851E-04	-0.664E-04
C = 0.17E+19	500000.	0.371E-03	-0.530E-05	0.696E-04	-0.488E-04	0.137E-03	-0.987E-04
	1000000.	0.295E-03	-0.500E-05	0.876E-04	-0.584E-04	0.165E-03	-0.118E-03
	1500000.	0.262E-03	-0.307E-05	0.997E-04	-0.646E-04	0.183E-03	-0.131E-03
	2000000.	0.242E-03	-0.189E-05	0.111E-03	-0.700E-04	0.196E-03	-0.140E-03
Cl VII 4D 4F	100000.	0.461	-0.118E-01	0.213E-01	-0.180E-01	0.419E-01	-0.360E-01
6699.3 Å	200000.	0.347	-0.127E-01	0.339E-01	-0.262E-01	0.671E-01	-0.527E-01
C = 0.67E + 21	500000.	0.250	-0.104E-01	0.499E-01	-0.359E-01	0.978E-01	-0.727E-01
	1000000.	0.203	-0.932E-02	0.621E-01	-0.429E-01	0.117	-0.865E-01
	5000000.	0.181	-0.761E-02	0.714E-01	-0.476E-01	0.129	-0.957E-01
	2000000.	0.168	-0.638E-02	0.771E-01	-0.501E-01	0.137	-0.101
Kr VIII4S 4P	200000.	0.991E-03	-0.143E-04	0.240E-04	-0.105E-04	0.475E-04	-0.210E-04
665.7 Å	500000.	0.656E-03	-0.169E-04	0.516E-04	-0.219E-04	0.103E-03	-0.439E-04
C = 0.67E+20	1000000.	0.499E-03	-0.155E-04	0.731E-04	-0.315E-04	0.146E-03	-0.633E-04
	1500000.	0.432E-03	-0.157E-04	0.808E-04	-0.376E-04	0.161E-03	-0.756E-04
	2000000.	0.393E-03	-0.152E-04	0.866E-04	-0.405E-04	0.173E-03	-0.814E-04
	3000000.	0.347E-03	-0.145E-04	0.939E-04	-0.451E-04	0.187E-03	-0.907E-04
Kr VIII4S 5P	200000.	0.175E-03	0.751E-06	0.134E-04	0.320E-06	0.265E-04	0.639E-06
182.1 Å	500000.	0.121E-03	0.113E-05	0.201E-04	0.731E-06	0.401E-04	0.146E-05
C = 0.20E+19	1000000.	0.956E-04	0.973E-06	0.228E-04	0.115E-05	0.455E-04	0.230E-05
	1500000.	0.848E-04	0.100E-05	0.243E-04	0.139E-05	0.486E-04	0.279E-05
	2000000.	0.785E-04	0.890E-06	0.254E-04	0.158E-05	0.507E-04	0.317E-05
	3000000.	0.709E-04	0.105E-05	0.265E-04	0.177E-05	0.528E-04	0.355E-05
Kr VIII5S 5P	200000.	0.185E-01	-0.514E-03	0.121E-02	-0.584E-03	0.240E-02	-0.117E-02
1692.0 Å	500000.	0.131E-01	-0.623E-03	0.187E-02	-0.929E-03	0.373E-02	-0.186E-02
C = 0.17E+21	1000000.	0.105E-01	-0.578E-03	0.218E-02	-0.114E-02	0.435E-02	-0.230E-02
	1500000.	0.941E-02	-0.546E-03	0.237E-02	-0.126E-02	0.472E-02	-0.254E-02
	2000000.	0.873E-02	-0.550E-03	0.251E-02	-0.136E-02	0.499E-02	-0.275E-02
	3000000.	0.789E-02	-0.474E-03	0.269E-02	-0.150E-02	0.534E-02	-0.303E-02
Kr VIII4P 5S	200000.	0.302E-03	0.204E-04	0.112E-04	0.198E-04	0.222E-04	0.396E-04
294.2 Å	500000.	0.211E-03	0.252E-04	0.260E-04	0.309E-04	0.519E-04	0.621E-04
C = 0.51E+19	1000000.	0.167E-03	0.231E-04	0.380E-04	0.378E-04	0.761E-04	0.760E-04
	1500000.	0.148E-03	0.222E-04	0.437E-04	0.419E-04	0.876E-04	0.843E-04
	2000000.	0.136E-03	0.219E-04	0.477E-04	0.449E-04	0.956E-04	0.903E-04
	3000000.	0.122E-03	0.199E-04	0.553E-04	0.497E-04	0.109E-03	0.100E-03
Kr VIII4P 6S	200000.	0.227E-03	0.327E-04	0.196E-04	0.295E-04	0.391E-04	0.592E-04
184.4 Å	500000.	0.166E-03	0.320E-04	0.373E-04	0.401E-04	0.748E-04	0.805E-04
C = 0.10E+19	1000000.	0.136E-03	0.298E-04	0.479E-04	0.478E-04	0.956E-04	0.960E-04
	1500000.	0.121E-03	0.286E-04	0.550E-04	0.526E-04	0.110E-03	0.105E-03
	2000000.	0.112E-03	0.263E-04	0.612E-04	0.560E-04	0.121E-03	0.112E-03
	3000000.	0.101E-03	0.231E-04	0.666E-04	0.597E-04	0.131E-03	0.119E-03
Kr VIII50 6S	200000.	0.467E-02	0.439E-03	0.359E-03	0.416E-03	0.716E-03	0.833E-03
697.9 Å	500000.	0.341E-02	0.421E-03	0.602E-03	0.565E-03	0.121E-02	0.114E-02
C = 0.14E+20	1000000.	0.279E-02	0.395E-03	0.746E-03	0.671E-03	0.150E-02	0.135E-02
	1500000.	0.250E-02	0.377E-03	0.851E-03	0.739E-03	0.171E-02	0.149E-02
	2000000.	0.233E-02	0.347E-03	0.932E-03	0.788E-03	0.184E-02	0.158E-02
	3000000.	0.210E-02	0.299E-03	0.101E-02	0.839E-03	0.198E-02	0.169E-02

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and semiclassical calculations is within the limits of 20 percents, which is the predicted accuracy of the semiclassical method [15].

2. Results and discussion

Within the semiclassical-perturbation formalism, we have calculated electron-, proton-, and He III-impact line widths and shifts for 2 fluorine VI, 10 chlorine VII and 6 krypton VIII multiplets. Energy levels for F VI, Cl VII and Kr VIII have been taken from Refs. [16,17] and [18] respectively.

The obtained results for Stark widths (FWHM) and shifts are shown in Table I, for a perturber density of 10^{17} cm^{-3} and temperatures $T = 100\,000 - 2\,000\,000$ K for F VI and CL VII, and $T = 200\,000 - 3\,000\,000$ K for Kr VIII. The lower limit of the temperature range is conditioned by the validity of the applied approach, since toward lower temperatures the importance of quantum effects increases and the semiclassical method becomes questionable. The temperature range upper limit is conditioned with the decrease of the considered ion presence due to ionization in the higher ionization stages. Such temperature interval is of interest for subphotospheric layers, soft X ray lasers and laser produced plasma research, and higher temperatures are of interest for fusion plasma research as well as for stellar interiors considerations. For each value given in Table I, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid [1,2]. Stark broadening parameters for densities lover than tabulated are linear with perturber density. When the impact approximation is not valid, the ion broadening contribution may be estimated by using quasistatic approach [15 or 19]. In the region where neither of these two approximations is valid, a unified type theory should be used. For example in Ref. [20], simple analytical formulas for such a case are given. The accuracy of the results obtained decreases when broadening by ion interactions becomes important. At high densities, the results are no longer linear with density due to Debye screening. This effect is more important for the shift than for the width. Stark-broadening parameter tables for high densities will be published elsewhere [21].

There are no experimental results concerning F VI, Cl VII and Kr VIII. However, predictions on the basis of systematic trends along isoelectronic sequences exist for the F VI $3s^1S$ - $3p^1P^o$, 2464.8 Å line for $T = 45\,000$ K and electron density of 10^{17}cm^{-3} and for the Cl VII $4s^2S$ - $4p^2P^o$, 2178.8 Å line for $T = 60\,000$ K and electron density of 10^{17}cm^{-3} [22]. We have not calculated Stark broadening parameters for the F VI 2464.8 Å line due to the lack of reliable atomic data. For the Cl VII 2178.8 Å the result in Ref. [22] for $T = 60\,000$ K is $W = 0.036$ Å, while our result for $T = 200\,000$ K is 0.0435 Å which gives a very encouraging agreement.

References

1. Sahal-Bréchot, S., Astron. Astrophys. **1**, 91 (1969).
2. Sahal-Bréchot, S., Astron. Astrophys. **2**, 322 (1969).
3. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transfer **31**, 301 (1984).
4. Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V., Astron. Astrophys. Suppl. Series **89**, 581 (1991).
5. Dimitrijević, M. S., Astrophys. Space Sci. **252**, 415 (1997).
6. Moore, C. E., Minnaert, M. G. J. and Houtgast, J., "The Solar Spectrum 2935Å to 8770 Å," NBS Monographs 61, (U. S. Department of Commerce, NBS, Washington D.C. 1966).
7. Merrill, P. W., "Lines of the Chemical Elements in Astronomical Spectra," (Carnegie Inst. of Washington, Publication 610, Washington D. C. 1956).
8. Trimble, V., Astron. Astrophys. Rev., **3**, 1 (1991).
9. Cardelli, J. A., Savage, B. D. and Ebbets, D. C. Astrophys. J. **383**, L23 (1991).
10. Fill, E. E. and Schöning, T., J. Appl. Phys. **76**, 1423 (1994).
11. Griem, H. R. and Moreno, J. C., in: "X-Ray Lasers," (ed. G. Tallents), (Institute of Physics, Bristol, **301**, 1990).
12. Fleurier, C., Sahal-Bréchot, S. and Chapelle, J., J. Quant. Spectrosc. Radiat. Transfer **17**, 595 (1977).
13. Sahal-Bréchot, S., Astron. Astrophys. **35**, 321 (1974).
14. Dimitrijević, M. S. and Sahal-Bréchot, S., Phys. Rev. A**31**, 316 (1985).
15. Griem, H. R., "Spectral Line Broadening by Plasmas," (Academic Press, New York, 1974).
16. Bashkin, S. and Stoner, Jr. J. J., "Atomic Energy Levels and Grotrian Diagrams," (North Holland, Amsterdam, 1975) **Vol. 1.**
17. Bashkin, S. and Stoner, Jr. J. J., "Atomic Energy Levels and Grotrian Diagrams," (North Holland, Amsterdam 1978) **Vol. 2**.
18. Sugar, J., Musgrove, A., J. Phys. Chem. Ref. Data **20**, 875 (1991).
19. Sahal-Bréchot, Astron. Astrophys. **245**, 322 (1991).
20. Barnard, A. J., Cooper, J., Smith, E. W., J. Quant. Spectrosc. Radiat. Transfer **14**, 1025 (1974).
21. Dimitrijević, M. S. and Sahal-Bréchot, S., Serb. Astron. J. **158**, 93 (1988); **159**, 73 (1999).
22. Purić, J. *et al*., Z. Phys. D **10**, 431 (1988).

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On the Variation of Stark Line Shifts within a given Spectrum in the Case of Irregular Energy Level Structure

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Abstract

The knowledge on regularities and systematic trends for Stark line shifts within a given spectrum as e.g. similarities among Stark line shifts within a multiplet, supermultiplet or transitions array and systematic trends within a spectral series, is useful for the interpolation of new data and the critical evaluation of experimental data. In this paper exceptions to the established regularities have been analyzed on the basis of critically selected experimental data as well as of results of semi-classical calculations. It has been demonstrated that the principal reason for the irregularities discussed is irregularities of energy level structure. An additional reason is the influence of the intercombination and forbidden perturbing transitions.

1. Introduction

Broadening of spectral lines by interaction with charged particles (Stark broadening) is of interest for diagnostic, analysis and modeling of laboratory, stellar and laser produced plasmas, as well as for investigation of plasmas in various devices in technology and for fusion research. For some problems, as e.g. the calculation of stellar opacities, a large number of spectral lines is needed. When one has to collect a set of reliable Stark broadening data needed for such purposes, the knowledge on regularities and systematic trends may be useful for a critical selection of data from literature by checking their consistency with other reliable data from the aspect of established regularities. Moreover, when reliable data do not exist, regularities and systematic trends may offer a possibility of obtaining new data by appropriate interpolation or scaling in order to complete the data set needed.

The first attempt to identify regularities within the Stark broadening parameters has been made by Purić and Ćirković in 1973 [1,2]. Since then, a considerable number of papers on this subject has been published (see Ref. [3] and references therein). All published papers have been divided in [3] in two groups. In the first group, different types of regularities and systematic trends (such as dependence on atomic charge number, ionization potential, atomic polarisability, principal quantum number, or the rest core charge of the radiator as seen by the optical electron undergoing transitions) have been evaluated on the basis of Stark broadening width and shift formulas within different approximations (see [3,4] and references therein). In the second group (see [5,6]), regularities have been identified on the basis of critically selected experimental results. We might add here a third group, where the analysis of regularities, the explanation of the identified irregular behaviour or, critical evaluation of existing theoretical and experimental data, has been performed basically by the analysis of atomic energy level diagrams (see [7]). Also we might add a fourth group, where the analysis of possible regularities or irregularities has been performed by semi-classical perturbation calculations. For spectral series this has been done in [8–17], for a multiplet e.g. in [18], for a transition array e.g. in [19], and for an isoelectronic sequence e.g. in [20].

Such studies of regularities have been undertaken not only for Stark broadening parameters but also for wavelengths and energy levels [21], transition probabilities [22] and collision cross sections [23] entering in expressions for Stark widths and shifts [24].

Wiese and Konjević carried out in 1982 [5] a study of regularities and systematic trends for Stark widths of non-hydrogenic emitter lines on the basis of critically selected experimental data. They found agreement of Stark widths within a multiplet, and to a lesser degree within a supermultiplet (i.e. a group of multiplets with common upper and lower configurations and with the same parent term and spin multiplicity as e.g. all doublets, triplets, etc.), and a transition array (all multiplets between quantum numbers n, ℓ and n', $\ell \pm 1$ regardless of their multiplicity). They found also regularities for analogous transitions of homologous atoms and ions, and systematic trends along spectral series. In the same year (1982), Dimitrijević [7] analyzed with the help of energy levels diagrams, the exceptions of the previously established regularities (see [25] and references therein). He found that the reasons for such exceptions may be divided in two categories:

(*i*) irregular energy level structure and
(*ii*) inadequacy of the used model of the emitter structure.

In 1992, Wiese and Konjević published results of similar investigations of experimental Stark line shifts, as in 1982 for Stark line widths, and they showed by numerous examples the same regularities and systematic trends as for the width, but apparent in a lesser degree. They examined some examples of irregular behaviour as well, concluding that when the shift is significantly smaller than 50% of the width, even small variations of energy level positions may result in larger variations of Stark shifts within a multiplet, supermultiplet and transition array.

Our aim here is to find the pronounced irregularities and analyse them with help of atomic energy level diagrams, in order to explain the reasons for such situations, since a better knowledge of limitations of regularities and systematic trends allow their more reliable use for critical evalu-

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ation of data from literature and for acquisition of new data by interpolation or scaling.

2. Stark line widths and shifts

In order to consider differences in the theoretical determination of Stark line widths and shifts, we will use the semi-classical approximation [24]. Within this approximation the line width of an isolated non-hydrogenic line may be expressed [24] as the sum of contributions due to strong and weak collisions, where the weak collision contribution has dipole and quadrupole parts ([24], Eqs. (151–156). In an other version of the semi-classical method [26–28], contributions of elastic collisions and resonances are determined separately. For shift determination in [24] (Eqs. 151–156), dipole and quadrupole contributions have been included.

In order to analyze differences between shifts and widths, we will limit ourselves here to the dipole contribution, which is the most important and often the largest one. The expression for the dipole contribution to the halfwidth at half maximum w_d and shift d_d are [24,29,30]

$$w_d + \mathrm{i}d_d = N_e \int_0^\infty \frac{4\pi}{3}\left(\frac{h}{2\pi m v}\right)^2 v f(v)\mathrm{d}v \times \int_{\rho_{\min}}^{\rho_D}\left[\sum_{i'\neq i} \boldsymbol{R}^2_{i,i'}(A_{ii'} + \mathrm{i}B_{ii'}) + \sum_{f'\neq f} \boldsymbol{R}^2_{f,f'}(A_{ff'} - \mathrm{i}B_{ff'})\right]\rho\mathrm{d}\rho. \quad (1)$$

Here, N_e is the electron density, ρ is the impact parameter and $f(v)$ the Maxwellian velocity distribution function for electrons. The initial (upper) and final (lower) state of the isolated line are denoted by (i, f) with (i', f') being corresponding perturbing states within the dipole approximation. In the above expression, $\boldsymbol{R}^2_{j,j'}$ is the square of the coordinate operator matrix element (in units of the Bohr Radius a_0^2) summed over all components of the operator and over the magnetic substates of total momentum j' and averaged over the magnetic substates of j.

In Eq. (1), the principal differences between neutral (straight-line perturber paths) and ionized (hyperbolic-line perturber paths) emitters are contained in the Stark broadening functions $A(\Delta E_{kk'}, Z, v, \rho)$ and $B(\Delta E_{kk'}, Z, v, \rho)$ (see GBKO [31]). Here, Z-1 is the ionic charge and $\rho_{\min}$ the minimal impact parameter (ρ) allowed by the unitarity conditions for the scattering matrix (see e.g. [24]). The principal difference between width and shift calculations is that for the width, the particular contributions are positive. For the shift however, the initial level contribution in Eq. (1) has the opposite sign to the final level contribution. Moreover, energy differences in Eq. (2) may be both positive and negative so that the contributions of perturbative interactions with different radiator states entering in the summation in Eq. (1) may be of different signs. Consequently, due to the cancelation of terms with different signs, one may have a large width and a small shift.

Generally, shift calculations are more sensitive to the small variations of different parameters and one may expect that for shifts regular behaviour will be less evident than for widths. Shifts are also produced in average by more distant collisions than widths. It has been demonstrated in [32] that for shift calculations one should take into account a larger number of perturbing levels than in the case of widths. Even the sign may be changed if an unsufficient number of perturbing levels is used. This is also illustrated in [33], where relative contributions to width and shift for the various angular momenta of the colliding electron have been analyzed. It has been demonstrated that the summation over different angular momenta converge better for the width than for the shift, where larger computational efforts are needed in order to obtain a good accuracy.

In order to demonstrate the differences between width and shift functions behaviour we will limit ourselves to the simpler case of neutral emitters (straight-line perturber paths). In such a case, if we introduce the quantity [24]:

$$z_{k,k'} = \frac{2\pi\rho}{hv}(E_k - E_{k'}), \qquad k = i, f, \quad (2)$$

and perform the integration of Stark broadening functions over ρ, we have

$$a(z) = \int_z^\infty A(z)\mathrm{d}z/z = \mid z \mid K_0(\mid z \mid)K_1(\mid z \mid), \quad (3)$$

$$b(z) = \int_z^\infty B(z)\mathrm{d}z/z = \frac{1}{2}\pi - \pi z K_0(z) I_1(z). \quad (4)$$

Here, K_0, and K_1 are the modified Bessel functions of the second kind and I_1 the modified Bessel function of the first kind (see e.g. [34]). If one neglects the influence of Debye shielding, taking infinity as the upper limit of the integration over ρ in Eq.(1) instead of ρ_D, one has from Eqs. 1–4 [24]:

$$w_d + \mathrm{i}d_d = N_e \int_0^\infty \frac{4\pi}{3}\left(\frac{h}{2\pi m v}\right)^2\left[\sum_{i'\neq i} \boldsymbol{R}^2_{i,i'}(a_{ii'} + \mathrm{i}b_{ii'}) + \sum_{f'\neq f} \boldsymbol{R}^2_{f,f'}(a_{ff'} - \mathrm{i}b_{ff'})\right] v f(v)\mathrm{d}v. \quad (5)$$

The quantity $z_{kk'}$ from Eq. (2) is a measure of the deviation from the hydrogen like behaviour. For significantly contributing perturbing levels, impact parameters and electron velocities, the magnitude of $z_{kk'}$ is less than one. Consequently, in order to see the influence of irregularities in atomic energy level structure on width and shift regularities, it is of interest to analyze the limit when $z_{kk'}$ tends to zero. In such a case [24]:

$$a(z) \to \ln\left(\frac{1}{z}\right) \to \infty, \qquad b(z) \to \frac{1}{2}\pi. \quad (6)$$

One may see from Eq. (5) and (6) that for the shift, the influence of a very close perturbing level is not so "dramatic" as for the width. Moreover if we have several close perturbing levels, so close that $z_{kk'} \leq 0.1$ for them then their contribution to the shift value is proportional to $\sum \boldsymbol{R}^2_{kk'}\frac{\pi}{2}$. Also one must take into account that $b(z)$ varies with z more slowly than $a(z)$, so that for $z = 1$, $b(z) = 0.82$, and $a(z) = 0.25$, for $z = 2$, $b(z) = 0.43$ and $a(z) = 0.032$. Consequently the influence of a close perturbing level for shifts (where $\lim_{z\to 0} b(z) = \frac{\pi}{2}$) is not so pronounced as for widths

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(where $\lim_{z\to 0} a(z) = \infty$) and for the shift, the larger matrix element value for a close perturbing level, has larger influence.

In order to analyze the reasons for irregular behaviour of the Stark broadening parameters, compilations of critically selected data [35–39] have been used. In order to select the most reliable data for the regularities studies, data with lowest accuracy have been avoided and only data sets measured under the same experimental conditions and from the same experimental group have been used. In such a way the additional influences of Stark broadening parameter differences within a considered data set, have been reduced.

3. On the deviations from established similarities and systematics trends within a given spectrum

Systematic trends of Stark shifts within spectral series have been analyzed experimentally (see e.g. [40–45]) and theoretically [4,8–17,24]. An analysis of the experimental work has been given in [6]. It has been concluded that "shifts within a spectral series show pronounced increases with increasing principal quantum number of the upper state. Thus, interpolations or limited extrapolations along a spectral series should yield additional reliable data."

The regular situation is that the energy difference between the upper level and the closest perturbing levels decreases with increasing principal quantim number n, so that the corresponding cross section increases. For large n however, with further decrease of energy differences among interacting levels, they may become degenerate in a plasma field and a linear Stark effect instead of the quadratic one influences the corresponding spectral lines. It has been stated in [6] also, that the described systematic trend is most applicable for relatively simple radiators with a pronounced spectral series structure, like alkalis or alkaline-earths.

In a number of papers [8–17,24] the systematic behaviour of Stark line shifts within spectral series has been analyzed within the semi-classical perturbation approach [14,24, 26–28,31]. It has been demonstrated that the absolute values of electron and proton impact line shifts in angular frequency units increase regularly with increasing of n for LiI $2p^2P^0$-ns^2S ($3 \leq n \leq 8$) [13]; NaI $3p^2P^0$–ns^2S ($4 \leq n \leq 10$)[10,12]; KI $4p^2P^0$–ns^2S ($5 \leq n \leq 12$) [11]; KI $4p^2P^0$–nd^2D ($3 \leq n \leq 9$) [11]; LiII $2s^3S$–np^3P^0 ($3 \leq n \leq 5$) [17]; CIV $2s^2S$–np^2P^0 ($2 \leq n \leq 5$) [14] and OVI $2s^2S^0$-np^2P^0 ($4 \leq n \leq 10$) [16]. For other examples [9,15] a trend exists but it is less pronounced.

Sometimes, the first value in the spectral series deviates from the expected trend since an important perturbing level, existing for other members of the series, does not exist for the first one. An example is the HeI $2s^1S$–np^1P^0 spectral series [8]. Here, since the $2d^1D$ level does not exist, the composition of the set of perturbing levels is different for the $2p^1P^0$ than for the higher members. It is interesting that it is not so evident for the width, where all contributions are positive and the absence of a term with a particular sign has no such consequences.

It has been found and demonstrated as well that the influence of Debye shielding is much more evident for shifts than for widths of lines within spectral series. A good example is the NaI $3p^2P^0$–ns^2S ($4 \leq n \leq 10$) series [12] where increasing of shift values decreases with increasing principal quantum number of the upper level, which is more pronouced at $T = 80000$ K than at $T = 2500$ K.

It has been stated in [6] that the identified regular increase of the shift values within a spectral series is most applicable for relatively simple radiators like alkalis or alkali-earths. Analysing the results of semi-classical calculations of Benett and Griem [24,29] however, just for an alkali earth CaI $4s^1S$–np^1P^0 spectral series ($4 \leq n \leq 7$), regular increase for $n = 4$, 5 and 6 is followed by a sharp decrease for $n = 7$ (see Fig. 1), so that even the sign is changed. If we look at the partial energy level diagram in Fig. 2 one can see that the energy distance between the upper level and the most important perturbing levels changes irregularly with increasing n. This is more clearly demonstrated in Figs. 3 and 4 where energy gaps between the upper level of the transition np^1P^0 and principal d and s perturbing levels respectively, are shown. One can see that the $7p^1P^0$ level is much closer to the $6d^1D$ level contributing negatively to the shift, than to the $7d^1D$ level contibuting positively. On the other hand, $6p^1P^0$ is on a similar distance from $6d^1D$ and the $5d^1D$ perturbing levels. One must take into account as well that, due to the presence of important perturbing levels contributing with opposite signs, mutual cancelation occurs and the resulting shift is smaller than the width and more sensitive to the irregular decrease of energy gaps to the important perturbing levels within the considered spectral series.

Within the complex atom spectra, similarities of Stark line shifts have been established [6] within a multiplet, i.e. a

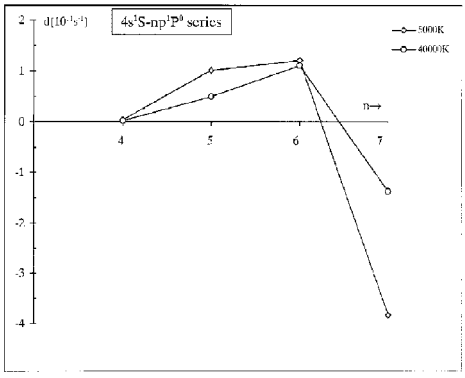

Fig. 1. Stark line shifts within the CaI $4s^1S$–np^1P^0 spectral series as a function of the principal quantum number n, of the upper level. Results of semi-classical calculations of Benett and Griem 1971 [29] (published also in [24]) for an electron density of 10^{16}cm^{-3} are shown for $T = 5000$ K (denoted with –◇–) and $T = 40000$ K (denoted with –o–).

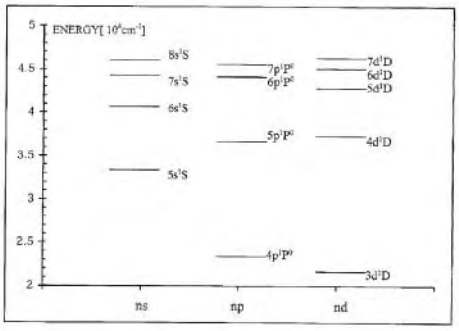

Fig. 2. Partial Energy level diagram for CaI $4s^1S$–np^1P^0, $n = 4$–7.

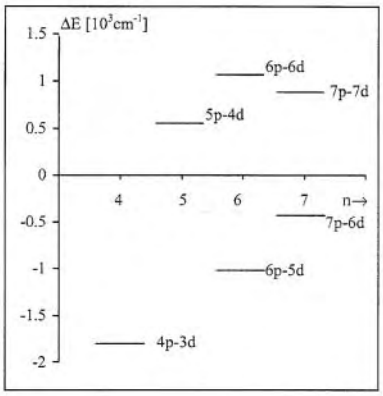

Fig. 3. Energy gaps (ΔE) between the upper level of the transition, np^1P^0, and principal d perturbing levels for CaI $4s^1S$–np^1P^0, $n = 4$–7

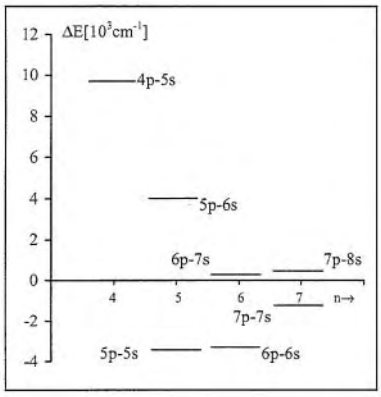

Fig. 4. Energy gaps (ΔE) between the upper level of the transition, np^1P^0, and principal s perturbing levels for CaI $4s^1S$–np^1P^0, $n = 4$–7.

group of all possible allowed transitions between all levels of two terms defined by quantum numbers $n^{2S+1}L_J$. In a lesser degree, similarities have been found for line shifts within a supermultiplet, i.e. a group of multiplets with common upper and lower configurations and with the same parent terms and spin multiplicity, as well as within a transition array, a group of supermultiplets with common upper and lower configurations and with the same parent terms regardless of the multiplicity.

It has been found in [6] that similarities between Stark line shifts are much better maintained when shifts are at least 50 percent of widths than when shifts are only a small fraction of the widths. Such situation exist when we have several important perturbing levels with opposite signs, leading to partial cancelations and resulting in shifts, small in comparison to the width. In such a case, relatively small differences in the positions of perturbing levels may produce differences in shifts, while widths, where all contributions are positive, remain approximately equal.

Another irregular situation, for a doublet and a quartet of the 3s–4p transition array of NI, has been discusssed in [6]. In this case, positions of upper levels of the doublet and the quartet are different in comparison with the principal perturbing levels, so that even signs of the shifts are different.

Wiese and Konjević have found variations of experimental [46] shifts of an order of magnitude within the $2p^43s$–$2p^43p$ transition array of FI, as an example of the situation of mutal cancelations of the important perturbing level contributions.

A detailed analysis of Stark broadening parameters as functions of the impact electron angular momentum quantum number ℓ and temperature, has been performed for this transition array in [19]. The analysis performed demonstrated that higher ℓ values are much more important for the shift than for the width so that the convergence of the shift value with the increase of the number of perturbing levels is much slower for the shift than for the width. The analysis demonstrated as well that the largest differences within the considered transition array exist for the elastic collision contribution. Consequently, the line shift, produced mainly by elastic collisions, is more sensitive to the atomic parameter variations than the line width. The analysis in [19] demonstrated also that the differences will be smaller toward the high temperature limit, since the influence of the lower ℓ values, contributing mainly to the differences, then decreases.

With the help of the semi-classical perturbation approach, Stark shifts within the $4s^2L$–$4p^2L'$ supermultiplet of singly charged argon ion, have been analyzed in [18]. It has been found that signs of the shifts may be different when an important perturbing level is embedded within the energy levels of the supermultiplet (multiplet). It has been shown also that the Debye shielding may reduce shift differences.

It has been shown in [6], on the basis of experimental data from [47], that Stark shifts within the PII $4s^3P^0$–$4p^3D$ multiplet are approximately equal. If we look however at the supermultiplet as a whole, using the experimental results of the same experiment [47], shown in Table I, we can see that the Stark shift for the 5425.91 Å line from the $4s^3P^0$–$4p^3P$ multiplet of the same supermultiplet has the opposite sign. If we look at the partial energy levels diagram shown in Fig. 5, we can see that 3d levels, which are the principal perturbing levels, are embedded between 4p levels. Their contribution to the Stark shift within the $4s^3P^0$–$4p^3D$ multiplet is positive and for $4s^3P^0$–$4p^3P$ negative, determining the sign of the Stark line shift in both cases. One can see in Fig. 6, that the shift difference decreases with temperature, since with increasing temperature, the influence of a particular close perturbing level decreases, while the significance of more distant perturbing levels increases.

It is not only due to a perturbing level embedded within energy levels of a multiplet or supermultiplet that large differences between Stark shifts exist. Such a situation may also happen if the energy separation between energy levels within a term of a mutiplet, or between upper/lower terms of a supermultiplet, is not negligible compared to the energy distance to the most important perturbing levels. An illustrative example are OIII 3s–3p singlets. Experimental values for

Table I. *Experimental Stark shifts* d *(in angular frequency units) of Purić et al. (1985) [47] for PII 4s–4p triplets, and of Purić et al. (1988) [48] for OIII 3s–3p singlets.*

Element	Transition	λ[Å]	T[K]	$N_e[10^{17}\mathrm{cm}^{-3}]$	$d[10^{11}\mathrm{s}^{-1}]$
	$4s^3P^0$–$4p^3D$	6043.12	20000	1	1.806
PII	$4s^3P^0$–$4p^3D$	6024.18	20000	1	1.609
	$4s^3P^0$–$4p^3D$	6034.04	20000	1	1.811
	$4s^3P^0$–$4p^3P$	5425.91	20000	1	−2.944
OIII	$3s^1P^0$–$3p^1P$	5592.37	42500	2.18	−0.446
	$3s^1P^0$–$3p^1D$	2983.78	42500	2.18	0.000

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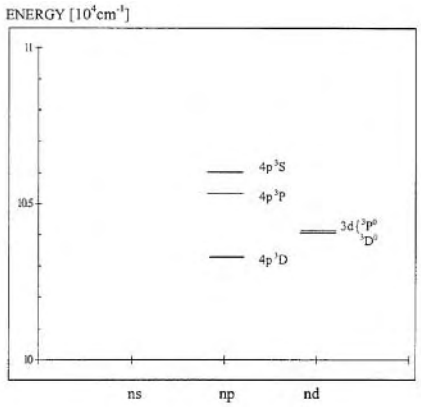

Fig. 5. Partial energy level diagram for PII showing $4p^3L$ levels and their principal perturbing levels.

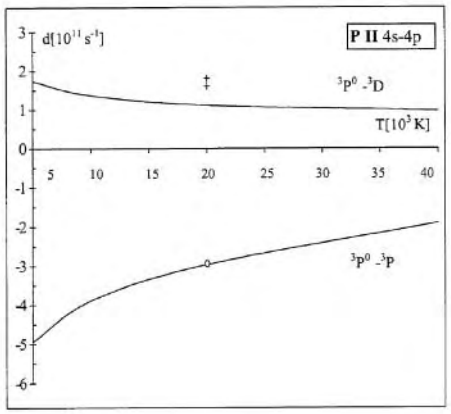

Fig. 6. Theoretical results (Jones *et al.*, 1971 [24,30]) for Stark line shifts within PII $4s^3L^0$–$4p^3L'$ supermultiplet *vs.* the electron temperature. Experimental values for Stark line shifts for PII $4s^3P^0$–$4p^3D$ and $4s^3P^0$–$4p^3P$ multiplets (Purić *et al.*, 1985 [47]) are shown for $T = 20000$ K (denoted with + and ○, respectively). The electron density is 10^{17} cm^{-3}.

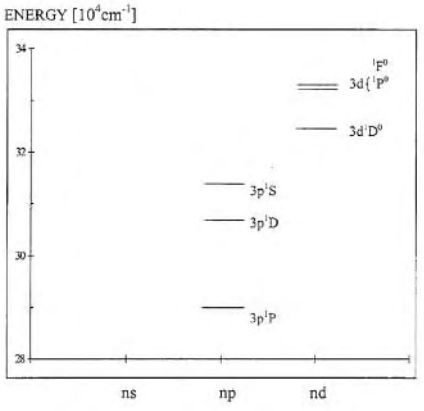

Fig. 7. Partial energy level diagram for OIII showing $3p^1L$ levels and their principal perturbing levels.

Stark line shifts, obtained by Purić *et al.* (1988) [48], are shown in Table I. For the OIII $3s^1P^0$–$3p^1P$ 5592.37 Å line, they have obtained $d = -4.5 \cdot 10^{10}\text{s}^{-1}$ and for the OIII $3s^1P^0$–$3p^1D$ 2983.78 Å line, the experimental Stark line shift is equal to zero. On the partial energy level diagram shown in Fig. 7, one can see that the energy distance between upper terms of the OIII 3s–3p (singlets) supermultiplet is comparable to the energy distance to the 3d perturbing levels. The $3p^1P$ term is more distant from 3d terms contributing positively to the shift in comparison to the $3p^1D$ term, and closer to the $3s^1P^0$ term contributing negatively. Consequently, the corresponding line shift is negative for the OIII $3s^1P^0$–$3p^1P$ 5592.37 Å line, while for the OIII $3s^1P^0$–$3p^1D$ 2983.78 Å line, positive and negative contributions to the shift cancel and the resulting Stark line shift is zero.

An additional reason for the deviations from expected regularities and systematic trends is the influence of intercombination and forbidden perturbing transitions, perturbing only a part of the members of a multiplet, supermultiplet or transition array, or perturbing them in a different manner. An example is given in [49], where Stark line shifts along the isoelectronic sequence of boron have been investigated experimentally and theoretically within the semi-classical perturbation approach. It has been found experimentally in this work, that Stark widths and shifts for OIV deviates from the theoretical results. The inclusion of the perturbing transition, i.e. the perturbing levels with different parent terms, in addition to those from allowed dipole transitions in the semi-classical perturbation calculations, changed the direction of the shift of the considered OIV lines from blue to red, improving considerably the agreement between theory and experiment.

4. Conclusions

Exceptions of established Stark shift regularities and systematic trends within a given spectrum have been considered.

Shift values are generally more sensitive to small variations of different parameters than widths, particularly when due to the cancelation of terms with different signs, they are considerably smaller than for the widths. Shifts are also produced by more distant collisions than widths, and the influence of a particular close perturbing level is not so pronounced as for widths. When we have several close perturbing levels, the importance of the corresponding matrix element values increases, which may be seen from the $b(z)$ function behaviour for $z < 0.1$.

Generally, similarities and systematic trends are better maintained when the shifts are at least fifty percent of the widths than when they are only a small fraction of the width.

Systematic trends within spectral series are not so pronounced for shifts as for widths. Even within alkali-earth spectra like CaI, the energy distance between the energy level forming transition and the most important perturbing levels may change irregularly with increasing n.

Irregular behaviour of Stark shifts values within a transition array may occur when the energy difference between the atomic energy level forming transition and the principal perturbing levels is different for the transition array members with different multiplicity.

Even signs of shifts within a multiplet or supermultiplet may be different when an important perturbing level is embedded within the energy levels of the supermultiplet/multiplet. Debye shielding may reduce such differences. Such differences also decrease with temperature since with increasing temperature the influence of more distant perturbing levels and the contribution of a close perturbing level decreases. Such situation may also happen if the energy separation between energy levels within a term of a

multiplet/supermultiplet is not negligible compared to the energy distance to the most important perturbing levels.

The deviation from established similarities within a multiplet/supermultiplet may occur as well, due to the influence of intercombination or forbidden perturbing transitions, perturbing only a part of the members of a multiplet/supermultiplet, or perturbing them in a different manner.

Generally, if energy differences to the perturbing levels are not similar or, if the influence of intercombination or forbidden transitions exists, an accurate description of Stark line shifts within a multiplet/supermultiplet is obtained only when every particular component is adequately taken into account.

Acknowledgements

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References

1. Purić, J. and Ćirković, Lj., Contributed Papers, IX Int. Conf. Phen. Ioniz. Gases, Prague 398 (1973).
2. Purić, J., Ćirković, Lj. and Labat, J., Fizika **6**, 211 (1974).
3. Purić, J., Zh. Prikl. Spektrosk. **63**, 816 (1996).
4. Purić, J., Proc. of Invited Lectures of XXI Int. Conf. Phen. Ioniz. Gases, Ruhr-Universität Bochum (Arbeitsgemeinschaft Plasmaphysik, 1994).
5. Wiese, W. L. and Konjević, N., J. Quant. Spectrosc. Radiat. Transfer **28**, 185 (1982).
6. Wiese, W. L. and Konjević, N., J. Quant. Spectrosc. Radiat. Transfer **47**, 185 (1992).
7. Dimitrijević, M. S., Astron. Astrophys. **112**, 251 (1982).
8. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transfer **31**, 301 (1984).
9. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. **136**, 289 (1984).
10. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transfer **34**, 149 (1985).
11. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transfer **38**, 37 (1987).
12. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transfer **44**, 421 (1990).
13. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiat. Transfer **46**, 41 (1991).
14. Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V., Astron. Astrophys. Suppl. Series **89**, 581 (1991).
15. Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V., Astron. Astrophys. Suppl. Series **89**, 591 (1991).
16. Dimitrijević, M. S. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **93**, 359 (1992).
17. Dimitrijević, M. S. and Sahal-Bréchot, S., Physica Scripta **54**, 50 (1996).
18. Dimitrijević, M. S. and Truong Bach, Z. Naturforsch. **41a**, 772 (1986).
19. Dimitrijević, M. S., Astron. Astrophys. Suppl. Series **64**, 591 (1986).
20. Blagojević, B., Popović, M. V., Konjević, N. and Dimitrijević, M. S., Phys. Rev. **E 54**, 743 (1996).
21. Edlén, B., In: "Handbuch der Physik.," Vol. XXVII, (ed. S. Fluegge), (Springer Verlag, Berlin, 1964).
22. Wiese, W. L., Weiss, A. W., Phys. Rev. **175**, 50 (1968).
23. Phaneuf, R. A. In: "Atomic Processes in Electron-Ion and Ion-Ion Collisions," (ed. F. Brouillard), (Plenum Press, New York, NY, 1968).
24. Griem, H.R., "Spectral Line Broadening by Plasmas," (McGraw-Hill, New York, 1974).
25. Konjević, N. and Dimitrijević, M. S., In: "Spectral Line Shapes," (ed. B. Wende and W. de Gruyter), (Berlin, New York, 241, 1981).
26. Sahal-Bréchot, S., Astron. Astrophys. **1**, 91 (1969).
27. Sahal-Bréchot, S., Astron. Astrophys. **2**, 322 (1969).
28. Fleurier, C., Sahal-Bréchot, S. and Chapelle, J., J. Quant. Spectrosc. Radiat. Transfer **17**, 595 (1977).
29. Benett, S. M. and Griem, H. R., "Calculated Stark Broadening Parameters for Isolated Spectral Lines from the Atoms Helium through Calcium and Cesium," Techn. Rep. No 71-097, Univ. Maryland (1971).
30. Jones, W. W., Benett, S. M. and Griem, H. R, "Calculated Electron-Impact Broadening Parameters for Isolated Spectral Lines from Singly Charged Ions: Lithium through Calcium," Techn. Rep. No 71-128, Univ. Maryland (1971).
31. Griem, H. R., Baranger, M., Kolb, A. C. and Oertel, G. K., Phys. Rev. **125**, 177 (1962).
32. Roberts, D. E, J. Phys. B **1**, 53 (1968).
33. Dimitrijević, M. S, Feautrier, N. and Sahal-Bréchot, S., J. Phys. B **14**, 2559 (1981).
34. Abramovitz, M. and Stegun, I. A., "Handbook of Mathematical Functions," NBS Appl. Math. Ser. **55** (1964).
35. Konjević, N. and Roberts, J. R., J. Phys. Chem. Ref. Data **5**, 209 (1976).
36. Konjević, N. and Wiese, W. L., J. Phys. Chem. Ref. Data **5**, 259 (1976).
37. Konjević, N., Dimitrijević, M. S. and Wiese, W. L., J. Phys. Chem. Ref. Data **13**, 619 (1984).
38. Konjević, N., Dimitrijević, M. S. and Wiese, W. L., J. Phys. Chem. Ref. Data **13**, 649 (1984).
39. Konjević, N. and Wiese, W. L., J. Phys. Chem. Ref. Data **19**, 1307 (1990).
40. Kelleher, D. E., J. Quant. Spectrosc. Radiat. Transfer **25**, 191 (1981).
41. Krebs, D. J and Shearer, L. D., J. Chem. Phys. **76**, 2925 (1982).
42. Gridneva, S. M. and Kasabov, G. A., Proc. 7th Int. Conf. Phen. Ion. Gases, Vol. II, p. 582, (Gradjevinska Knjiga, Belgrade, 1966).
43. Rannson, P. and Chapelle, J., J. Quant. Spectrosc. Radiat. Transfer **14**, 1 (1974).
44. Bues, I., Haag, T. and Richter, J., Astron. Astrophys. **2**, 249 (1969).
45. Assous, R., J. Phys. (Paris) **29**, 877 (1968).
46. Djurović, S. and Konjević, N., Z. Phys. D. **10**, 425 (1988).
47. Purić, J., Ćuk, M. and Lakićević, I., Phys. Rev. A **32**, 1106 (1985).
48. Purić, J., Djeniže, S., Srećković, A., Platiša, M. and Labat, J., Phys. Rev. A **37**, 498 (1988).
49. Blagojević, B., Popović, M. V., Konjević, N. and Dimitrijević M. S., Phys. Rev. E **54**, 743 (1996).

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Electron-Impact Broadening Parameters for Ra II Spectral Lines

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Abstract

Stark broadening parameters for 53 Ra II spectral lines have been calculated. Calculations have been performed within the frame of the modified semiempirical approach within the temperature range 5000–50000 K. Stark broadening parameters for 43 Ra II spectral lines have been calculated for an electron density of $10^{20}\,\mathrm{m}^{-3}$, while Stark broadening parameters for 10 Ra II spectral lines, belonging $5f^2F^o$–$7d^2D$, $6d^2D$–$7p^2P^o$, $7d^2D$–$8p^2P^o$ and $8d^2D$–$9p^2P^o$ Ra II multiplets in the far infrared, have been presented for an electron density of $10^{20}\,\mathrm{m}^{-3}$. Results have been used for a discussion of Stark broadening regularities within multiplets and systematic trends along spectral series. Moreover, the results obtained have been compared with simple estimates based on regularities and systematic trends.

1. Introduction

The knowledge of Stark broadening data is important for various problems in plasma physics and astrophysics, e.g., for laboratory plasma diagnostics and investigations, fusion plasma and laser produced plasma research, stellar plasma modeling and research and abundance determinations. Electron-impact broadening parameters for many ionized elements have been calculated by using the semiclassical perturbation formalism [1–4] or the modified semiempirical approach [5–7] (for emitters with complex spectra see Ref. [8]).

Stark broadening parameters of Ra II lines may be of interest not only for comparisons with future laboratory measurements but also for comparisons with existing simple estimates [9,10], and for theoretical considerations, e.g., for the investigation of regularities and systematic trends.

Based on regularities along a homologous sequence of the second group in the periodic system, Stark widths for $7s^2S$–$7p^2P^o$ ($\lambda = 381.55$ nm), $7p^2P^o$–$8s^2S$ ($\lambda = 581.53$ nm) and $7p^2P^o$–$7d^2D$ ($\lambda = 434.19$ nm) Ra II spectral lines have been estimated in Ref. [9]. These values have been compared in Ref. [10] with Stark widths calculated in the same Ref. by using the simplified modified semiempirical approach [11]. Moreover, for the $7s^2S$–$7p^2P^o$($\lambda = 468.36$ nm) Ra II line the Stark width has been estimated in Ref. [10], based on regularities and systematic trends.

Regularities in Stark widths of non-hydrogenic lines, systematic trends along spectral series and similarities of line widths within multiplets, supermultiplets, transition arrays and for analogous transitions of homologous atoms and ions have been considered in Ref. [12]. Exceptions of the established regularities have been analyzed in Ref. [13]. This analysis shows that the reasons for such exceptions may be divided in two categories:

(*i*) irregular atomic energy level structure and
(*ii*) inadequacy of used model of the emitter structure. Similar investigations of experimental Stark shifts [14] show, for numerous examples, the same regularities and systematic trends. Exceptions of the found shift regularities have been considered in Ref. [15].

In order to enlarge the existing set of theoretical Stark broadening data, we present here the results of Stark broadening parameter calculations for 53 Ra II spectral lines. Since the full semiclassical perturbation method is not applicable in an adequate way and with the expected accuracy due to the lack of a reliable atomic energy level set, calculations have been performed within the modified semiempirical approach for an electron density of $10^{23}\,\mathrm{m}^{-3}$ and within the temperature range 5000–50000 K. Stark broadening parameters for 10 Ra II spectral lines, belonging to the $5f^2F^o$–$7d^2D$, $6d^2D$–$7p^2P^o$, $7d^2D$–$8p^2P^o$ and $8d^2D$– $9p^2P^o$ Ra II multiplets, have been presented for an electron density of $10^{20}\,\mathrm{m}^{-3}$, since for higher densities they become non-isolated. Also, we performed an analysis of the Stark width and shift behavior along the Ra II $5f^2F^o_{5/2}$– $nd^2D_{5/2}$ spectral series ($6 < n < 8$). We also discussed similarities of Stark shifts within the $6d^2D$–$7p^2P^o$ multiplet.

2. Theoretical remarks

According to the modified semiempirical (MSE) approach [5,6] the electron impact full width (FHWM) of an isolated ion line is given as

$$
\begin{aligned}
W_{\mathrm{MSE}} = N\frac{8\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}\frac{\lambda^2}{2\pi c}
&\times\left\{\sum_{\ell_i\pm1}\sum_{A_{i'}J_{i'}}\vec{\Re}^2[n_i\ell_iA_iJ_i, n_i(\ell_i\pm1)A_{i'}J_{i'}]\tilde{g}(x_{\ell_i,\ell_i\pm1})\right.\\
&+\sum_{\ell_f\pm1}\sum_{A_{f'}J_{f'}}\vec{\Re}^2[n_f\ell_fA_fJ_f, n_f(\ell_f\pm1)A_{f'}J_{f'}]\tilde{g}(x_{\ell_f,\ell_f\pm1})\\
&+\left(\sum_{i'}\vec{\Re}^2_{ii'}\right)_{\Delta n\neq0} g(x_{n_i,n_i+1})\\
&\left.+\left(\sum_{f'}\vec{\Re}^2_{ff'}\right)_{\Delta n\neq0} g(x_{n_f,n_f+1})\right\},
\end{aligned}
\tag{1}
$$

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and the corresponding Stark shift as

$$
\begin{aligned}
d_{\mathrm{MSE}} = N\frac{4\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}\frac{\lambda^2}{2\pi c}\\
\times\Bigg\{\sum_{A_{i'}J_{i'}}\sigma_{J_iJ_{i'}}\vec{\Re}^2[n_i\ell_iA_iJ_i,\, n_i(\ell_i+1)A_{i'}J_{i'}]\tilde{g}_{\mathrm{sh}}(x_{\ell_i,\ell_i+1})\\
-\sum_{A_{i'}J_{i'}}\sigma_{J_iJ_{i'}}\vec{\Re}^2[n_i\ell_iA_iJ_i,\, n_i(\ell_i-1)A_{i'}J_{i'}]\tilde{g}_{\mathrm{sh}}(x_{\ell_i,\ell_i-1})\\
-\sum_{A_{f'}J_{f'}}\sigma_{J_fJ_{f'}}\vec{\Re}^2[n_f\ell_fA_fJ_f,\, n_f(\ell_f+1)A_{f'}J_{f'}]\tilde{g}_{\mathrm{sh}}(x_{\ell_f,\ell_f+1})\\
+\sum_{A_{f'}J_{f'}}\sigma_{J_fJ_{f'}}\vec{\Re}^2[n_f\ell_fA_fJ_f,\, n_f(\ell_f-1)A_{f'}J_{f'}]\tilde{g}_{\mathrm{sh}}(x_{\ell_f,\ell_f-1})\\
+\left(\sum_{i'}\vec{\Re}^2_{ii'}\right)_{\Delta n\neq 0}g_{\mathrm{sh}}(x_{n_i,n_i+1})\\
-2\sum_{i'(\Delta E_{ii'}<0)}\sum_{A_{i'}J_{i'}}\vec{\Re}^2(n_i\ell_iA_iJ_i,\, n_{i'}\ell_{i'}A_{i'}J_{i'})g_{\mathrm{sh}}(x_{\ell_i,\ell_{i'}})\\
-\left(\sum_{f'}\vec{\Re}^2_{ff'}\right)_{\Delta n\neq 0}g_{\mathrm{sh}}(x_{n_f,n_f+1})\\
+2\sum_{f'(\Delta E_{ff'}<0)}\sum_{A_{f'}J_{f'}}\vec{\Re}^2(n_f\ell_fA_fJ_f,\, n_{f'}\ell_{f'},\, A_{f'}J_{f'})g_{\mathrm{sh}}(x_{\ell_f,\ell_{f'}})\\
+\sum_k\delta_k\Bigg\},
\end{aligned}
\tag{2}
$$

where the initial level is denoted as i and the final one as f and the square of the matrix element $\{\vec{\Re}^2[n_k\ell_kA_kJ_k, n_k(\ell_k\pm 1)A_{k'}J_{k'}],\quad k=i,f\}$ is

$$
\begin{aligned}
&\vec{\Re}^2[n_k\ell_kA_kJ_k, n_k(\ell_k\pm 1)A_{k'}J_{k'}]\\
&\quad=\frac{\ell_>}{2J_k+1}Q[\ell_kA_k,(\ell_k\pm 1)A_{k'}]Q(J_k,J_{k'})[R^{n_k^*(\ell_k\pm 1)}_{n_k^*\ell_k}]^2.
\end{aligned}
\tag{3}
$$

Also, $\ell_> = \max(\ell_k, \ell_k\pm 1)$ and

$$
\left(\sum_{k'}\vec{\Re}^2_{kk'}\right)_{\Delta n\neq 0}=\left(\frac{3n_k^*}{2Z}\right)^2\frac{1}{9}(n_k^{*2}+3\ell_k^2+3\ell_k+11).
\tag{4}
$$

In Eqs. (1) and (2)

$$
x_{\ell_k,\ell_{k'}}=\frac{E}{\Delta E_{\ell_k,\ell_{k'}}},\quad k=i,f,
$$

and $E=\frac{3}{2}kT$ is the electron kinetic energy and $\Delta E_{\ell_k,\ell_{k'}} = |E_{\ell_k}-E_{\ell_{k'}}|$ is the energy difference between levels ℓ_k and $\ell_k\pm 1$ $(k=i,f)$,

$$
x_{n_k,n_k+1}\approx\frac{E}{\Delta E_{n_k,n_k+1}},
$$

where for $\Delta n\neq 0$, the energy difference between energy levels with n_k and n_k+1, $\Delta E_{n_k,n_k+1}$ is estimated as $\Delta E_{n_k,n_k+1}\approx 2Z^2E_{\mathrm{H}}/n_k^{*3}$, $n_k^*=[E_{\mathrm{H}}Z^2/(E_{\mathrm{ion}}-E_k)]^{1/2}$ is the effective principal quantum number, Z is the residual ionic charge (for example $Z=1$ for neutrals) and E_{ion} is the appropriate spectral series limit.

If we have an oscillator strength, e.g. from literature, the corresponding matrix element may be calculated as

$$
\vec{\Re}^2_{k,k'}\approx 3\frac{E_{\mathrm{H}}}{E_{k'}-E_k}\cdot f_{k'k},\qquad (E_{k'}>E_k),\quad k=i,f
$$

or

$$
\vec{\Re}^2_{k,k'}\approx 3\frac{E_{\mathrm{H}}}{E_k-E_{k'}}\frac{2k'+1}{2k+1}\cdot f_{kk'},\qquad (E_{k'}<E_k),\quad k=i,f
\tag{5}
$$

where $f_{k'k}$ (for $E_{k'}>E_k$) and $f_{kk'}$ (for $E_{k'}<E_k$) are oscillator strengths and E_{H} is the hydrogen ionization energy.

Possible configuration mixing may be taken into account (see e.g. Ref. [16]) if one represents $\vec{\Re}^2_{\alpha\beta}$ as

$$
\vec{\Re}^2_{\alpha\beta}=K_\alpha\cdot\vec{\Re}^2_{\alpha\alpha'}+K_\beta\cdot\vec{\Re}^2_{\beta\beta'},
\tag{6}
$$

where K_α, and K_β are mixing coefficients for two configurations and $K_\alpha+K_\beta=1$.

In Eqs. (1–4) N and T are electron density and temperature, respectively, while $Q(\ell A,\ell' A')$ and $Q(J,J')$ are multiplet and line factors. The value of A depends on the coupling approximation (see e.g. [17]). In the case of the LS coupling approximation, applied here, $A=L$, for the jK approximation $A=K$ and for the jj approximation $A=j$. The $[R^{n_k^*(\ell_k\pm 1)}_{n_k^*\ell_k}]$ is the radial integral, and with $g(x)$ [18], $\tilde{g}(x)$ [5] and g_{sh} [18], $\tilde{g}_{\mathrm{sh}}(x)$ [6] are denoted the corresponding Gaunt factors for width and shift, respectively. The factor $\sigma_{kk'}=(E_{k'}-E_k)/|E_{k'}-E_k|$, where E_k and $E_{k'}$, are the energy of the considered and its perturbing level. The sum $\sum_k\delta_k$ is different from zero only if perturbing levels with $\Delta n\neq 0$ strongly violating the assumed approximations exist, so that they should be taken into account separately, and may be evaluated as

$$
\delta_i=\pm\vec{\Re}^2_{ii'}\left[g_{\mathrm{sh}}\left(\frac{E}{\Delta E_{i,i'}}\right)\mp g_{\mathrm{sh}}(x_{n_i,n_i+1})\right],
\tag{7}
$$

for the upper level, and

$$
\delta_f=\mp\vec{\Re}^2_{ff'}\left[g_{\mathrm{sh}}\left(\frac{E}{\Delta E_{f,f'}}\right)\mp g_{\mathrm{sh}}(x_{n_f,n_f+1})\right],
\tag{8}
$$

for the lower level. In Eqs. (7) and (8) the lower signs correspond to $\Delta E_{kk'}<0$, $k=i,f$.

Modified semiempirical formulas for Stark width and shift [5,6] can be simplified supposing that $(E/\Delta E)\leq 2$. Based on this assumption, simplified modified semiempirical formulas for the Stark width

$$
\begin{aligned}
W_{\mathrm{SMSE}}(\mathrm{nm}) = 2.2151\cdot 10^{-29}\frac{[\lambda(\mathrm{nm})]^2N(\mathrm{m}^{-3})}{\sqrt{T(\mathrm{K})}}\left(0.9-\frac{1.1}{Z}\right)\\
\times\sum_{k=i,f}\left(\frac{3n_k^*}{2Z}\right)^2(n_k^{*2}-\ell_k^2-\ell_k-1)
\end{aligned}
\tag{9}
$$

and shift

$$
\begin{aligned}
d_{\mathrm{SMSE}}\ (\mathrm{nm}) = 1.1076\cdot 10^{-29}\frac{[\lambda(\mathrm{nm})]^2N(\mathrm{m}^{-3})}{\sqrt{T(\mathrm{K})}}\left(0.9-\frac{1.1}{Z}\right)\frac{9}{4Z^2}\\
\times\sum_{k=i,f}\left(\frac{n_k^{*2}\varepsilon_k}{2\ell_k+1}\right)(n_k^{*2}-3\ell_k^2-3\ell_k-1)
\end{aligned}
\tag{10}
$$

(in the case of the allowed dipole transitions for $\ell\rightarrow\ell+1$ or

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$\ell \to \ell - 1$),

$$d_{\mathrm{SMSE}}\,(\mathrm{nm}) = 1.1076 \cdot 10^{-29} \frac{[\lambda(\mathrm{nm})]^2 N(\mathrm{m}^{-3})}{\sqrt{T(\mathrm{K})}} \left(0.9 - \frac{1.1}{Z}\right) \frac{9}{4Z^2} \times \sum_{k=i,f} \left(\frac{n_k^{*2}\varepsilon_k}{\ell_k + 1}\right) \times \left\{(\ell_k + 1)[n_k^{*2} - (\ell_k + 1)^2] - \ell_k(n_k^{*2} - \ell_k^2)\right\} \tag{11}$$

(for other dipole transitions), are obtained [11]. In Eqs. (10) and (11) $\varepsilon_k = 1$, for $k = i$, and $\varepsilon_k = -1$, for $k = f$.

Stark width values for the Ra II $7s^2S$–$7p^2P^o$ ($\lambda = 381.55$ nm), $7p^2P^o$–$7d^2D$ ($\lambda = 434.19$ nm) and $7p^2P^o$–$8s^2S$ ($\lambda = 581.53$ nm) spectral lines, calculated in Ref. [9] by using the simplified modified semiempirical approach, have been compared in this Ref. with Stark widths obtained on the basis of regularities along a homologous sequence of the second group in the periodic system. It has been shown, on the basis of such analysis, that the Stark width depends on the upper-level ionization potential for the homologous sequence of the second group in the periodic system for three types of transitions of singly ionized atoms. That dependence, for an electron density of $10^{23}\,\mathrm{m}^{-3}$, is expressed by the following formulas [9]

$$w_{n\mathrm{s}-n\mathrm{p}} = 2.65 \cdot 10^{19} Z^{-1} T^{-1/2} I^{-5.10} (\mathrm{rad/s}), \tag{12}$$

$$w_{n\mathrm{p}-n\mathrm{d}} = 2.30 \cdot 10^{18} Z^{-1} T^{-1/2} I^{-4.89} (\mathrm{rad/s}), \tag{13}$$

$$w_{n\mathrm{p}-(n+1)\mathrm{s}} = 1.64 \cdot 10^{20} Z^{-1} T^{-1/2} I^{-6.94} (\mathrm{rad/s}) \tag{14}$$

for ns–np, np–nd and np-$(n+1)$s transitions, respectively. Here, I(eV) is the upper-level ionization potential of the corresponding spectral transition.

Another source of Stark broadening in stellar atmospheres are collisions with protons. We can estimate the correction to the Stark width due to the proton-impact contribution using the expression for the ''quadrupole'' ion-impact width [19] for the case considered:

$$W(\mathrm{nm}) = 0.8148 \cdot 10^{-31} [\lambda(\mathrm{nm})]^2 N_{\mathrm{p}}(\mathrm{m}^{-3})(n_i^{*2} - n_f^{*2})^2 / Z_{\mathrm{p}}^2. \tag{15}$$

Here, with the index p are denoted the corresponding values for perturbers. For typical stellar conditions ($N_{\mathrm{e}} \sim 10^{19}\,\mathrm{m}^{-3}$) the impact approximation is usually valid also for proton perturbers. The total Stark width is obtained by adding electron and proton impact widths.

When dipole interactions are more important or impact approximation is not valid one can use the approximate formulae [20] to calculate the full line width W_{tot} and shift d_{tot} (see Ref. [21])

$$W_{\mathrm{tot}} = W + 1.75\alpha(1 - 1.2R)W, \tag{16}$$

$$d_{\mathrm{tot}} = d \mp \alpha(1 - 1.2R)W, \tag{17}$$

where W, d, α and R are electron impact width (FWHM), shift, quasi-static ion broadening parameter and Debye-shielding parameter, respectively. In addition, there are certain restrictions to the applicability of Eqs. (1) and (17) and they are:

$$0.05 \lesssim \alpha \lesssim 0.5, \quad R \lesssim 0.8. \tag{18}$$

Eqs. (16) and (17) are valid for singly emitters. For neutral emitters $1.2R$ has to be replaced by $0.75R$.

3. Results and discussion

The energy levels for Ra II, which are needed for these calculations, were taken from Ref. [22]. The oscillator strengths have been calculated by using the Bates-Damgaard method [23]. In the case of Ra II transitions, the *LS* coupling approximation for the dipole matrix element calculation has been used.

In Table I the Stark broadening parameters for 43 Ra II spectral lines are presented as a function of temperature for an electron density of $10^{23}\,\mathrm{m}^{-3}$.

The spectral lines belonging to the $5f^2F^o$–$7d^2D$, $6d^2D$–$7p^2P^o$, $7d^2D$–$8p^2P^o$ and $8d^2D$–$9p^2P^o$ multiplets are too large at the electron density of $10^{23}\,\mathrm{m}^{-3}$ and they become non-isolated. Stark broadening calculations for these lines have been performed at a lower density of $10^{20}\,\mathrm{m}^{-3}$ since they are of interest for regularities and systematic trend investigations. Obtained Stark broadening parameters for these Ra II spectral lines are shown as a function of temperature.

Stark broadening parameters for electron densities not used in Tables I, II may be obtained by linear extrapolation, taking into account that for sufficiently higher densities a correction for Debye shielding effect [21] should be applied and that lines may become non isolated.

In Figs. 1–4 our results for Stark widths are compared, for $T = 20000$ K, with estimated Stark widths from Ref. [9] for the $7s^2S$–$7p^2P^o$ ($\lambda = 381.55$ nm), $7p^2P^o$–$7d^2D$ ($\lambda = 434.19$ nm) and $7p^2P^o$–$8s^2S$ ($\lambda = 581.53$ nm) Ra II spectral lines as well as with an estimated Stark width values from Ref. [10] for the $7s^2S$–$7p^2P^o$ ($\lambda = 468.36$ nm) Ra II line, respectively. Taking into account that the values obtained on the basis of regularities in Refs [9] and [10] are approximate ones, we may conclude that this disagreement is reasonable for such complex spectra.

We must emphasis that in Tables I and II Stark broadening values are presented in nm. In order to analyze Stark width and shift regularities and similarities, these values should be expressed in s^{-1}, in order to avoid the influence of wavelength differences.

The Ra II spectrum is appropriate for a demonstration of exceptions to established Stark broadening parameters regularities and systematic trends [12,14] due to its irregular structure. For example, in Figs. 5 and 6 the Stark line widths and shifts within the Ra II $5f^2F^o_{5/2}$– $nd^2D_{5/2}$ ($6 < n < 8$) spectral series are presented as a function of the principal quantum number of the upper level n. In these Figures one can see that for the considered spectral series irregular Stark width and shift behavior exists. Such Stark width and shift behavior can be explained in terms of irregular Ra II energy level atomic structure. In Fig. 7 one can see that in the case of $6d^2D_{5/2}$ and $7d^2D_{5/2}$ energy levels, the most important perturbing levels ($7p^2P^o_{3/2}$ and $5f^2F^o_{7/2}$ respectively) contribute with positive sign to the shift

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Table I. *Stark widths* (W) *(full widths at half maximum) and shifts* (d) *in nm for 43 Ra II spectral lines, calculated by using the modified semiempirical approach, for an electron density of* $10^{23}\,m^{-3}$ *and within the temperature range 5000 K–50000 K.*

Transition	T (K)	W (nm)	d (nm)
	5000.	0.679E–01	–0.191E–01
	10000.	0.473E–01	–0.145E–01
$7s^2S_{1/2}$–$7p^2P^o_{1/2}$	20000.	0.339E–01	–0.124E–01
$\lambda = 468.36$ nm	30000.	0.289E–01	–0.130E–01
	40000.	0.265E–01	–0.136E–01
	50000.	0.254E–01	–0.142E–01
	5000.	0.497E–01	–0.891E–02
	10000.	0.346E–01	–0.670E–02
$7s^2S_{1/2}$–$7p^2P^o_{3/2}$	20000.	0.244E–01	–0.547E–02
$\lambda = 381.55$ nm	30000.	0.205E–01	–0.539E–02
	40000.	0.186E–01	–0.595E–02
	50000.	0.176E–01	–0.631E–02
	5000.	0.383E-01	–0.163E–01
	10000.	0.327E–01	–0.224E–01
$7s^2S_{1/2}$–$8p^2P^o_{1/2}$	20000.	0.304E–01	–0.259E–01
$\lambda = 190.60$ nm	30000.	0.284E–01	–0.251E–01
	40000.	0.276E–01	–0.239E–01
	50000.	0.270E–01	–0.228E–01
	5000.	0.505E–01	–0.908E–02
	10000.	0.399E–01	–0.158E–01
$7s^2S_{1/2}$–$8p^2P^o_{3/2}$	20000.	0.355E–01	–0.255E–01
$\lambda = 190.87$ nm	30000.	0.347E–01	–0.297E–01
	40000.	0.329E–01	–0.300E–01
	50000.	0.314E–01	–0.300E–01
	5000.	0.103	–0.565E–01
	10000.	0.953E–01	–0.843E–01
$7s^2S_{1/2}$–$9p^2P^o_{3/2}$	20000.	0.873E–01	–0.947E–01
$\lambda = 157.70$ nm	30000.	0.804E–01	–0.924E–01
	40000.	0.777E–01	–0.877E–01
	50000.	0.632E–01	–0.905E–01
	5000.	2.66	–1.16
	10000.	2.16	–1.38
$8s^2S_{1/2}$–$8p^2P^o_{1/2}$	20000.	1.94	–1.53
$\lambda = 1388.70$ nm	30000.	1.83	–1.49
	40000.	1.79	–1.42
	50000.	1.78	–1.33
	5000.	2.21	–0.535
	10000.	1.70	–0.713
$8s^2S_{1/2}$–$8p^2P^o_{3/2}$	20000.	1.49	–1.03
$\lambda = 1112.71$ nm	30000.	1.45	–1.17
	40000.	1.39	–1.17
	50000.	1.35	–1.15
	5000.	1.14	–0.614
	10000.	1.03	–0.882
$8s^2S_{1/2}$–$9p^2P^o_{3/2}$	20000.	0.934	–0.984
$\lambda = 499.87$ nm	30000.	0.863	–0.961
	40000.	0.836	–0.911
	50000.	0.693	–0.936
	5000.	0.168	0.600E–01
	10000.	0.118	0.460E–01
$7p^2P^o_{1/2}$–$8s^2S_{1/2}$	20000.	0.879E–01	0.412E–01
$\lambda = 453.44$ nm	30000.	0.782E–01	0.413E–01
	40000.	0.745E–01	0.403E–01
	50000.	0.733E–01	0.371E–01
	5000.	0.285	0.892E–01
	10000.	0.200	0.683E–01
$7p^2P^o_{3/2}$–$8s^2S_{1/2}$	20000.	0.148	0.607E–01
$\lambda = 581.53$ nm	30000.	0.131	0.601E–01
	40000.	0.125	0.584E–01
	50000.	0.122	0.534E–01

Table I. *continued.*

Transition	T (K)	W (nm)	d (nm)
	5000.	0.151	0.256E–01
	10000.	0.142	0.255E–01
$7p^2P^o_{1/2}$–$7d^2D_{3/2}$	20000.	0.124	0.225E–01
$\lambda = 365.06$ nm	30000.	0.113	0.211E–01
	40000.	0.106	0.200E–01
	50000.	0.102	0.188E–01
	5000.	0.228	0.323E–01
	10000.	0.213	0.335E–01
$7p^2P^o_{3/2}$–$7d^2D_{3/2}$	20000.	0.185	0.291E–01
$\lambda = 443.75$ nm	30000.	0.169	0.266E–01
	40000.	0.159	0.250E–01
	50000.	0.151	0.234E–01
	5000.	0.369	0.266E–01
	10000.	0.298	0.209E–01
$7p^2P^o_{3/2}$–$7d^2D_{5/2}$	20000.	0.242	0.193E–01
$\lambda = 434.19$ nm	30000.	0.215	0.191E–01
	40000.	0.197	0.183E–01
	50000.	0.185	0.175E–01
	5000.	0.167	–0.331E–01
	10000.	0.144	–0.441E–01
$7p^2P^o_{3/2}$–$8d^2D_{5/2}$	20000.	0.130	–0.578E–01
$\lambda = 279.60$ nm	30000.	0.118	–0.597E–01
	40000.	0.112	–0.593E–01
	50000.	0.105	–0.562E–01
	5000.	3.21	–0.191
	10000.	2.74	–0.133
$8p^2P^o_{3/2}$–$8d^2D_{5/2}$	20000.	2.54	–0.532E–01
$\lambda = 1043.65$ nm	30000.	2.41	0.206E–01
	40000.	2.31	0.254E–01
	50000.	2.19	0.629E–01
	5000.	0.641E–01	–0.249E–01
	10000.	0.551E–01	–0.362E–01
$6d^2D_{3/2}$–$8p^2P^o_{1/2}$	20000.	0.516E–01	–0.429E–01
$\lambda = 259.59$ nm	30000.	0.484E–01	–0.421E–01
	40000.	0.470E–01	–0.402E–01
	50000.	0.462E-01	–0.383E–01
	5000.	0.834E–01	–0.123E–01
	10000.	0.661E–01	–0.246E–01
$6d^2D_{3/2}$–$8p^2P^o_{3/2}$	20000.	0.591E–01	–0.415E–01
$\lambda = 248.09$ nm	30000.	0.579E–01	–0.490E–01
	40000.	0.551E–01	–0.497E–01
	50000.	0.527E–01	–0.496E–01
	5000.	0.909E–01	–0.135E–01
	10000.	0.720E–01	–0.268E–01
$6d^2D_{5/2}$–$8p^2P^o_{3/2}$	20000.	0.643E–01	–0.452E–01
$\lambda = 258.74$ nm	30000.	0.630E–01	–0.533E–01
	40000.	0.599E–01	–0.540E–01
	50000.	0.572E–01	–0.541E–01
	5000.	0.156	–0.844E–01
	10000.	0.145	–0.127
$6d^2D_{3/2}$–$9p^2P^o_{3/2}$	20000.	0.133	–0.144
$\lambda = 194.83$ nm	30000.	0.122	–0.140
	40000.	0.118	–0.133
	50000.	0.963E–01	–0.138
	5000.	0.167	–0.902E–01
	10000.	0.154	–0.136
$6d^2D_{5/2}$–$9p^2P^o_{3/2}$	20000.	0.142	–0.153
$\lambda = 201.34$ nm	30000.	0.131	–0.150
	40000.	0.126	–0.142
	50000.	0.103	–0.147
	5000.	0.451E–01	0.214E–02
	10000.	0.342E–01	0.343E–02
$6d^2D_{3/2}$–$6f^2F^o_{5/2}$	20000.	0.289E–01	0.489E–02
$\lambda = 210.83$ nm	30000.	0.271E–01	0.368E–02
	40000.	0.264E–01	0.152E–02
	50000.	0.259E–01	0.159E–03

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Table I. *continued.*

Transition	T (K)	W (nm)	d (nm)
	5000.	0.485E–01	0.221E–02
	10000.	0.367E–01	0.362E–02
$6d^2D_{5/2}$–$6f^2F^o_{5/2}$	20000.	0.310E–01	0.523E–02
$\lambda = 218.47$ nm	30000.	0.291E–01	0.395E–02
	40000.	0.283E–01	0.163E–02
	50000.	0.278E–01	0.161E–03
	5000.	0.496E–01	0.236E–02
	10000.	0.378E–01	0.392E–02
$6d^2D_{5/2}$–$6f^2F^o_{7/2}$	20000.	0.322E–01	0.555E–02
$\lambda = 217.05$ nm	30000.	0.302E–01	0.420E–02
	40000.	0.294E–01	0.177E–02
	50000.	0.287E–01	0.161E–03
	5000.	0.818E–01	–0.129E–01
	10000.	0.642E–01	–0.186E–01
$6d^2D_{3/2}$–$7f^2F^o_{5/2}$	20000.	0.551E–01	–0.325E–01
$\lambda = 183.70$ nm	30000.	0.514E–01	–0.386E–01
	40000.	0.504E–01	–0.413E–01
	50000.	0.492E–01	–0.421E–01
	5000.	0.871E–01	–0.137E–01
	10000.	0.683E–01	–0.198E–01
$6d^2D_{5/2}$–$7f^2F^o_{5/2}$	20000.	0.586E–01	–0.346E–01
$\lambda = 189.47$ nm	30000.	0.547E–01	–0.411E–01
	40000.	0.536E–01	–0.439E–01
	50000.	0.523E–01	–0.448E–01
	5000.	0.887E–01	–0.121E–01
	10000.	0.697E–01	–0.172E–01
$6d^2D_{5/2}$–$7f^2F^o_{7/2}$	20000.	0.596E–01	–0.321E–01
$\lambda = 188.86$ nm	30000.	0.557E–01	–0.392E–01
	40000.	0.546E–01	–0.422E–01
	50000.	0.475E–01	–0.427E–01
	5000.	2.23	–1.14
	10000.	2.09	–1.67
$7d^2D_{3/2}$–$9p^2P^o_{3/2}$	20000.	1.94	–1.85
$\lambda = 681.83$ nm	30000.	1.80	–1.79
	40000.	1.73	–1.69
	50000.	1.66	–1.74
	5000.	2.73	–1.21
	10000.	2.48	–1.75
$7d^2D_{5/2}$–$9p^2P^o_{3/2}$	20000.	2.24	–1.96
$\lambda = 705.72$ nm	30000.	2.06	–1.90
	40000.	1.97	–1.80
	50000.	1.88	–1.85
	5000.	0.980	–0.196
	10000.	0.802	–0.247
$7d^2D_{3/2}$–$7f^2F^o_{3/2}$	20000.	0.721	–0.364
$\lambda = 562.50$ nm	30000.	0.679	–0.412
	40000.	0.658	–0.430
	50000.	0.641	–0.433
	5000.	1.24	–0.198
	10000.	1.01	–0.241
$7d^2D_{5/2}$–$7f^2F^o_{5/2}$	20000.	0.871	–0.372
$\lambda = 578.66$ nm	30000.	0.808	–0.426
	40000.	0.776	–0.447
	50000.	0.748	–0.450
	5000.	1.24	–0.180
	10000.	1.01	–0.214
$7d^2D_{5/2}$–$7f^2F^o_{7/2}$	20000.	0.866	–0.343
$\lambda = 573.04$ nm	30000.	0.805	–0.403
	40000.	0.773	–0.425
	50000.	0.719	–0.425
	5000.	0.464E–01	0.169E–01
	10000.	0.583E–01	0.157E–01
$5f^2F^o_{5/2}$–$6d^2D_{3/2}$	20000.	0.490E–01	0.963E–02
$\lambda = 270.98$ nm	30000.	0.447E–01	0.575E–02
	40000.	0.422E–01	0.385E–02
	50000.	0.406E–01	0.235E–02

Table I. *continued.*

Transition	T (K)	W (nm)	d (nm)
	5000.	0.510E–01	0.186E–01
	10000.	0.637E–01	0.172E–01
$5f^2F^o_{5/2}$–$6d^2D_{5/2}$	20000.	0.535E-01	0.106E–01
$\lambda = 283.73$ nm	30000.	0.489E–01	0.633E–02
	40000.	0.461E–01	0.425E–02
	50000.	0.444E–01	0.261E–02
	5000.	0.118	0.289E–01
	10000.	0.933E–01	0.195E–01
$5f^2F^o_{7/2}$–$6d^2D_{5/2}$	20000.	0.745E–01	0.122E–01
$\lambda = 281.46$ nm	30000.	0.660E–01	0.754E–02
	40000.	0.610E–01	0.530E–02
	50000.	0.577E–01	0.351E–02
	5000.	1.48	–0.115
	10000.	1.31	–0.210
$5f^2F^o_{5/2}$–$8d^2D_{5/2}$	20000.	1.21	–0.364
$\lambda = 770.07$ nm	30000.	1.11	–0.413
	40000.	1.06	–0.429
	50000.	1.05	–0.420
	5000.	1.87	–0.373E–01
	10000.	1.61	–0.199
$5f^2F^o_{7/2}$–$8d^2D_{5/2}$	20000.	1.43	–0.367
$\lambda = 787.31$ nm	30000.	1.30	–0.422
	40000.	1.23	–0.440
	50000.	1.21	–0.431
	5000.	1.46	–0.668E–01
	10000.	1.34	–0.794E–01
$6f^2F^o_{5/2}$–$7d^2D_{3/2}$	20000.	1.26	–0.103
$\lambda = 928.38$ nm	30000.	1.20	–0.772E–01
	40000.	1.16	–0.461E–01
	50000.	1.10	–0.262E–01
	5000.	2.36	–0.956E–01
	10000.	1.95	–0.143
$6f^2F^o_{5/2}$–$7d^2D_{5/2}$	20000.	1.70	–0.156
$\lambda = 973.24$ nm	30000.	1.58	–0.117
	40000.	1.50	–0.788E–01
	50000.	1.41	–0.535E–01
	5000.	2.25	–0.100
	10000.	1.87	–0.149
$6f^2F^o_{7/2}$–$7d^2D_{5/2}$	20000.	1.64	–0.160
$\lambda = 945.62$ nm	30000.	1.52	–0.118
	40000.	1.45	–0.802E–01
	50000.	1.36	–0.538E–01
	5000.	26.4	–4.60
	10000.	21.0	–4.08
$6f^2F^o_{5/2}$–$8d^2D_{5/2}$	20000.	19.9	–3.01
$\lambda = 4067.79$ nm	30000.	20.2	–1.87
	40000.	20.6	–1.05
	50000.	20.0	–0.592
	5000.	34.8	–6.20
	10000.	27.9	–5.64
$6f^2F^o_{7/2}$–$8d^2D_{5/2}$	20000.	26.6	–4.20
$\lambda = 4633.43$ nm	30000.	26.9	–2.59
	40000.	27.4	–1.50
	50000.	26.5	–0.847
	5000.	12.5	–0.129
	10000.	10.8	1.10
$7f^2F^o_{5/2}$–$8d^2D_{5/2}$	20000.	10.4	3.39
$\lambda = 2198.75$ nm	30000.	10.3	4.37
	40000.	9.81	4.71
	50000.	9.43	4.81
	5000.	11.9	–0.432
	10000.	10.3	0.636
$7f^2F^o_{7/2}$–$8d^2D_{5/2}$	20000.	9.90	2.84
$\lambda = 2119.81$ nm	30000.	9.74	3.83
	40000.	9.26	3.99
	50000.	8.90	4.71

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Table II. *Stark widths* (W) *(full widths at half maximum) and shifts* (d) *in 10^{-3} nm for 10 Ra II spectral lines, calculated by using the modified semiempirical approach, for an electron density of 10^{20} m^{-3} within the temperature range 5000 K–50000 K.*

Transition	T (K)	W (10^{-3} nm)	d (10^{-3} nm)
	5000.	0.326	–0.436E–01
	10000.	0.227	–0.360E–01
$6d^2D_{3/2}$–$7p^2P^o_{1/2}$	20000.	0.164	–0.368E–01
$\lambda = 1079.12$ nm	30000.	0.142	–0.464E–01
	40000.	0.132	–0.527E–01
	50000.	0.128	–0.572E–01
	5000.	0.156	–0.593E–02
	10000.	0.109	–0.547E–02
$6d^2D_{3/2}$–$7p^2P^o_{3/2}$	20000.	0.770E–01	–0.645E–02
$\lambda = 707.99$ nm	30000.	0.656E–01	–0.874E–02
	40000.	0.604E–01	–0.121E–01
	50000.	0.578E–01	–0.138E–01
	5000.	0.202	–0.872E–02
	10000.	0.140	–0.779E–02
$6d^2D_{5/2}$–$7p^2P^o_{3/2}$	20000.	0.990E–01	–0.856E–02
$\lambda = 802.20$ nm	30000.	0.841E–01	–0.113E–01
	40000.	0.772E–01	–0.154E–01
	50000.	0.738E–01	–0.179E–01
	5000.	46.9	–17.5
	10000.	47.0	–22.2
$7d^2D_{3/2}$–$8p^2P^o_{1/2}$	20000.	44.4	–23.8
$\lambda = 5370.65$ nm	30000.	41.6	–22.5
	40000.	39.7	–21.2
	50000.	38.5	–19.9
	5000.	15.2	–3.28
	10000.	14.1	–4.73
$7d^2D_{3/2}$–$8p^2P^o_{3/2}$	20000.	12.9	–6.48
$\lambda = 2741.22$ nm	30000.	12.5	–7.16
	40000.	11.8	–7.10
	50000.	11.3	–6.97
	5000.	29.0	–4.14
	10000.	23.8	–5.72
$7d^2D_{5/2}$–$8p^2P^o_{3/2}$	20000.	20.6	–8.27
$\lambda = 3173.02$ nm	30000.	19.4	–9.30
	40000.	18.2	–9.24
	50000.	17.2	–9.11
	5000.	263.	–98.4
	10000.	248.	–144.
$8d^2D_{5/2}$–$9p^2P^o_{3/2}$	20000.	234.	–155.
$\lambda = 6960.94$ nm	30000.	218.	–147.
	40000.	211.	–137.
	50000.	192.	–128.
	5000.	0.254E+04	662.
	10000.	0.260E+04	640.
$5f^2F^o_{5/2}$–$7d^2D_{3/2}$	20000.	0.232E+04	459.
$\lambda = 40993.06$ nm	30000.	0.214E+04	340.
	40000.	0.203E+04	273.
	50000.	0.195E+04	219.
	5000.	0.363E+04	581.
	10000.	0.321E+04	505.
$5f^2F^o_{5/2}$–$7d^2D_{5/2}$	20000.	0.269E+04	357.
$\lambda = 39604.18$ nm	30000.	0.244E+04	264.
	40000.	0.227E+04	208.
	50000.	0.215E+04	163.
	5000.	0.294E+06	0.497E+05
	10000.	0.240E+06	0.349E+05
$5f^2F^o_{7/2}$–$7d^2D_{5/2}$	20000.	0.197E+06	0.246E+05
$\lambda = 314169.02$ nm	30000.	0.176E+06	0.182E+05
	40000.	0.162E+06	0.145E+05
	50000.	0.153E+06	0.114E+05

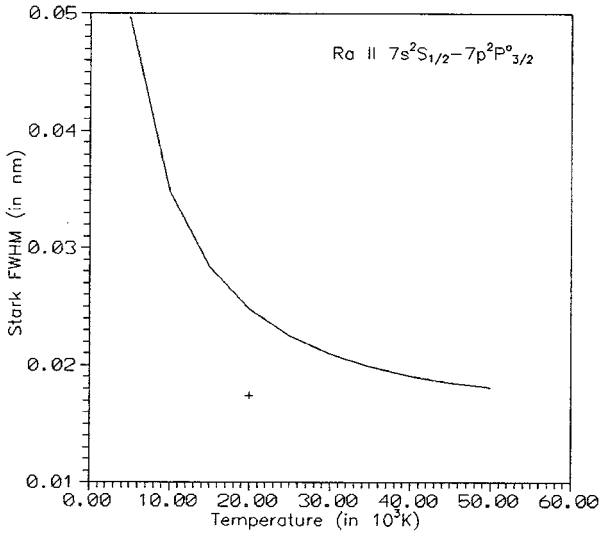

Fig. 1. Stark width (full widths at half maximum) for the $7s^2S$–$7p^2P^o$ ($\lambda = 381.55$ nm) Ra II spectral line as a function of temperature, for an electron density of 10^{23} m^{-3}. The full line denotes the Stark width calculated by using the modified semiempirical approach, and △ the estimated Stark width from Ref. [9].

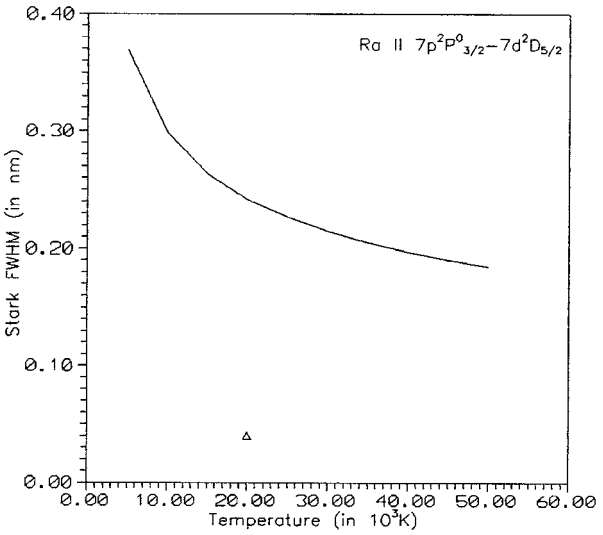

Fig. 2. Same as in Fig. 1 but for the $7p^2P^o$–$7d^2D$ ($\lambda = 434.19$ nm) Ra II spectral line.

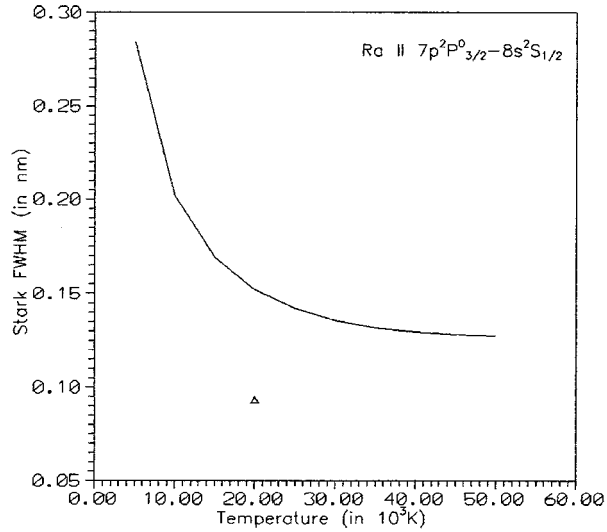

Fig. 3. Same as in Fig. 1 but for the $7p^2P^o$–$8s^2S$ ($\lambda = 581.53$ nm) Ra II spectral line.

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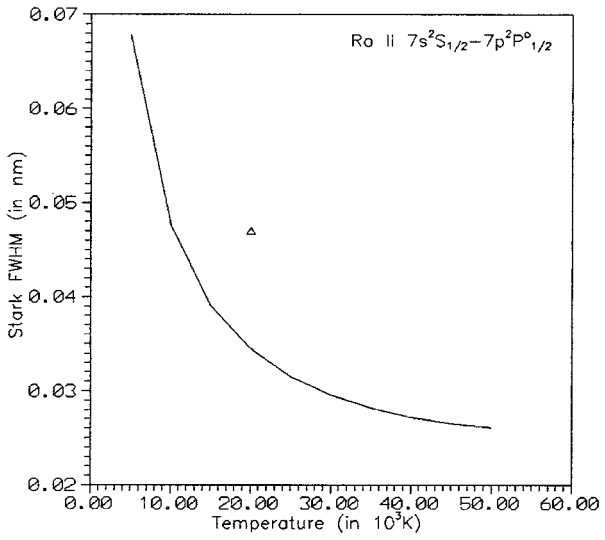

Fig. 4. Same as in Fig. 1 but for the $7s^2S-7p^2P^o$ ($\lambda = 468.36$ nm) Ra II spectral line. + denotes the estimated Stark widths from Ref. [10].

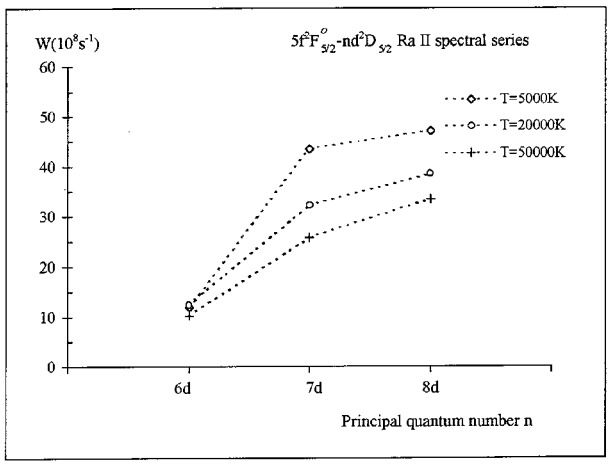

Fig. 5. Stark widths (full widths at half maximum) along the Ra II $5f^2F^o_{5/2} - nd^2D_{5/2}$ spectral series as a function of the principal quantum number n of the upper level. Results of our Stark line shift calculations, within the frame of the modified semiempirical approach, for an electron density of $10^{20}\,m^{-3}$, are shown for $T = 5000\,K$ (denoted with -◇-), $T = 20000\,K$ (denoted with -o-) and $T = 50000$ (denoted with -+-).

(shifting the line toward red), while in the case of $8d^2D_{5/2}$ the principal perturbing levels $6f^2F^o$ contribute with negative sign to the shift (shifting the line toward blue). Due to these reasons, irregular Stark shift behavior occurs within $5f^2F^o_{5/2} - nd^2D_{5/2}$ ($6 < n < 8$) spectral series, for all considered temperatures. In the case of the width the situation is different, since all contributions are positive. Consequently, the behavior is not influenced by the signs of important contributions but by the energy gap to important perturbing levels. Namely, as one can see in Fig. 7 the energy gaps between $7d^2D_{5/2}$ energy level and its principal $5f^2F^o$ perturbing levels are smaller than the energy gaps between $6d^2D_{5/2}$ or $8d^2D_{5/2}$ levels and their principal perturbing levels. This is the reason why an irregular an increase of Stark width for $n = 7$ exists, as one can see in Fig. 5.

The second interesting example is an exception of the established similarities of Stark shifts within the $6d^2D$–$7p^2P^o$ multiplet. In Fig. 8, where Stark shifts are presented as a function of temperature for lines belonging to the considered multiplet, one can see that for the $6d^2D_{3/2}$–$7p^2P^o_{1/2}$ Ra II spectral line the Stark shift is significantly smaller than for two other lines from this multiplet. This situation can be explained with the help of the partial energy level diagram for Ra II (Fig. 7). If we look in Fig. 7, one can see that $6d^2D$ energy levels are the principal perturbing levels for $7p^2P^o$ levels. Also, the energy gap between $7p^2P^o$ energy levels is comparable to the energy gap between the $7p^2P^o$ energy levels and $6d^2D$ perturbing levels. Moreover the energy gap between $7p^2P^o_{1/2}$ energy level and its $6d^2D_{3/2}$ perturbing level, contributing negatively to the shift, is significantly smaller than the energy gap between $7p^2P^o_{3/2}$ and $6d^2D$ perturbing levels. Consequently, the $6d^2D_{3/2}$–$7p^2P^o_{1/2}$ line has a different and more negative shift than the $6d^2D_{3/2}$–$7p^2P^o_{3/2}$ and $6d^2D_{5/2}$–$7p^2P^o_{3/2}$ lines which have practically the same shift characteristic for regular spectra.

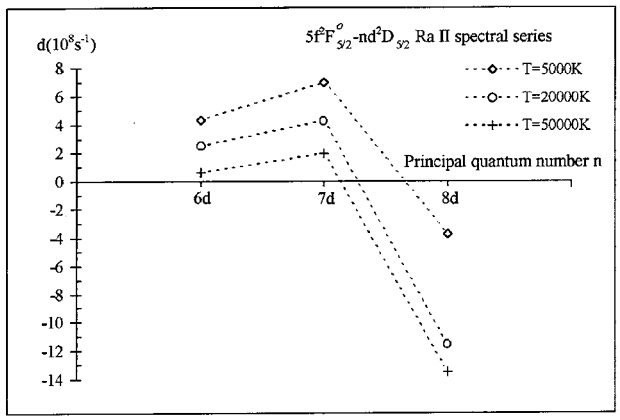

Fig. 6. Stark line shifts for members of the Ra II $5f^2F^o_{5/2} - nd^2D_{5/2}$ spectral series as a function of the principal quantum number n of the upper level. Results of our Stark line shift calculations, with the modified semiempirical approach, for an electron density of $10^{20}\,m^{-3}$, are shown, for $T = 5000\,K$ (denoted with –◇–), $T = 20000\,K$ (denoted with –o–) and $T = 50000$ (denoted with –+–).

4. Conclusions

The Stark broadening parameters for 53 Ra II spectral lines have been calculated within the modified semiempirical approach in temperature range 5000–50000K. For spectral lines non-isolated at higher densities, which are belonging to the $5f^2F^o$–$7d^2D$, $6d^2D$–$7p^2P^o$, $7d^2D$–$8p^2P^o$ and $8d^2D$–$9p^2P^o$ Ra II multiplets, results of Stark broadening parameter calculations have been presented for an electron density of $10^{20}\,m^{-3}$. For the other 43 Ra spectral lines calculations have been performed for an electron density of $10^{23}\,m^{-3}$.

In addition, the Ra II spectrum is appropriate for a demonstration of exceptions to the established regularities and systematic trends of Stark broadening parameters, due to its irregular structure. Two important examples have been presented. First example shows that irregular behavior of Stark width and shift (for $T = 5000\,K$) values exists along the Ra II $5f^2F^o_{5/2}$–$nd^2D_{5/2}$ spectral series ($6 < n < 8$). Second example presents an exception of the established similarities for Stark shift within the $6d^2D$–$7p^2P^o$ multiplet.

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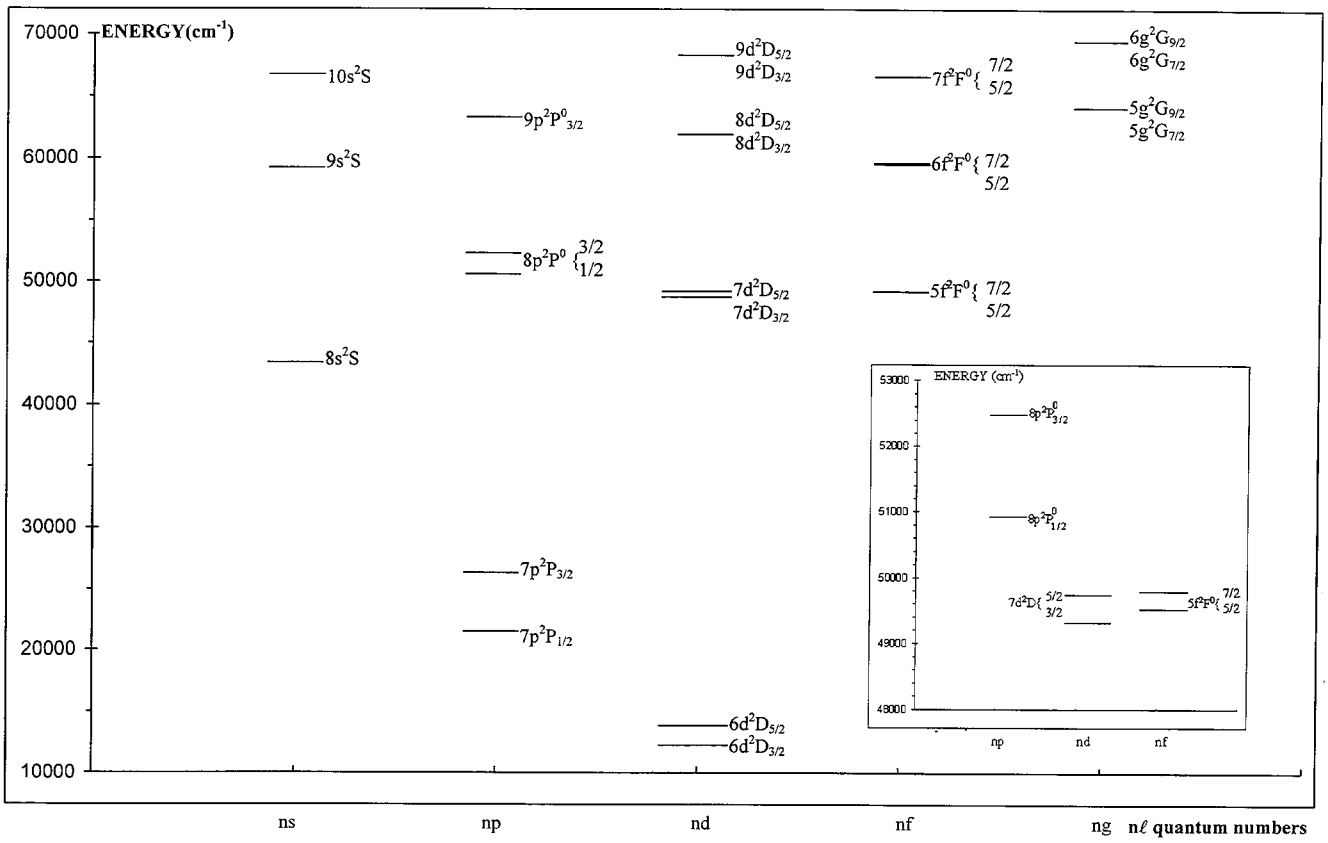

Fig. 7. Partial energy level diagram for Ra II.

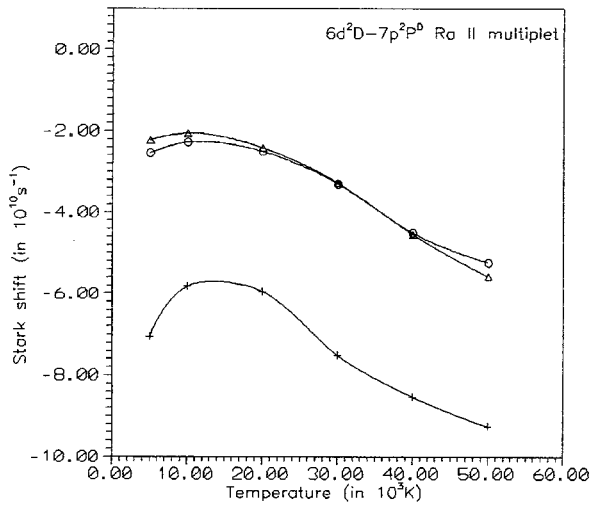

Fig. 8. Stark shifts for the Ra II spectral lines within the $6d^2D–7p^2P^o$ multiplet, as a function of temperature, for an electron density of $10^{20}\,m^{-3}$. –+– denotes the Stark shift for the $6d^2D_{3/2}–7p^2P^o_{1/2}$ –△– the Stark shift for the $6d^2D_{3/2}–7p^2P^o_{3/2}$ and –o– the Stark shift for the $6d^2D_{5/2}–7p^2P^o_{3/2}$ Ra II spectral lines.

Computer-readable data of Tables I and II may be obtained from authors by request (emails: dtankosic@aob.bg.ac.yu, lpopovic@aob.bg.ac.yu and mdimitrijevic@aob.bg.ac.yu).

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References

1. Sahal-Bréchot, S., Astron. Astrophys. **1**, 91 (1969).
2. Sahal-Bréchot, S., Astron. Astrophys. **2**, 322 (1969).
3. Fleurier, C., Sahal-Bréchot, S. and Chapelle, J., J. Quant. Spectrosc. Radiat. Transfer **17**, 595 (1977).
4. Dimitrijević, M. S., Bommier, V. and Sahal-Bréchot, S., Astron. Astrophys. Suppl. Series **89**, 581 (1991).
5. Dimitrijević, M. S. and Konjević, N., J. Quant. Spectrosc. Radiat. Transfer **24**, 451 (1980).
6. Dimitrijević, M. S. and Kršljanin, V., Astron. Astophys. **165**, 269 (1986).
7. Dimitrijević M. S., Zh. Prikl. Spektrosk. **63**, 810 (1996).
8. Popović, L. Ć. and Dimitrijević, M. S., Physica Scripta **53**, 325 (1996).
9. Djeniže, S., Srećković, A., Labat, J., J. Quant. Spectrosc. Radiat. Transfer **46**, 433 (1991).
10. Lakićević, I. S. Astron. Astrophys. **127**, 37 (1983).
11. Dimitrijević, M. S. and Konjević, N., Astron. Astophys. **173**, 345 (1987).
12. Wiese, W. L. and Konjević, N., J. Quant. Spectrosc. Radiat. Transfer **28**, 185 (1982).
13. Dimitrijević, M. S., Astron. Astrophys. **112**, 251 (1982).
14. Wiese, W. L. and Konjević, N., J. Quant. Spectrosc. Radiat. Transfer **47**, 185 (1992).
15. Dimitrijević, M. S. and Tankosic, D., Physica Scritpa 7**62**, 177 (2000).
16. Dimitrijević, M. S. and Popović, L. Ć., Astron. Astophys. Suppl. Series **101**, 583 (1993).
17. Sobel'man, I. I., "Atomic Spectra and Radiative Transitions", (Springer-Verlag, Berlin, 1979),
18. Griem, H. R., Phys. Rev. **165**, 258 (1968).
19. Griem, H. R., "Spectral Line Broadening by Plasmas", (Academic Press, New York, 1974).
20. Griem, H. R., "Plasma Spectroscopy", (McGraw Hill, New York, 1964).
21. Cooper, J, Reports Progr. Phys. **39**, 35 (1974).
22. Moore, C. E., "Atomic Energy Levels", Vol. III, NSRDS – NBS 35, (U.S. Government Printing Office, Washington D.C., 1971).
23. Bates, D. R. and Damgaard, A., Trans. Roy. Soc. London, Ser. A **242**, 101 (1949).

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Stark Broadening of In II Spectral Lines

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Abstract

Using a semiclassical approach, we have calculated electron-, proton-, and ionized helium-impact line widths and shifts for 101 In II multiplets. The resulting data have been compared with existing experimental and theoretical values.

1. Introduction

Stark widths for some neutral and singly ionized indium lines, have been determined experimentally [1] by the spectroscopic observation of a sodium-indium arc. Moreover recently have been determined theoretically within the semiclassical perturbation approach [2,3] Stark broadening parameters for 20 In III multiplets [4,5]. In Ref. [1] Stark widths for 7 In I multiplets have been determined within the GBKO semiclassical theory [6], and for 10 In II multiplets within Griem's semiempirical approach [7]. Also, Stark widths and shifts for the resonance In I and In II lines have been estimated with the help of regularities and systematic trends [8]. Such data are useful in the characterization and analysis of plasmas. Moreover, with the development of space technology and satellite born astronomical instruments, astrophysical interest for data on trace element spectral lines increases. Stark broadening parameters of ion lines are also of interest for solar and stellar opacities calculations, investigations of subphotospheric layers, stellar plasma modelling and diagnostic, abundance determinations, etc.

In order to continue our efforts to provide to astrophysicists and plasma physicists Stark broadening data needed for the consideration and modeling of astrophysical and laboratory plasmas as well as laser produced and fusion plasmas (see e.g. Ref. [9] and references therein), we have calculated within the semiclassical-perturbation formalism [2,3,10–15] electron-, proton-, and He II-impact line widths and shifts for 101 In II multiplets. The used formalism has been reviewed briefly e.g. in Refs [9] and [15]. Here, we present and discuss the results for In II, along with a comparison with experimental [1] and other theoretical results [1,8].

2. Theory

The formalism has been described in detail in Refs [2] and [3], and a brief summary together with innovations and modifications has been repeated several times, e.g. in Ref. [13]. Consequently, only the basic details of calculations will be presented here. Stark full width (W) at the intensity half maximum (FWHM) and shift (d) of an isolated spectral line, may be expressed as [2,3,13]

$$W = N\int vf(v)\mathrm{d}v\left(\sum_{i'\neq i}\sigma_{ii'}(v)+\sum_{f'\neq f}\sigma_{ff'}(v)+\sigma_{\mathrm{el}}\right)+W_R,$$
$$d = N\int vf(v)\mathrm{d}v\int_{R_3}^{R_D}2\pi\rho\mathrm{d}\rho\sin 2\phi_{\mathrm{p}} \tag{1}$$

where N is the electron density, $f(v)$ the Maxwellian velocity distribution function for electrons, ρ denotes the impact parameter of the incoming electron, i and f denote the initial and final atomic energy levels, and i', f' their corresponding perturber levels, while W_R gives the contribution of the Feshbach resonances [11]. The inelastic cross section $\sigma_{j,j'}(v)$ can be expressed by an integral over the impact parameter of the transition probability $P_{jj'}(\rho, v)$ as

$$\sum_{i'\neq i}\sigma_{jj'}(v)=\frac{1}{2}\pi R^2+\int_{R_1}^{R_{\mathrm{D}}}\sum_{j\neq j'}P_{jj'}(\rho,v), j=i,f \tag{2}$$

and the elastic cross section is given by

$$\sigma_{\mathrm{el}}=2\pi R_2^2+\int_{R_2}^{R_{\mathrm{D}}}8\pi\rho\mathrm{d}\rho\sin^2\delta$$
$$\delta=(\phi_{\mathrm{p}}^2+\phi_{\mathrm{q}}^2)^{1/2}. \tag{3}$$

The phase shifts ϕ_{p} and ϕ_{q} due respectively to the polarisation potential (r^{-4}) and to the quadrupolar potential (r^{-3}), are given in Section 3 of Chapter 2 in Ref. [2]. R_{D} is the Debye radius. All the cut-offs R_1, R_2, R_3 are described in Section 1 of Chapter 3 in Ref. [3]. The formulae for the ion-impact widths and shifts are analogous. We note here that inelastic collision contribution to the ion-impact widths is included as well.

The semiclassical perturbation method has been compared with critically selected experimental data for 13 He I multiplets [16] and it was found that the agreement between experimental data and semiclassical calculations is within the limits of 20 percent, that is the predicted accuracy of the semiclassical method [17].

3. Results and discussion

Energy levels for In II lines have been taken from Ref. [18]. Oscillator strengths have been calculated by using the method of Bates and Damgaard [19,20]. For higher levels, the method described in Ref. [21] has been used. In addition to electron-impact full halfwidths and shifts, Stark-broad-

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Table I. *This Table shows electron-, proton-, and He II- impact broadening parameters for In II for perturber density of 10^{16} cm^{-3} and temperatures from 5000 up to 100000 K. Transitions and averaged wavelengths for the multiplet (in Å) are also given. By dividing C by the corresponding full width at half maximum [13], we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the collision volume multiplied by the perturber density (the condition for validity of the impact approximation) lies between 0.1 and 0.5. (available electronically).*

Perturber Density = 1.E+16 cm^{-3}

Perturbers are:			Electrons			Protons			Ionized Helium	
Transition	T(K)		Width (A)	Shift (A)		Width (A)	Shift (A)		Width (A)	Shift (A)
In II 5S–5P	5000.		0.690E−02	−0.384E−03		0.133E−03	−0.373E−05		0.219E−03	−0.373E−05
1586.5 A	10000.		0.471E−02	−0.390E−03		0.274E−03	−0.805E−05		0.380E−03	−0.803E−05
C = 0.86E+19	20000.		0.340E−02	−0.205E−03		0.428E−03	−0.162E−04		0.532E−03	−0.157E−04
	30000.		0.284E−02	−0.180E−03		0.522E−03	−0.233E−04		0.589E−03	−0.217E−04
	50000.		0.228E−02	−0.165E−03		0.595E−03	−0.338E−04		0.646E−03	−0.302E−04
	100000.		0.177E−02	−0.129E−03		0.673E−03	−0.485E−04		0.720E−03	−0.417E−04
In II 5S–6P	5000.		0.951E−02	0.348E−02		0.571E−03	0.277E−03		0.696E−03	0.247E−03
911.0 A	10000.		0.762E−02	0.263E−02		0.844E−03	0.435E−03		0.931E−03	0.373E−03
C = 0.34E+18	20000.		0.651E−02	0.199E−02		0.105E−02	0.583E−03		0.108E−02	0.479E−03
	30000.		0.612E−02	0.175E−02		0.115E−02	0.660E−03		0.116E−02	0.540E−03
	50000.		0.572E−02	0.150E−02		0.128E−02	0.753E−03		0.126E−02	0.611E−03
	100000.		0.520E−02	0.117E−02		0.143E−02	0.885E−03		0.136E−02	0.713E−03
In II 5S–7P	5000.		0.239E−01	−0.102E−01	*	0.224E−02	−0.143E−02	*	0.224E−02	−0.112E−02
783.9 A	10000.		0.202E−01	−0.849E−02	*	0.287E−02	−0.197E−02	*	0.276E−02	−0.157E−02
C = 0.55E+17	20000.		0.179E−01	−0.681E−02	*	0.345E−02	−0.253E−02	*	0.324E−02	−0.203E−02
	30000.		0.170E−01	−0.603E−02	*	0.387E−02	−0.288E−02	*	0.349E−02	−0.229E−02
	50000.		0.160E−01	−0.528E−02		0.420E−02	−0.316E−02	*	0.370E−02	−0.252E−02
	100000.		0.145E−01	−0.423E−02		0.492E−02	−0.364E−02	*	0.406E−02	−0.289E−03
In II 5S–8P	5000.		0.406E−01	−0.211E−01						
734.8 A	10000.		0.348E−01	−0.176E−01						
C = 0.38E+17	20000.		0.313E−01	−0.143E−01	*	0.705E−02	−0.466E−02			
	30000.		0.302E−01	−0.126E−01	*	0.759E−02	−0.528E−02			
	50000.		0.291E−01	−0.109E−01	*	0.812E−02	−0.587E−02			
	100000.		0.270E−01	−0.865E−02	*	0.917E−02	−0.657E−02	*	0.786E−02	−0.517E−02
In II 5S–9P	5000.	*	0.745E−01	−0.387E−01						
710.0 A	10000.		0.647E−01	−0.330E−01						
C = 0.22E+17	20000.		0.596E−01	−0.288E−01						
	30000.		0.585E−01	−0.257E−01						
	50000.		0.568E−01	−0.218E−01						
	100000.		0.531E−01	−0.170E−01						
In II 6S–6P	5000.		0.849	0.131		0.414E−01	0.169E−01		0.509E−01	0.153E−01
7843.1 A	10000.		0.678	0.953E−01		0.609E−01	0.268E−01		0.680E−01	0.232E−01
C = 0.25E+20	20000.		0.572	0.596E−01		0.748E−01	0.372E−01		0.782E−01	0.302E−01
	30000.		0.530	0.608E−01		0.818E−01	0.420E−01		0.841E−01	0.342E−01
	50000.		0.498	0.480E−01		0.902E−01	0.478E−01		0.906E−01	0.390E−01
	100000.		0.456	0.357E−01		0.998E−01	0.563E−01		0.958E−01	0.454E−01
In II 6S–7P	5000.		0.450	−0.192	*	0.394E−01	−0.251E−01	*	0.392E−01	−0.198E−01
3274.1 A	10000.		0.376	−0.162	*	0.502E−01	−0.346E−01	*	0.484E−01	−0.276E−01
C = 0.97E+18	20000.		0.329	−0.133	*	0.605E−01	−0.445E−01	*	0.563E−01	−0.356E−01
	30000.		0.311	−0.118	*	0.678E−01	−0.506E−01	*	0.607E−01	−0.403E−01
	50000.		0.293	−0.104		0.738E−01	−0.559E−01	*	0.647E−01	−0.444E−01
	100000.		0.266	−0.842E−01		0.871E−01	−0.642E−01	*	0.710E−01	−0.509E−01
In II 6S–8P	5000.		0.512	−0.260						
2559.7 A	10000.		0.436	−0.217						
C = 0.46E+18	20000.		0.390	−0.179	*	0.856E−01	−0.567E−01			
	30000.		0.375	−0.159	*	0.923E−01	−0.643E−01			
	50000.		0.362	−0.138	*	0.990E−01	−0.717E−01			
	100000.		0.336	−0.109	*	0.112	−0.801E−01	*	0.949E−01	−0.627E−01
In II 6S–9P	5000.	*	0.784	−0.401						
2282.3 A	10000.		0.679	−0.343						
C = 0.23E+18	20000.		0.623	−0.301						
	30000.		0.612	−0.269						
	50000.		0.594	−0.230						
	100000.		0.555	−0.180						

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Table I. *Continued*

Perturber Density = 1.E+16 cm^{-3} Perturbers are:		Electrons		Protons		Ionized Helium	
Transition	T(K)	Width (A)	Shift (A)	Width (A)	Shift (A)	Width (A)	Shift (A)
In II 7S–8P	5000.	5.49	– 2.83				
7859.1 A	10000.	4.68	– 2.51				
C = 0.43E+19	20000.	4.18	– 2.07 *	0.848	– 0.566		
	30000.	4.01	– 1.86 *	0.904	– 0.639		
	50000.	3.86	– 1.62 *	1.00	– 0.716		
	100000.	3.58	– 1.28 *	1.03	– 0.774 *	0.919	– 0.624
In II 7S–9P	5000. *	5.16	– 2.67				
5723.4 A	10000.	4.48	– 2.34				
C = 0.14E+19	20000.	4.14	– 2.07				
	30000.	4.07	– 1.87				
	50000.	3.96	– 1.61				
	100000.	3.70	– 1.26				
In II 5P–6S	5000.	0.564E−01	0.246E−01	0.549E−03	0.700E−03	0.844E−03	0.665E−03
2941.9 A	10000.	0.405E−01	0.184E−01	0.124E−02	0.128E−02	0.152E−02	0.114E−02
C = 0.11E+20	20000.	0.287E−01	0.143E−01	0.206E−02	0.188E−02	0.226E−02	0.161E−02
	30000.	0.236E−01	0.120E−01	0.262E−02	0.225E−02	0.255E−02	0.183E−02
	50000.	0.201E−01	0.103E−01	0.313E−02	0.259E−02	0.294E−02	0.210E−02
	100000.	0.168E−01	0.833E−02	0.379E−02	0.307E−02	0.347E−02	0.251E−02
In II 5P–7S	5000.	0.619E−01	0.290E−01	0.140E−02	0.200E−02	0.132E−02	0.168E−02
1657.4 A	10000.	0.428E−01	0.253E−01	0.249E−02	0.302E−02	0.239E−02	0.245E−02
C = 0.12E+19	20000.	0.327E−01	0.205E−01	0.370E−02	0.381E−02	0.318E−02	0.310E−02
	30000.	0.291E−01	0.197E−01	0.432E−02	0.434E−02	0.362E−02	0.350E−02
	50000.	0.262E−01	0.168E−01	0.509E−02	0.488E−02	0.424E−02	0.398E−02
	100000.	0.229E−01	0.135E−01	0.630E−02	0.571E−02	0.506E−02	0.456E−02
In II 5P–8S	5000.	0.752E−01	0.363E−01	0.291E−02	0.344E−02 *	0.282E−02 *	0.283E−02
1418.1 A	10000.	0.538E−01	0.351E−01	0.478E−02	0.482E−02 *	0.409E−02 *	0.388E−02
C = 0.51E+18	20000.	0.448E−01	0.295E−01	0.627E−02	0.619E−02 *	0.522E−02 *	0.502E−02
	30000.	0.418E−01	0.267E−01	0.715E−02	0.705E−02	0.614E−02	0.564E−02
	50000.	0.371E−01	0.244E−01	0.833E−02	0.791E−02	0.689E−02	0.621E−02
	100000.	0.338E−01	0.196E−01	0.101E−01	0.886E−02	0.782E−02	0.713E−02
In II 5P–9S	5000.	0.122	0.620E−01 *	0.810E−02 *	0.686E−02		
1309.8 A	10000.	0.937E−01	0.621E−01 *	0.109E−01 *	0.971E−02 *	0.897E−02 *	0.765E−02
C = 0.25E+18	20000.	0.800E−01	0.540E−01 *	0.139E−01 *	0.127E−01 *	0.113E−01 *	0.100E−01
	30000.	0.753E−01	0.491E−01 *	0.153E−01 *	0.144E−01 *	0.126E−01 *	0.113E−01
	50000.	0.703E−01	0.446E−01 *	0.177E−01 *	0.159E−01 *	0.136E−01 *	0.127E−01
	100000.	0.657E−01	0.365E−01 *	0.205E−01 *	0.180E−01 *	0.166E−01 *	0.147E−01
In II 6P–7S	5000.	1.13	0.465	0.404E−01	0.274E−01	0.477E−01	0.231E−01
7356.9 A	10000.	0.898	0.366	0.615E−01	0.414E−01	0.647E−01	0.349E−01
C = 0.22E+20	20000.	0.789	0.286	0.778E−01	0.539E−01	0.763E−01	0.440E−01
	30000.	0.768	0.256	0.861E−01	0.608E−01	0.836E−01	0.498E−01
	50000.	0.748	0.218	0.968E−01	0.691E−01	0.914E−01	0.561E−01
	100000.	0.712	0.175	0.112	0.805E−01	0.981E−01	0.640E−01
In II 6P–8S	5000.	0.641	0.320	0.269E−01	0.277E−01 *	0.276E−01 *	0.228E−01
4206.3 A	10000.	0.486	0.273	0.420E−01	0.389E−01 *	0.381E−01 *	0.314E−01
C = 0.45E+19	20000.	0.439	0.222	0.547E−01	0.500E−01 *	0.475E−01 *	0.403E−01
	30000.	0.413	0.205	0.614E−01	0.566E−01	0.526E−01	0.461E−01
	50000.	0.393	0.178	0.719E−01	0.625E−01	0.598E−01	0.511E−01
	100000.	0.376	0.143	0.854E−01	0.733E−01	0.682E−01	0.577E−01
In II 6P–9S	5000.	0.825	0.398 *	0.537E−01 *	0.447E−01		
3377.6 A	10000.	0.635	0.391 *	0.714E−01 *	0.636E−01 *	0.599E−01 *	0.494E−01
C = 0.17E+19	20000.	0.560	0.337 *	0.903E−01 *	0.829E−01 *	0.752E−01 *	0.625E−01
	30000.	0.538	0.304 *	0.991E−01 *	0.931E−01 *	0.846E−01 *	0.736E−01
	50000.	0.509	0.275 *	0.114 *	0.103 *	0.901E−01 *	0.817E−01
	100000.	0.486	0.224 *	0.135 *	0.119 *	0.110 *	0.952E−01
In II 7P–8S	5000.	20.1	8.40 *	1.29 *	0.910		
16720.8 A	10000.	16.5	7.77 *	1.66 *	1.26		
C = 0.25E+20	20000.	14.1	6.95 *	2.03 *	1.63 *	1.82 *	1.31
	30000.	13.2	6.33 *	2.24 *	1.84 *	1.96 *	1.49
	50000.	12.4	5.62 *	2.55 *	2.07 *	2.18 *	1.65
	100000.	11.2	4.65	2.83	2.31 *	2.22 *	1.81

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Table I. *Continued*

Perturber Density = 1.E+16 cm^{-3} Perturbers are:		Electrons		Protons		Ionized Helium	
Transition	T(K)	Width (A)	Shift (A)	Width (A)	Shift (A)	Width (A)	Shift (A)
In II 7P–9S	5000.	7.56	2.96 *	0.489 *	0.352		
8464.5 A	10000.	6.24	2.96 *	0.638 *	0.511		
C = 0.65E+19	20000.	5.38	2.92 *	0.803 *	0.678		
	30000.	5.06	2.67 *	0.889 *	0.764		
	50000.	4.80	2.33 *	1.01 *	0.844 *	0.808 *	0.661
	100000.	4.43	2.01 *	1.05 *	0.957 *	0.890 *	0.734
In II 5P–5D	5000.	0.476E−01	−0.231E−03	0.250E−02	−0.574E−03	0.313E−02	−0.525E−03
1966.7 A	10000.	0.366E−01	−0.581E−03	0.365E−02	−0.983E−03	0.415E−02	−0.835E−03
C = 0.16E+19	20000.	0.295E−01	−0.905E−03	0.440E−02	−0.140E−02	0.473E−02	−0.116E−02
	30000.	0.266E−01	−0.115E−02	0.477E−02	−0.159E−02	0.506E−02	−0.131E−02
	50000.	0.240E−01	−0.753E−03	0.521E−02	−0.182E−02	0.539E−02	−0.149E−02
	100000.	0.212E−01	−0.764E−03	0.566E−02	−0.217E−02	0.564E−02	−0.177E−02
In II 5P–6D	5000.	0.662E−01	0.458E−02	0.560E−02	0.324E−02 *	0.616E−02 *	0.271E−02
1571.5 A	10000.	0.580E−01	0.617E−02	0.739E−02	0.464E−02 *	0.745E−02 *	0.374E−02
C = 0.22E+18	20000.	0.532E−01	0.520E−02	0.893E−02	0.591E−02 *	0.866E−02 *	0.478E−02
	30000.	0.508E−01	0.503E−02	0.977E−02	0.670E−02 *	0.921E−02 *	0.542E−02
	50000.	0.481E−01	0.506E−02	0.108E−01	0.754E−02	0.997E−02	0.607E−02
	100000.	0.437E−01	0.405E−02	0.122E−01	0.868E−02	0.110E−01	−0.708E−02
In II 5P–7D	5000.	0.925E−01	0.481E−02 *	0.111E−01 *	0.437E−02		
1381.9 A	10000.	0.851E−01	0.692E−02 *	0.133E−01 *	0.605E−02		
C = 0.13E+18	20000.	0.839E−01	0.526E−02 *	0.154E−01 *	0.770E−02		
	30000.	0.839E−01	0.517E−02 *	0.163E−01 *	0.879E−02 *	0.155E−01 *	0.706E−02
	50000.	0.832E−01	0.506E−02 *	0.173E−01 *	0.966E−02 *	0.163E−01 *	0.770E−02
	100000.	0.794E−01	0.346E−02	0.191E−01	0.112E−01 *	0.172E−01 *	0.884E−02
In II 5P–8D	5000.	0.150	0.894E−02				
1292.5 A	10000.	0.148	0.550E−02				
C = 0.73E+17	20000.	0.151	0.603E−02				
	30000.	0.154	0.648E−02 *	0.297E−01 *	0.153E−01		
	50000.	0.157	0.501E−02 *	0.311E−01 *	0.170E−01		
	100000.	0.151	0.334E−02 *	0.340E−01 *	0.193E−01		
In II 5P–9D	5000. *	0.247 *	0.993E−02				
1243.1 A	10000. *	0.254 *	0.435E−02				
C = 0.43E+17	20000.	0.269	0.505E−02				
	30000.	0.277	0.647E−02				
	50000.	0.284	0.381E−02				
	100000.	0.275	0.318E−02				
In II 6P–6D	5000.	1.18	−0.326E−01	0.871E−01	0.395E−01 *	0.962E−01 *	0.333E−01
5920.4 A	10000.	1.02	−0.263E−02	0.111	0.582E−01 *	0.114 *	0.465E−01
C = 0.32E+19	20000.	0.939	0.287E−02	0.131	0.736E−01 *	0.131 *	0.596E−01
	30000.	0.903	0.158E−02	0.144	0.837E−01 *	0.138 *	0.674E−01
	50000.	0.857	0.792E−02	0.154	0.933E−01 *	0.145 *	0.751E−01
	100000.	0.785	0.750E−02	0.170	0.107	0.153	0.855E−01
In II 6P–7D	5000.	0.827	−0.110E−01 *	0.911E−01 *	0.328E−01		
3903.2 A	10000.	0.757	0.184E−02 *	0.109 *	0.453E−01		
C = 0.11E+19	20000.	0.745	0.190E−02 *	0.125 *	0.580E−01		
	30000.	0.744	0.290E−02 *	0.131 *	0.656E−01 *	0.128 *	0.533E−01
	50000.	0.736	0.890E−02 *	0.139 *	0.736E−01 *	0.131 *	0.584E−01
	100000.	0.702	0.308E−02	0.153	0.854E−01 *	0.137	0.665E−01
In II 6P–8D	5000.	1.00	0.205E−01				
3265.0 A	10000.	0.991	0.792E−02				
C = 0.47E+19	20000.	1.02	0.161E−02				
	30000.	1.03	0.926E−02 *	0.190 *	0.963E−01		
	50000.	1.05	0.795E−02 *	0.201 *	0.107		
	100000.	1.01	0.246E−02 *	0.219 *	0.123		
In II 6P–9D	5000. *	1.44 *	0.267E−01				
2967.0 A	10000. *	1.48 *	0.145E−01				
C = 0.25E+18	20000.	1.57	0.295E−02				
	30000.	1.62	0.104E−01				
	50000.	1.66	0.116E−02				
	100000.	1.60	0.315E−02				

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Table I. *Continued*

Perturber Density = 1.E+16 cm^{-3} Perturbers are:		Electrons		Protons		Ionized Helium	
Transition	T(K)	Width (A)	Shift (A)	Width (A)	Shift (A)	Width (A)	Shift (A)
In II 7P–7D	5000.	12.1	3.08				
12776.1 A	10000.	11.2	2.79	* 1.53	* 0.822		
C = 0.11E+20	20000.	10.8	2.22	* 1.78	* 1.07		
	30000.	10.8	1.98	* 1.91	* 1.20		
	50000.	10.6	1.79	* 2.03	* 1.32	* 1.85	* 1.05
	100000.	10.0	1.40	* 2.24	* 1.51	* 2.05	* 1.26
In II 7P–8D	5000.	* 6.75	* 1.14				
7791.2 A	10000.	6.58	0.956				
C = 0.26E+19	20000.	6.73	0.808				
	30000.	6.87	0.780				
	50000.	6.92	0.677	* 1.29	* 0.753		
	100000.	6.66	0.517	* 1.41	* 0.887		
In II 7P–9D	5000.	* 7.03	* 0.724				
6285.1 A	10000.	* 7.20	* 0.569				
C = 0.11E+19	20000.	7.63	0.554				
	30000.	7.88	0.532				
	50000.	8.03	0.416				
	100000.	7.77	0.345				
In II 5D–6P	5000.	11.4	3.24	0.671	0.265	* 0.820	* 0.226
24362.4 A	10000.	9.10	2.29	0.950	0.403	1.01	0.342
C = 0.24E+21	20000.	7.75	1.58	1.11	0.527	1.15	0.431
	30000.	7.27	1.45	1.21	0.597	1.23	0.486
	50000.	6.79	1.23	1.32	0.683	1.30	0.553
	100000.	6.18	0.939	1.44	0.790	1.37	0.634
In II 5D–7P	5000.	2.36	– 0.789	* 0.206	– 0.122		
7305.4 A	10000.	1.99	– 0.676	* 0.260	– 0.168	* 0.254	– 0.134
C = 0.48E+19	20000.	1.77	– 0.554	* 0.310	– 0.214	* 0.295	– 0.174
	30000.	1.69	– 0.494	* 0.343	– 0.245	* 0.315	– 0.197
	50000.	1.60	– 0.435	0.373	– 0.268	* 0.330	– 0.214
	100000.	1.46	– 0.354	0.433	– 0.313	* 0.359	– 0.244
In II 5D–8P	5000.	1.61	– 0.764				
4502.1 A	10000.	1.39	– 0.636				
C = 0.14E+19	20000.	1.25	– 0.519	* 0.268	– 0.173		
	30000.	1.21	– 0.460	* 0.289	– 0.197		
	50000.	1.17	– 0.399	* 0.306	– 0.217		
	100000.	1.09	– 0.318	* 0.347	– 0.245	* 0.300	– 0.193
In II 5D–9P	5000.	* 2.10	– 1.05				
3709.2 A	10000.	1.82	– 0.889				
C = 0.60E+18	20000.	1.68	– 0.776				
	30000.	1.65	– 0.692				
	50000.	1.60	– 0.588				
	100000.	1.50	– 0.460				
In II 6D–8P	5000.	10.7	– 4.86				
10609.0 A	10000.	9.30	– 4.07				
C = 0.78E+19	20000.	8.43	– 3.33	* 1.66	– 1.08		
	30000.	8.13	– 2.92	* 1.75	– 1.21		
	50000.	7.86	– 2.51	* 1.94	– 1.34		
	100000.	7.28	– 2.00	* 2.04	– 1.54	* 1.71	– 1.18
In II 6D–9P	5000.	* 8.31	– 3.99				
7055.2 A	10000.	7.27	– 3.39				
C = 0.22E+19	20000.	6.74	– 2.99				
	30000.	6.61	– 2.66				
	50000.	6.41	– 2.26				
	100000.	5.97	– 1.77				
In II 5D–4F	5000.	2.26	0.313	0.159	0.426E−01	* 0.192	* 0.369E−01
10189.5 A	10000.	1.78	0.223	0.213	0.655E−01	* 0.229	* 0.555E−01
C = 0.31E+20	20000.	1.48	0.163	0.245	0.857E−01	0.258	– 0.703E−01
	30000.	1.35	0.148	0.263	0.976E−01	0.273	– 0.797E−01
	50000.	1.23	0.122	0.283	0.111	0.284	– 0.903E−01
	100000.	1.10	0.950E−01	0.298	0.129	0.293	– 0.105

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Table I. *Continued*

Perturber Density = 1.E+16 cm^{-3} Perturbers are:		Electrons		Protons		Ionized Helium	
Transition	T(K)	Width (A)	Shift (A)	Width (A)	Shift (A)	Width (A)	Shift (A)
In II 5D–5F	5000.	1.72	0.893 *	0.176 *	0.115		
4975.2 A	10000.	1.49	0.729 *	0.225 *	0.167		
C = 0.13E+19	20000.	1.36	0.587 *	0.272 *	0.219		
	30000.	1.32	0.520 *	0.300 *	0.248		
	50000.	1.27	0.445 *	0.333 *	0.279 *	0.282 *	0.214
	100000.	1.17	0.347 *	0.385 *	0.305 *	0.312 *	0.243
In II 5D–6F	5000. *	2.16 *	1.16				
3890.9 A	10000.	1.88	1.02				
C = 0.51E+18	20000.	1.74	0.839				
	30000.	1.71	0.745				
	50000.	1.67	0.630				
	100000.	1.55	0.489				
In II 5D–7F	5000. *	3.09 *	1.68				
3439.4 A	10000. *	2.77 *	1.49				
C = 0.27E+18	20000. *	2.65 *	1.30				
	30000.	2.61	1.15				
	50000.	2.55	0.974				
	100000.	2.37	0.757				
In II 5D–8F	5000.						
3199.0 A	10000. *	4.17 *	2.20				
C = 0.16E+18	20000. *	4.10 *	1.88				
	30000. *	4.06 *	1.74				
	50000. *	3.94 *	1.47				
	100000.	3.68	1.16				
In II 5D–9F	5000.						
3053.1 A	10000.						
C = 0.11E+18	20000.						
	30000. *	6.17 *	2.51				
	50000. *	5.98 *	2.14				
	100000. *	5.59 *	1.72				
In II 6D–6F	5000. *	8.78 *	4.53				
7742.9 A	10000.	7.82	3.77				
C = 0.20E+19	20000.	7.47	3.09				
	30000.	7.41	2.76				
	50000.	7.26	2.33				
	100000.	6.78	1.81				
In II 6D–7F	5000. *	10.00 *	5.21				
6139.2 A	10000. *	9.09 *	4.60				
C = 0.86E+18	20000. *	8.77 *	4.00				
	30000.	8.70	3.53				
	50000.	8.50	3.00				
	100000.	7.95	2.33				
In II 6D–8F	5000.						
5413.2 A	10000. *	12.1 *	6.18				
C = 0.47E+18	20000. *	12.0 *	5.28				
	30000. *	11.9 *	4.89				
	50000. *	11.6 *	4.13				
	100000.	10.8	3.27				
In II 6D–9F	5000.						
5008.2 A	10000.						
C = 0.29E+18	20000.						
	30000. *	16.8 *	6.68				
	50000. *	16.3 *	5.68				
	100000. *	15.3 *	4.58				
In II 4F–7D	5000.	4.10	0.131 *	0.450 *	0.158		
8545.9 A	10000.	3.70	0.210 *	0.536 *	0.219		
C = 0.51E+19	20000.	3.61	0.138 *	0.615 *	0.280		
	30000.	3.58	0.131 *	0.646 *	0.317 *	0.631 *	0.257
	50000.	3.52	0.137 *	0.685 *	0.356 *	0.643 *	0.283
	100000.	3.34	0.798E−01 *	0.751 *	0.415 *	0.679 *	0.319

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Table I. *Continued*

Perturber Density = 1.E+16 cm^{-3} Perturbers are:		Electrons		Protons		Ionized Helium	
Transition	T(K)	Width (A)	Shift (A)	Width (A)	Shift (A)	Width (A)	Shift (A)
In II 4F–8D	5000.	3.46	0.128				
5984.6 A	10000.	3.38	0.620E−01				
C = 0.16E+19	20000.	3.43	0.570E−01				
	30000.	3.48	0.827E−01	* 0.645	* 0.324		
	50000.	3.52	0.725E−01	* 0.677	* 0.362		
	100000.	3.39	0.401E−01	* 0.738	* 0.413		
In II 4F–9D	5000. *	4.24	* 0.111				
5054.3 A	10000. *	4.33	* 0.710E−01				
C = 0.71E+18	20000.	4.57	0.433E−01				
	30000.	4.71	0.680E−01				
	50000.	4.80	0.318E−01				
	100000.	4.65	0.322E−01				
In II 5F–6D	5000.	14.1	− 5.65	* 1.30	− 0.791		
13673.0 A	10000.	12.8	− 4.57	* 1.63	− 1.13		
C = 0.99E+19	20000.	12.3	− 3.71	* 1.98	− 1.48		
	30000.	12.1	− 3.31	* 2.19	− 1.67		
	50000.	11.7	− 2.83	* 2.38	− 1.86	* 2.08	− 1.51
	100000.	10.9	− 2.24	* 2.78	− 2.14	* 2.34	− 1.65
In II 6S–6P	5000.	0.735	− 0.259	0.292E−01	− 0.952E−02	0.366E−01	− 0.869E−02
7029.8 A	10000.	0.543	− 0.199	0.432E−01	− 0.157E−01	0.494E−01	− 0.136E−01
C = 0.29E+20	20000.	0.410	− 0.154	0.531E−01	− 0.223E−01	0.565E−01	− 0.181E−01
	30000.	0.354	− 0.135	0.579E−01	− 0.250E−01	0.607E−01	− 0.205E−01
	50000.	0.306	− 0.116	0.638E−01	− 0.287E−01	0.651E−01	− 0.235E−01
	100000.	0.258	− 0.931E−01	0.700E−01	− 0.343E−01	0.693E−01	− 0.275E−01
In II 6S–7P	5000.	0.284	− 0.117	* 0.252E−01	− 0.849E−02	* 0.278E−01	− 0.723E−02
3011.3 A	10000.	0.216	− 0.912E−01	0.312E−01	− 0.128E−01	* 0.329E−01	− 0.102E−01
C = 0.21E+19	20000.	0.181	− 0.754E−01	0.360E−01	− 0.161E−01	* 0.370E−01	− 0.130E−01
	30000.	0.167	− 0.669E−01	0.388E−01	− 0.182E−01	* 0.386E−01	− 0.148E−01
	50000.	0.153	− 0.573E−01	0.409E−01	− 0.205E−01	* 0.401E−01	− 0.163E−01
	100000.	0.138	− 0.472E−01	0.449E−01	− 0.239E−01	0.420E−01	− 0.191E−01
In II 6S–8P	5000.	0.361	− 0.163				
2380.1 A	10000.	0.293	− 0.136	* 0.536E−01	− 0.236E−01		
C = 0.67E+18	20000.	0.257	− 0.119	* 0.605E−01	− 0.304E−01		
	30000.	0.243	− 0.106	* 0.642E−01	− 0.348E−01		
	50000.	0.232	− 0.909E−01	* 0.674E−01	− 0.380E−01	* 0.647E−01	− 0.304E−01
	100000.	0.217	− 0.738E−01	* 0.744E−01	− 0.445E−01	* 0.652E−01	− 0.344E−01
In II 6S–9P	5000. *	0.585	− 0.291				
2134.0 A	10000.	0.502	− 0.252				
C = 0.27E+18	20000.	0.458	− 0.224				
	30000.	0.447	− 0.197				
	50000.	0.437	− 0.172				
	100000.	0.411	− 0.135	* 0.134	− 0.934E−01		
In II 7S–7P	5000.	11.8	− 4.48	* 0.880	− 0.352	* 0.958	− 0.297
17576.0 A	10000.	9.19	− 4.07	1.10	− 0.518	* 1.14	− 0.414
C = 0.72E+20	20000.	7.67	− 3.43	1.28	− 0.657	* 1.29	− 0.531
	30000.	7.09	− 3.09	1.38	− 0.746	* 1.35	− 0.600
	50000.	6.49	− 2.75	1.46	− 0.828	* 1.41	− 0.669
	100000.	5.83	− 2.28	1.60	− 0.958	1.46	− 0.761
In II 7S–8P	5000.	3.25	− 1.54				
6898.6 A	10000.	2.67	− 1.30	* 0.453	− 0.206		
C = 0.56E+19	20000.	2.36	− 1.16	* 0.515	− 0.267		
	30000.	2.24	− 1.04	* 0.543	− 0.302		
	50000.	2.13	− 0.898	* 0.582	− 0.340	* 0.555	− 0.272
	100000.	1.99	− 0.727	* 0.627	− 0.384	* 0.542	− 0.297
In II 7S–9P	5000. *	3.52	− 1.78				
5170.4 A	10000.	3.04	− 1.56				
C = 0.16E+19	20000.	2.78	− 1.39				
	30000.	2.72	− 1.24				
	50000.	2.66	− 1.08				
	100000.	2.50	− 0.849	* 0.782	− 0.550		

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Table I. *Continued*

Perturber Density = 1.E+16 cm^{-3} Perturbers are:		Electrons			Protons			Ionized Helium		
Transition	T(K)	Width (A)	Shift (A)		Width (A)		Shift (A)	Width (A)		Shift (A)
In II 5P–6S	5000.	0.225E−01	0.103E−01		0.139E−03		0.263E−03	0.223E−03		0.252E−03
2027.9 A	10000.	0.156E−01	0.766E−02		0.354E−03		0.487E−03	0.462E−03		0.442E−03
C = 0.58E+19	20000.	0.109E−01	0.596E−02		0.658E−03		0.729E−03	0.730E−03		0.633E−03
	30000.	0.893E−02	0.497E−02		0.888E−03		0.888E−03	0.881E−03		0.734E−03
	50000.	0.746E−02	0.425E−02		0.111E−02		0.102E−02	0.104E−02		0.842E−03
	100000.	0.614E−02	0.345E−02		0.141E−02		0.123E−02	0.127E−02		0.101E−02
In II 5P–7S	5000.	0.238E−01	0.132E−01		0.360E−03		0.696E−03	0.428E−03		0.603E−03
1301.5 A	10000.	0.163E−01	0.107E−01		0.772E−03		0.107E−02	0.760E−03		0.907E−03
C = 0.96E+18	20000.	0.120E−01	0.821E−02		0.129E−02		0.140E−02	0.113E−02		0.115E−02
	30000.	0.110E−01	0.742E−02		0.154E−02		0.160E−02	0.131E−02		0.130E−02
	50000.	0.969E−02	0.634E−02		0.183E−02		0.182E−02	0.156E−02		0.148E−02
	100000.	0.830E−02	0.508E−02		0.231E−02		0.210E−02	0.186E−02		0.171E−02
In II 5P–8S	5000.	0.399E−01	0.195E−01		0.132E−02		0.172E−02	0.130E−02		0.144E−02
1130.4 A	10000.	0.279E−01	0.184E−01		0.238E−02		0.246E−02	0.204E−02		0.200E−02
C = 0.37E+18	20000.	0.233E−01	0.151E−01		0.316E−02		0.314E−02	0.264E−02		0.255E−02
	30000.	0.210E−01	0.141E−01		0.358E−02		0.357E−02	0.301E−02		0.289E−02
	50000.	0.189E−01	0.123E−01		0.423E−02		0.399E−02	0.354E−02		0.322E−02
	100000.	0.170E−01	0.981E−02		0.511E−02		0.460E−02	0.417E−02		0.376E−02
In II 5P–9S	5000.	0.656E−01	0.335E−01	*	0.392E−02	*	0.366E−02	* 0.346E−02	*	0.275E−02
1057.9 A	10000.	0.487E−01	0.323E−01	*	0.554E−02	*	0.506E−02	* 0.459E−02	*	0.399E−02
C = 0.18E+18	20000.	0.422E−01	0.277E−01	*	0.698E−02	*	0.654E−02	* 0.578E−02	*	0.530E−02
	30000.	0.398E−01	0.252E−01	*	0.792E−02	*	0.739E−02	* 0.652E−02	*	0.599E−02
	50000.	0.364E−01	0.226E−01	*	0.918E−02	*	0.829E−02	* 0.748E−02	*	0.662E−02
	100000.	0.340E−01	0.184E−01		0.104E−01		0.936E−02	* 0.785E−02	*	0.733E−02
In II 6P–7S	5000.	1.29	0.466		0.390E−01		0.287E−01	0.457E−01		0.242E−01
7522.4 A	10000.	0.951	0.419		0.601E−01		0.433E−01	0.635E−01		0.365E−01
C = 0.32E+20	20000.	0.723	0.362		0.777E−01		0.564E−01	0.754E−01		0.460E−01
	30000.	0.651	0.313		0.863E−01		0.636E−01	0.829E−01		0.521E−01
	50000.	0.571	0.283		0.974E−01		0.723E−01	0.912E−01		0.587E−01
	100000.	0.484	0.230		0.114		0.842E−01	0.986E−01		0.670E−01
In II 6P–8S	5000.	0.599	0.257		0.215E−01		0.228E−01	* 0.224E−01	*	0.189E−01
4012.3 A	10000.	0.442	0.250		0.347E−01		0.323E−01	* 0.316E−01	*	0.261E−01
C = 0.46E+19	20000.	0.364	0.209		0.450E−01		0.412E−01	0.389E−01		0.334E−01
	30000.	0.337	0.188		0.514E−01		0.472E−01	0.443E−01		0.381E−01
	50000.	0.301	0.174		0.596E−01		0.526E−01	0.492E−01		0.417E−01
	100000.	0.270	0.140		0.691E−01		0.597E−01	0.589E−01		0.481E−01
In II 6P–9S	5000.	0.664	0.317	*	0.383E−01	*	0.344E−01	* 0.338E−01	*	0.259E−01
3227.0 A	10000.	0.501	0.310	*	0.531E−01	*	0.475E−01	* 0.446E−01	*	0.376E−01
C = 0.17E+19	20000.	0.431	0.266	*	0.669E−01	*	0.612E−01	* 0.567E−01	*	0.499E−01
	30000.	0.407	0.245	*	0.750E−01	*	0.695E−01	* 0.632E−01	*	0.562E−01
	50000.	0.375	0.222	*	0.874E−01	*	0.780E−01	* 0.724E−01	*	0.621E−01
	100000.	0.351	0.182		0.101		0.883E−01	* 0.753E−01	*	0.704E−01
In II 7P–8S	5000.	14.8	5.61	*	0.926	*	0.538	* 0.950	*	0.436
16834.0 A	10000.	11.9	5.18	*	1.18	*	0.750	* 1.16	*	0.600
C = 0.66E+20	20000.	10.1	4.92		1.41		0.962	* 1.34	*	0.775
	30000.	9.29	4.50		1.54		1.09	* 1.43	*	0.885
	50000.	8.57	4.00		1.70		1.21	* 1.51	*	0.975
	100000.	7.80	3.40		1.86		1.38	* 1.70	*	1.13
In II 7P–9S	5000.	5.40	2.12	*	0.343	*	0.249			
8329.9 A	10000.	4.38	2.21	*	0.445	*	0.348			
C = 0.11E+20	20000.	3.75	2.08	*	0.554	*	0.450	* 0.468	*	0.356
	30000.	3.53	1.90	*	0.618	*	0.510	* 0.517	*	0.410
	50000.	3.33	1.70	*	0.676	*	0.560	* 0.566	*	0.443
	100000.	3.10	1.43		0.767		0.642	* 0.628	*	0.528
In II 5P–5D	5000.	0.220E−01	0.191E−02		0.833E−03		0.241E−03	0.116E−02		0.229E−03
1735.8 A	10000.	0.158E−01	0.168E−02		0.134E−02		0.441E−03	0.166E−02		0.392E−03
C = 0.18E+19	20000.	0.117E−01	0.141E−02		0.184E−02		0.649E−03	0.198E−02		0.556E−03
	30000.	0.101E−01	0.142E−02		0.200E−02		0.777E−03	0.213E−02		0.632E−03
	50000.	0.853E−02	0.133E−02		0.221E−02	*	0.893E−03	0.231E−02		0.726E−03
	100000.	0.701E−02	0.119E−02		0.248E−02		0.106E−02	0.247E−02		0.867E−03

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Table I. *Continued*

Perturber Density = 1.E+16 cm^{-3} Perturbers are:		Electrons			Protons			Ionized Helium	
Transition	T(K)	Width (A)	Shift (A)		Width (A)	Shift (A)		Width (A)	Shift (A)
In II 5P–6D	5000.	0.408E−01	−0.153E−02		0.267E−02	−0.134E−02	*	0.312E−02	−0.114E−02
1247.1 A	10000.	0.341E−01	−0.231E−02		0.364E−02	−0.203E−02	*	0.377E−02	−0.162E−02
C = 0.18E+18	20000.	0.308E−01	−0.168E−02		0.431E−02	−0.255E−02	*	0.433E−02	−0.206E−02
	30000.	0.295E−01	−0.180E−02		0.474E−02	−0.288E−02		0.461E−02	−0.235E−02
	50000.	0.281E−01	−0.169E−02		0.521E−02	−0.327E−02		0.494E−02	−0.263E−02
	100000.	0.257E−01	−0.134E−02		0.572E−02	−0.376E−02		0.522E−02	−0.300E−02
In II 5P–7D	5000.	0.589E−01	−0.327E−02	*	0.650E−02	−0.239E−02			
1109.4 A	10000.	0.540E−01	−0.430E−02	*	0.774E−02	−0.334E−02			
C = 0.99E+17	20000.	0.531E−01	−0.366E−02	*	0.892E−02	−0.425E−02	*	0.884E−02	−0.343E−02
	30000.	0.533E−01	−0.344E−02	*	0.946E−02	−0.483E−02	*	0.917E−02	−0.388E−02
	50000.	0.533E−01	−0.344E−02	*	0.100E−01	−0.532E−02	*	0.963E−02	−0.438E−02
	100000.	0.510E−01	−0.255E−02		0.106E−01	−0.608E−02	*	0.994E−02	−0.498E−02
In II 5P–8D	5000.	0.889E−01	−0.247E−02						
1046.2 A	10000.	0.887E−01	−0.336E−02						
C = 0.64E+17	20000.	0.937E−01	−0.288E−02	*	0.162E−01	−0.207E−02			
	30000.	0.970E−01	−0.279E−02	*	0.166E−01	−0.235E−02			
	50000.	0.994E−01	−0.268E−02	*	0.170E−01	−0.268E−02			
	100000.	0.972E−01	−0.231E−02	*	0.174E−01	−0.302E−02	*	0.173E−01	−0.242E−02
In II 5P–9D	5000.	0.613E−01	−0.173E−01						
1013.2 A	10000.	0.464E−01	−0.149E−01						
C = 0.38E+17	20000.	0.378E−01	−0.122E−01						
	30000.	0.348E−01	−0.118E−01						
	50000.	0.320E−01	−0.105E−01						
	100000.	0.296E−01	−0.826E−02						
In II 6P–6D	5000.	1.18	0.621E−01		0.727E−01	−0.286E−01	*	0.838E−01	−0.243E−01
6007.5 A	10000.	0.971	0.262E−01		0.944E−01	−0.433E−01	*	0.992E−01	−0.347E−01
C = 0.41E+19	20000.	0.859	0.194E−01		0.110	−0.544E−01	*	0.113	−0.444E−01
	30000.	0.814	0.143E−01		0.120	−0.616E−01	*	0.120	−0.500E−01
	50000.	0.766	0.840E−02		0.130	−0.703E−01		0.126	−0.562E−02
	100000.	0.696	0.603E−02		0.140	−0.801E−01		0.131	−0.650E−01
In II 6P–7D	5000.	0.750	−0.802E−02	*	0.773E−01	−0.266E−01			
3758.7 A	10000.	0.678	−0.227E−01	*	0.919E−01	−0.371E−01			
C = 0.11E+19	20000.	0.658	−0.202E−01	*	0.105	−0.476E−01	*	0.105	−0.383E−01
	30000.	0.657	−0.196E−01	*	0.111	−0.538E−01	*	0.108	−0.439E−01
	50000.	0.651	−0.222E−01	*	0.117	−0.600E−01		0.114	−0.480E−01
	100000.	0.621	−0.150E−01		0.124	−0.685E−01	*	0.118	−0.562E−01
In II 6P–8D	5000.	0.833	−0.172E−01						
3120.2 A	10000.	0.824	−0.189E−01						
C = 0.57E+18	20000.	0.863	−0.159E−01						
	30000.	0.890	−0.152E−01	*	0.150	−0.196E−01			
	50000.	0.910	−0.145E−01	*	0.153	−0.220E−01			
	100000.	0.887	−0.123E−01	*	0.157	−0.257E−01	*	0.155	−0.206E−01
In II 6P–9D	5000.	0.518	−0.144						
2844.1 A	10000.	0.394	−0.118						
C = 0.30E+18	20000.	0.323	−0.940E−01						
	30000.	0.297	−0.892E−01						
	50000.	0.273	−0.774E−01						
	100000.	0.252	−0.584E−01						
In II 7P–7D	5000.	11.2	0.919	*	1.09	−0.241			
13120.9 A	10000.	9.96	0.641	*	1.29	−0.342			
C = 0.14E+20	20000.	9.63	0.639	*	1.45	−0.437			
	30000.	9.58	0.571	*	1.50	−0.500	*	1.52	−0.403
	50000.	9.46	0.434	*	1.56	−0.558	*	1.55	−0.442
	100000.	9.01	0.391		1.67	−0.633	*	1.57	−0.513
In II 7P–8D	5000.	5.47	0.369						
7653.3 A	10000.	5.38	0.238						
C = 0.34E+19	20000.	5.64	0.202						
	30000.	5.81	0.179	*	0.951	−0.303E−01			
	50000.	5.94	0.145	*	0.970	−0.346E−01			
	100000.	5.79	0.118	*	1.01	−0.412E−01			

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Table I. *Continued*

Perturber Density = 1.E+16 cm^{-3} Perturbers are:		Electrons		Protons		Ionized Helium	
Transition	T(K)	Width (A)	Shift (A)	Width (A)	Shift (A)	Width (A)	Shift (A)
In II 7P–9D	5000.	2.72	−0.500				
6181.7 A	10000.	2.13	−0.348				
C = 0.14E+19	20000.	1.80	−0.272				
	30000.	1.69	−0.254				
	50000.	1.58	−0.195				
	100000.	1.48	−0.151				
In II 8P–9D	5000.	16.2	0.494				
13567.2 A	10000.	13.5	0.858				
C = 0.69E+19	20000.	12.1	0.898				
	30000.	11.6	0.853				
	50000.	11.2	0.851				
	100000.	10.6	0.761				
In II 5D–6P	5000.	4.35	−1.17	0.222	−0.586E−01	0.275	−0.535E−01
16865.4 A	10000.	3.22	−0.911	0.318	−0.959E−01	0.353	−0.832E−01
C = 0.17E+21	20000.	2.46	−0.690	0.379	−0.136	0.403	−0.110
	30000.	2.17	−0.617	0.410	−0.152	0.431	−0.125
	50000.	1.87	−0.530	0.447	−0.175	0.458	−0.142
	100000.	1.58	−0.424	0.482	−0.207	0.476	−0.167
In II 5D–7P	5000.	0.522	−0.204	* 0.471E−01	−0.152E−01	* 0.515E−01	−0.130E−01
4014.0 A	10000.	0.398	−0.156	0.579E−01	−0.229E−01	* 0.611E−01	−0.182E−01
C = 0.38E+19	20000.	0.331	−0.127	0.666E−01	−0.287E−01	* 0.687E−01	−0.233E−01
	30000.	0.305	−0.113	0.714E−01	−0.326E−01	* 0.715E−01	−0.265E−01
	50000.	0.279	−0.963E−01	0.754E−01	−0.367E−01	* 0.745E−01	−0.291E−01
	100000.	0.251	−0.782E−01	0.822E−01	−0.427E−01	0.773E−01	−0.343E−01
In II 5D–8P	5000.	0.568	−0.255				
2965.7 A	10000.	0.461	−0.213	* 0.843E−01	−0.366E−01		
C = 0.10E+19	20000.	0.405	−0.183	* 0.950E−01	−0.472E−01		
	30000.	0.382	−0.164	* 0.101	−0.541E−01		
	50000.	0.364	−0.139	* 0.106	−0.592E−01	* 0.102	−0.473E−01
	100000.	0.339	−0.112	* 0.117	−0.691E−01	* 0.102	−0.535E−01
In II 5D–9P	5000. *	0.869	−0.431				
2593.1 A	10000.	0.746	−0.373				
C = 0.39E+18	20000.	0.681	−0.331				
	30000.	0.663	−0.291				
	50000.	0.648	−0.252				
	100000.	0.609	−0.198	* 0.199	−0.138		
In II 6D–8P	5000.	6.08	−2.09				
8974.0 A	10000.	5.14	−1.82	* 0.792	−0.291		
C = 0.92E+19	20000.	4.69	−1.50	* 0.884	−0.375		
	30000.	4.54	−1.34	* 0.933	−0.430		
	50000.	4.38	−1.14	* 0.967	−0.475	* 0.933	−0.378
	100000.	4.11	−0.917	* 1.01	−0.535	* 0.988	−0.430
In II 6D–9P	5000. *	5.43	−2.41				
6254.5 A	10000.	4.75	−2.09				
C = 0.23E+19	20000.	4.41	−1.84				
	30000.	4.33	−1.62				
	50000.	4.26	−1.40				
	100000.	4.02	−1.10	* 1.17	−0.783		
In II 5D–5F	5000.	0.692	0.372				
3151.5 A	10000.	0.607	0.310	* 0.964E−01	0.727E−01		
C = 0.57E+18	20000.	0.559	0.249	* 0.121	0.956E−01		
	30000.	0.544	0.217	* 0.130	0.107		
	50000.	0.528	0.189	* 0.149	0.119		
	100000.	0.489	0.147	* 0.158	0.137	* 0.127	0.105
In II 5D–6F	5000. *	1.02	0.560				
2678.2 A	10000.	0.896	0.480				
C = 0.26E+18	20000.	0.822	0.408				
	30000.	0.812	0.361				
	50000.	0.795	0.307				
	100000.	0.742	0.238				

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Table I. *Continued*

Perturber Density = 1.E+16 cm^{-3} Perturbers are:		Electrons		Protons		Ionized Helium	
Transition	T(K)	Width (A)	Shift (A)	Width (A)	Shift (A)	Width (A)	Shift (A)
In II 5D–7F	5000.	* 1.60	* 0.892				
2456.1 A	10000.	* 1.43	* 0.787				
C = 0.15E+18	20000.	* 1.38	* 0.690				
	30000.	1.37	0.614				
	50000.	1.34	0.521				
	100000.	1.25	0.402				
In II 5D–8F	5000.	* 1.02	* 0.562				
2678.2 A	10000.	0.897	0.481				
C = 0.26E+18	20000.	0.822	0.410				
	30000.	0.813	0.363				
	50000.	0.796	0.309				
	100000.	0.743	0.239				
In II 5D–9F	5000.						
2252.3 A	10000.						
C = 0.68E+17	20000.						
	30000.	* 3.37	* 1.42				
	50000.	* 3.27	* 1.21				
	100000.	* 3.07	* 0.974				
In II 6D–6F	5000.	* 7.24	* 3.71				
6773.6 A	10000.	6.40	3.17				
C = 0.17E+19	20000.	5.92	2.72				
	30000.	5.84	2.41				
	50000.	5.71	2.04				
	100000.	5.33	1.59				
In II 6D–7F	5000.	* 8.55	* 4.57				
5512.6 A	10000.	* 7.65	* 4.03				
C = 0.76E+18	20000.	* 7.38	* 3.54				
	30000.	7.33	3.15				
	50000.	7.15	2.67				
	100000.	6.69	2.07				
In II 6D–8F	5000.						
4919.5 A	10000.	* 10.2	* 5.44				
C = 0.43E+18	20000.	* 10.1	* 4.62				
	30000.	* 10.1	* 4.34				
	50000.	* 9.81	* 3.66				
	100000.	9.19	2.89				
In II 6D–9F	5000.						
4582.3 A	10000.						
C = 0.28E+18	20000.						
	30000.	* 14.2	* 5.92				
	50000.	* 13.8	* 5.04				
	100000.	* 13.0	* 4.06				
In II 5D–4F	5000.	0.546	0.394E−01	0.321E−01	0.199E−01	* 0.375E−01	* 0.169E−01
4665.5 A	10000.	0.432	0.447E−01	0.460E−01	0.300E−01	* 0.466E−01	* 0.238E−01
C = 0.25E+19	20000.	0.357	0.437E−01	0.555E−01	0.377E−01	0.544E−01	0.306E−01
	30000.	0.322	0.417E−01	0.612E−01	0.425E−01	0.585E−01	0.345E−01
	50000.	0.283	0.397E−01	0.688E−01	0.481E−01	0.625E−01	0.384E−01
	100000.	0.240	0.350E−01	0.787E−01	0.563E−01	0.707E−01	0.452E−01
In II 4F–7D	5000.	5.01	− 0.609	* 0.478	− 0.199		
9009.2 A	10000.	4.53	− 0.555	* 0.578	− 0.274		
C = 0.65E+19	20000.	4.35	− 0.486	* 0.665	− 0.353		
	30000.	4.30	− 0.438	* 0.701	− 0.398	* 0.670	− 0.317
	50000.	4.22	− 0.417	* 0.751	− 0.444	* 0.707	− 0.353
	100000.	3.97	− 0.333	0.821	− 0.495	* 0.743	− 0.407
In II 4F–8D	5000.	3.49	− 0.362				
6044.3 A	10000.	3.41	− 0.307				
C = 0.21E+19	20000.	3.51	− 0.251				
	30000.	3.59	− 0.219	* 0.572	− 0.123		
	50000.	3.63	− 0.192	* 0.589	− 0.137		
	100000.	3.51	− 0.161	* 0.618	− 0.156	* 0.599	− 0.125

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Table I. *Continued*

Perturber Density = 1.E+16 cm^{-3} Perturbers are:		Electrons		Protons		Ionized Helium	
Transition	T(K)	Width (A)	Shift (A)	Width (A)	Shift (A)	Width (A)	Shift (A)
In II 4F–9D	5000.	1.90	– 0.639				
5087.8 A	10000.	1.47	– 0.525				
$C = 0.97$E+18	20000.	1.22	– 0.429				
	30000.	1.12	– 0.396				
	50000.	1.03	– 0.343				
	100000.	0.934	– 0.269				
In II 5F–6D	5000.	10.3	– 4.88				
10922.3 A	10000.	9.12	– 4.08	* 1.24	– 0.917		
$C = 0.68$E+19	20000.	8.43	– 3.28	* 1.51	– 1.19		
	30000.	8.21	– 2.85	* 1.66	– 1.37		
	50000.	7.99	– 2.48	* 1.86	– 1.48		
	100000.	7.42	– 1.93	* 2.07	– 1.76	* 1.57	– 1.35

ening parameters due to proton- and ionized-helium impacts have been calculated. Our results are shown in Table I (accessible electronically through the journal) for a perturber density of $10^{16}\,cm^{-3}$ and temperatures $T = 5000$–100 000 K. We also specify a parameter C [12,13] which, when it is divided by the corresponding electron-impact full width at half maximum, gives an estimate for the maximum perturber density for which the line may be treated as isolated. For each value given in Table I, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid [2,3]. Values for $0.1 < NV \leq 0.5$ are denoted by an asterisk. When the impact approximation is not valid, the ion-broadening contribution may be estimated by using quasistatic estimations [14,17]. The accuracy of the results obtained decreases when broadening by ion interactions becomes important. Also, the Bates Damgaard approximation [19] used here to obtain oscillator strengths is reasonable for high-n, high-ℓ cases. For the low-n states like for example the In II $5s^2$–5s5p transitions the accuracy is much lower, so "order of magnitude" results are what we expect. At high densities, the results are no longer linear with density due to Debye screening. This effect is more important for the shift than for the width. Stark-broadening parameter tables for high densities will be published elsewhere [22].

Table II. *Comparison of experimental Stark full widths at half maximum (W_{exp}) of N'Dolo and Fabry* [1] *obtained within the electron – density range of* $10^{14}\,cm^{-3}$–$2 \times 10^{15}\,cm^{-3}$ *and normalized to* $10^{17}\,cm^{-3}$ *with theoretical values:* W_{NF} *– calculations of N'Dolo and Fabry* [1] *within Griem's semiempirical theory* [7] *with quasistatic correction for ion broadening* [17]; W_e *– our results for electron - impact broadening;* $W_{Na\,II}$, $W_{In\,II}$ *– our results for Na II – impact and In II – impact broadening performed for the maximal experimental density of* $2 \times 10^{15}\,cm^{-3}$ *and then normalized to* $10^{17}\,cm^{-3}$.

+In II	W_{exp}	W_{NF}	W_e	W_{NaII}	W_{InII}
$5d^3D_1$–$7p^3P^o_1$	6.6	5.08	5.22	0.585	0.617

$\lambda = 4015.0$ Å, $T = 5000$ K.

We may compare our results with experimental results of N'Dolo and Fabry [1] only for In II $5d^3D_1$–$7p^3P^o_1$ $\lambda = 4015.0$ Å line. They presented their data for In II for an electron temperature of 5000 K and an electron density of $10^{17}\,cm^{-3}$, but in the sodium-indium arc plasma measured electron densities have been within the $10^{14}\,cm^{-3}$–$2 \times 10^{15}\,cm^{-3}$ range. Consequently, the impact approximation [2,3] is valid not only for electrons but also for ions. In experiments, the plasma is initiated in the presence of argon, with sodium–indium mixture as the cathode. Since the ionization potential of argon is 15.755 eV, of indium 5.785 eV and of sodium 5.138 eV it is obvious that at experimental temperatures, sodium and indium ions are the main ionic perturbers. For an electron temperature of 5000 K and an electron density of $10^{17}\,cm^{-3}$ N'Dolo and Fabry [1] give the full width at half maximun (FWHM) of 6.6 Å. The result of their calculation within the Griem's semiempirical theory [7] with quasistatic correction for ion broadening [17] included is 5.08 Å. Our result for electron broadening contribution is 5.22 Å, for Na II – impact broadening 0.585 Å and for In II – impact broadening 0.617 Å. We note that our calculation has been performed for the maximal reported [1] experimental density of $2 \times 10^{15}\,cm^{-3}$ in order to check the validity of impact approximation and then scaled to the electron density value of $10^{17}\,cm^{-3}$ tabulated in Ref. [1]. We did this since in Ref. [18] data obtained experimentally at various electron densities within the $10^{14}\,cm^{-3}$–$2 \times 10^{-15}\,cm^{-3}$ range have been normalized and scaled to $10^{17}\,cm^{-3}$. However, the impact approximation [2,3] for ion perturbers may be valid at lower densities ($10^{15}\,cm^{-3}$). A comparison with experiment is also shown in Table II. The difference between Na II – impact and In – II impact widths is such that with any ratio of sodium and indium ions in the total ion density, the total electron + ion width is 5.8 Å. The ratio between experimental and theoretical values is 1.14 which is a good agreement.

With the help of regularities and systematic trends, Lakićević [8] obtained for In II $5s^2{}^1S$–$5p^1P^o$ $\lambda = 1586.$ Å line, for an electron temperature of 20 000 K and an electron density of $10^{17}\,cm^{-3}$ a FWHM = 0.040 Å while our result is 0.034 Å which is a good agreement. However the estimated line shift is in disagreement with our result.

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We hope that the presented results will be useful for analysis of sodium – indium arc plasma, research of trace element spectra in astrophysics and investigation of Stark broadening regularities and systematic trends for analogous transitions in heavier elements.

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References

1. N'Dollo, M. and Fabry, M., J. Physique **48**, 703 (1987).
2. Sahal-Bréchot, S., Astron. Astrophys. **1**, 91 (1969).
3. Sahal-Bréchot, S., Astron. Astrophys. **2**, 322 (1969).
4. Dimitrijević, M. S. and Sahal-Bréchot, S., Zh. Prikl. Spektrosk. **66**, 753 (1999).
5. Dimitrijević, M. S. and Sahal-Bréchot, S., Serb. Astron. J. **158**, 81 (1998).
6. Griem, H. R., Baranger, M., Kolb, A. C. and Oertel, G. K., Phys. Rev. **125**, 177 (1962).
7. Griem, H. R., Phys. Rev. **165**, 258 (1968).
8. Lakićević, I., Astron. Astrophys. **127**, 37 (1983).
9. Dimitrijević, M. S., Zh. Prikl. Spektrosk. **63**, 810 (1996).
10. Sahal-Bréchot, S., Astron. Astrophys. **35**, 321 (1974).
11. Fleurier, C., Sahal-Bréchot, S. and Chapelle, J., J. Quant. Spectrosc. Radiative Transfer **17**, 595 (1977).
12. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiative Transfer **31**, 301 (1984).
13. Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V., Astron. Astrophys. Suppl. Series **89**, 581 (1991).
14. Sahal–Bréchot, S., Astron. Astrophys. **245**, 322 (1991).
15. Dimitrijević, M. S. and Sahal-Bréchot, Physica Scripta **52**, 41 (1995).
16. Dimitrijević, M. S. and Sahal-Bréchot, S., Phys. Rev. A **31**, 316 (1985).
17. Griem, H. R., "Spectral Line Broadening by Plasmas", (Academic Press, New York, 1974).
18. Moore, C., "Atomic Energy Levels III", NSRDS-NBS 35, U.S. Dept. of Commerce, National Bureau of Standards, (U.S. Govt. Printing Office, Washington D.C., 1971).
19. Bates, D. R. and Damgaard, A., Trans. Roy. Soc. London, Ser. A **242**, 101 (1949).
20. Oertel, G. K. and Shomo, L. P., Astrophys. J. Suppl. Series **16**, 175 (1968).
21. Van Regemorter, H., Hoang Binh Dy and Prud'homme, M., J. Phys. B **12**, 1073 (1979).
22. Dimitrijević, M. S. and Sahal-Bréchot, S., Serb. Astron. J. **162**, 57 (2000); **163**, 35 (2000).

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Stark Broadening of the Ar I Spectral Lines 763.51, 738.39 and 696.54 nm

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Abstract

Stark widths of three Ar I spectral lines have been measured in an Ar + He plasma at 13 000 K electron temperature and compared with existing experimental values. The Stark broadening parameters of these three experimentally investigated lines have been calculated within the semiclassical perturbation approach as a function of temperature and compared with the experimental data.

1. Introduction

A number of experimental and theoretical papers (see e.g. [1–19]) have dealt with Stark broadening of Ar I spectral lines, due to their importance for plasma diagnostics. The aim of this contribution is to supply additional experimental and theoretical data on Ar I spectral lines originating from lower multiplets. We have measured Stark FWHM (full-width at half intensity maximum, W) for the 763.51 nm (4s–4p transition) and, 738.39 nm and 696.54 nm (4s–4p′ transition) spectral lines. Moreover, Stark broadening parameters (the width and the shift) for these lines have been calculated within the semiclassical perturbation approach [20–23]. We wish to emphasize here the importance of the Ar I 696.543 nm line for plasma diagnostic purposes since this line is strong and well isolated.

Experimental results were obtained by using the plasma of a linear pulsed discharge superimposed to a glow discharge in an argon–helium mixture following the idea from [24]. The obtained experimental data have been compared with other authors experimental [1–17] and with the present semiclassical perturbation calculations.

2. Experiment

A reliable plasma source has been constructed following the ideas published in Refs [24,25]. The plasma was generated by a pulse discharge of 0.3 μF condenser initially charged up to 10 kV. A continuous glow discharge was simultaneously driven, in order to ensure good plasma reproducibility, between water-cooled copper electrodes, at a current of 50 mA. As a working gas we used a mixture Ar + He (72% + 28%) at a pressure of 260 Pa in a flowing regime. Auxiliary ring shaped electrodes were positioned at the optical axis on 8 cm distance and they were used to drive the pulse discharge (see Fig. 1 in [12] and Fig. 1 in [26]). The plasma source consists of a Pyrex discharge tube of 5 mm inner diameter and an effective plasma length of 8 cm. The spectroscopic observations are made end-on, along the axis of the discharge tube.

Scanning of the spectral line profiles was done by using a step-by-step technique with a photomultiplier (EMI 9659B) and a grating spectrograph system (Zeiss PGS-2, reciprocal linear dispersion 0.73 nm/mm in the first order) [28,29]. The system was calibrated by using an EOA-101 standard lamp located at 40 cm distance from the spectrograph input slit. The instrumental FWHM of 0.008 nm was determined by using narrow spectral lines emitted by a hollow cathode discharge. The recorded profiles of these lines are Gaussian in shape within 9% accuracy within the range of the investigated spectral line wavelengths. The spectrograph exit slit (10 μm) with the calibrated photomultiplier was micrometrically moved along the spectral plane in small wavelength steps (0.0073 nm). The averaged photomultiplier signal (five shots at the same spectral range) was digitized using an oscilloscope, interfaced to a computer. Van der Waals and resonance broadening [19] were estimated to be smaller by more than one order of magnitude in comparison to Stark, Doppler and instrumental broadening.

The measured profiles were fitted to the normalized line shape function known as the j profile (see Eq. (6.4) in [30]). The electric properties of the pulse discharge were measured by a Rogowski coil; the following values were found: discharge current maximum 4.0 kA, discharge period 5 μs, self-inductance 1.7 μH and decrement 1.55. Plasma reproducibility was monitored by Ar II line radiation and by the discharge current (it was found to be within ±6%).

In order to find existence of self-absorption of lines one has to check weather the ratio of their intensities (I) is the same as the ratio of products of spontaneous transition probabilities (A) and statistical weights (g) of their upper level, i.e. : $I_1 : I_2 = A_1 g_1 : A_2 g_2$. In the case of the 4s–4p′ transition these ratios were found to be the same (within ±14% error), during the whole plasma decay period, proving that no significant self-absorption exists [27,29].

Parameters of the pulse plasma were determined by a standard diagnostics method [31]. Electron temperature (T) was found from the ratio of relative intensities of Ar II 500.9 nm and Ar I 696.5 nm spectral lines assuming existence of the LTE. The maximal value of the electron temperature was 14 000 K with ±14% error. Atomic parameters required were taken from [32]. The electron density (N) decay was found by a single wavelength laser interferometry technique using the 632.8 nm He-Ne laser line [33]. The maximal value

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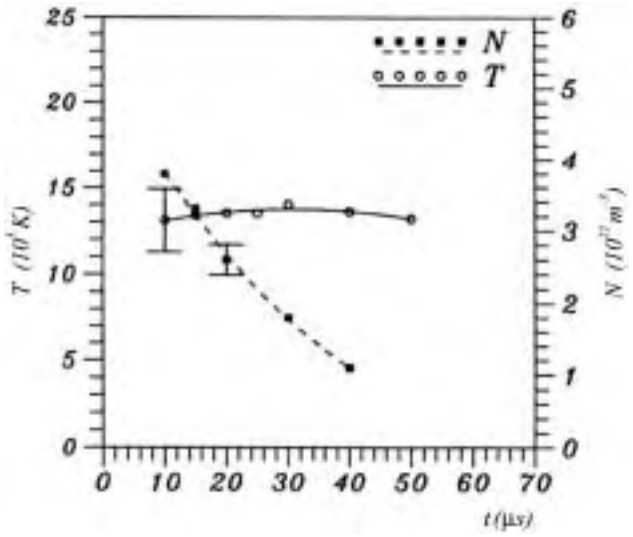

Fig. 1. Temporal evolution of N and T in our decaying plasma.

of the N was $3.8{\cdot}10^{22}$ M^{-3} with $\pm 8\%$ error. Temporal evolution of N and T in the decaying plasma are presented in Fig. 1.

3. Theory

The description of the semiclassical perturbation formalism is given in [20–23,34–36]. Within this formalism, Stark full-width (W) at the intensity half maximum (FWHM) and shift (d) of an isolated spectral line, may be expressed as [20,21]

$$W = N \int v f(v)\, \mathrm{d}v \left(\sum_{i' \neq i} \sigma_{ii'}(v) + \sum_{f' \neq f} \sigma_{ff'}(v) + \sigma_{\mathrm{el}} \right),$$
$$d = N \int v f(v)\, \mathrm{d}v \int_{R_3}^{R_D} 2\pi\rho\, \mathrm{d}\rho \sin 2\phi_p \tag{1}$$

where N is the electron density, $f(v)$ the Maxwellian velocity distribution function for electrons, ρ denotes the impact parameter of the incoming electron, i and f denote the initial and final atomic energy levels, and i', f' their corresponding perturbing levels. The inelastic cross section $\sigma_{j,j'}(v)$ can be expressed by an integral over the impact parameter of the transition probability $P'_{jj}(\rho, v)$ as

$$\sum_{j' \neq j} \sigma_{jj'}(v) = \frac{1}{2}\pi R_1^2 + \int_{R_1}^{R_D} \sum_{j \neq j'} P_{jj'}(\rho, v), \quad j = i, \tag{2}$$

and the elastic cross section is given by

$$\sigma_{\mathrm{el}} = 2\pi R_2^2 + \int_{R_2}^{R_D} 8\pi\rho\, \mathrm{d}\rho \sin^2 \delta,$$
$$\delta = (\phi_p^2 + \phi_q^2)^{1/2}. \tag{3}$$

The phase shifts ϕ_p and ϕ_q due respectively to the polarisation potential (r^{-4}) and to the quadrupolar potential (r^{-3}), are given in Section 3 of Chapter 2 in [20]. R_D is the Debye radius. All the cut-offs R_1, R_2, R_3 are described in Section 1 of Chapter 3 in [21].

For electrons hyperbolic paths due to the attractive Coulomb force were used, while for perturbing ions the paths are different since the force is repulsive. The formulae for the ion-impact widths and shifts are analogous to Eqs (1–3). The difference in calculation of the corresponding transition probabilities and phase shifts as functions of the impact parameter in Eqs (2) and (3) is in the ion perturber trajectories which are influenced by the repulsive Coulomb force instead of an attractive one as for electrons.

The Stark broadening data for neutral helium obtained within the semiclassical perturbation approach [20–23] have been compared with critically selected experimental data for 13 He I multiplets [34] and it was found that the agreement between experimental data and semiclassical calculations is within the limits of 20 percents, what is the predicted accuracy of the semiclassical method [19].

4. Results and discussion

Within the semiclassical-perturbation formalism, we have calculated electron-, proton-, and ionized argon-impact line widths and shifts for 763.51, 738.39 and 696.54 nm neutral argon lines. Energy levels have been taken from [37]. Oscillator strengths have been taken from [32,38,39]. The missing oscillator strengths have been derived from oscillator strengths of the other members of the same multiplet.

The obtained results for Stark widths (FWHM) and shifts are shown in Table I, for perturber densities $10^{21} - 10^{24}\,\mathrm{m}^{-3}$ and temperatures $T = 2\,500 - 50\,000$ K. For perturber densities lower than tabulated, Stark broadening parameters may be scaled linearly. For each value given in Table I, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid [19,20]. When the impact approximation is not valid, the ion broadening contribution may be estimated by using quasi-static approach [19] or [40]. In the region between where neither of these two approximations is valid, a unified type theory should be used. For example in [30], simple analytical formulas for such a case are given. The accuracy of the results obtained decreases when broadening by ion interactions becomes important. As may be seen from Table I, with the increase of the perturber density, the results start to deviate from linear behaviour due to Debye screening. This effect is more important for the shift than for the width.

The results of measured full-widths at half maximum (FWHM) W_m (in 10^{-1} nm) are shown in Table II. The Stark width data were determined with error of $\pm 15\%$.

The available experimental data of the other authors are given also, in the same table.

One can conclude:

In the case of the most investigated 696.54 nm spectral lines our data are in excellent agreement with results of Jones *et al.* [8], and agree well (within 16%) with values of Evans and Tankin [2], Popenoe and Shumaker [1], Vitel and Skowronek [10] and Kusz and Mazure [14].

In the case of the 763.51 nm and 738.39 nm spectral lines, our width values are smaller than those of the other authors and lies about 25% below our calculated (electron + argon ion) values. Similar behavior show the recent experimental data [16] for both of the mentioned Ar I lines.

Valognes *et al.* [17] have calculated the Ar I 696.54 nm profile in a high electron density plasma taking into account

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Table I. *This table shows electron-, proton-, and ionized argon-impact broadening parameters for Ar I lines, respectively, for perturber densities 10^{21}–10^{24} m^{-3} and temperatures from 2 500 up to 50 000 K. The width (FWHM) and shift values are given in 10^{-1} nm units. Transitions and wavelengths are also given in the table. By dividing C by the corresponding full width at half maximum [23], we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the value of collision volume multiplied by the perturber density (the condition for validity of the impact approximation) lies between 0.1 to 0.5. Data with this value larger than 0.5 are not tabulated.*

Perturbers are:		Electrons		Protons		Ionized argon	
Transition	T (K)	Width	Shift	Width	Shift	Width	Shift
Perturber density = 1.E + 21 m^{-3}							
4s[3/2]2–	2500.	0.556E−02	0.7250E−02	0.301E−02	0.677E−03	0.299E−02	0.405E−03
4p[3/2]2	5000.	0.592E−02	0.266E−02	0.303E−02	0.765E−03	0.299E−02	0.460E−03
763.51 nm	10 000.	0.704E−02	0.228E−02	0.304E−02	0.862E−03	0.300E−02	0.521E−0
C = 0.33E + 19	20 000.	0.929E−02	0.130E−02	0.306E−02	0.970E−03	0.300E−02	0.587E−03
	30 000.	0.112E−01	0.830E−03	0.308E−02	0.104E−02	0.301E−02	0.629E−03
	50 000.	0.138E−01	0.463E−03	0.310E−02	0.113E−02	0.301E−02	0.686E−03
4s[3/2]1–	2500.	0.560E−02	0.281E−02	0.273E−02	0.745E−03	0.269E−02	0.446E−03
4p′[3/2]2	5000.	0.600E−02	0.311E−02	0.275E−02	0.844E−03	0.270E−02	0.507E−03
738.40 nm	10 000.	0.686E−02	0.305E−02	0.277E−02	0.950E−03	0.270E−02	0.574E−03
C = 0.25E + 19	20 000.	0.864E−02	0.212E−02	0.280E−02	0.107E−02	0.271E−02	0.647E−03
	30 000.	0.102E−01	0.164E−02	0.283E−02	0.115E−02	0.272E−02	0.693E−03
	50 000.	0.124E−01	0.131E−02	0.286E−02	0.125E−02	0.273E−02	0.756E−03
4s[3/2]2–	2500.	0.473E−02	0.233E−02	0.247E−02	0.628E−03	0.244E−02	0.376E−03
4p′[1/2]1	5000.	0.512E−02	0.248E−02	0.249E−02	0.711E−03	0.245E−02	0.427E−03
696.54 nm	10 000.	0.611E−02	0.221E−02	0.250E−02	0.800E−03	0.246E−02	0.484E−03
C = 0.20E + 19	20 000.	0.801E−02	0.130E−02	0.253E−02	0.901E−03	0.246E−02	0.545E−03
	30 000.	0.967E−02	0.851E−03	0.255E−02	0.965E−03	0.247E−02	0.584E−03
	50 000.	0.119E−01	0.499E−03	0.257E−02	0.105E−02	0.247E−02	0.637E−03
Perturber density = 1.E + 22 m^{-3}							
4s[3/2]2–	2500.	0.556E−01	0.247E−01	0.300E−01	0.649E−02	*0.291E−01	*0.378E−02
4p[3/2]2	5000.	0.592E−01	0.264E−01	0.302E−01	0.745E−02	0.297E−01	0.441E−02
763.51 nm	10 000.	0.704E−01	0.227E−01	0.304E−01	0.848E−02	0.299E−01	0.507E−02
C = 0.33E + 20	20 000.	0.929E−01	0.130E−01	0.306E−01	0.962E−02	0.300E−01	0.577E−02
	30 000.	0.112	0.828E−02	0.308E−01	0.103E−01	0.301E−01	0.621E−02
	50 000.	0.138	0.463E−02	0.310E−01	0.113E−01	0.301E−01	0.681E−02
4s[3/2]1–	2500.	0.560E−01	0.277E−01	0.271E−01	0.712E−02	*0.263E−01	*0.413E−02
4p′[3/2]2	5000.	0.600E−01	0.309E−01	0.274E−01	0.819E−02	0.267E−01	0.484E−02
738.40 nm	10 000.	0.686E−01	0.304E−01	0.277E−01	0.934E−02	0.270E−01	0.557E−02
C = 0.25E + 20	20 000.	0.864E−01	0.212E−01	0.280E−01	0.106E−01	0.271E−01	0.635E−02
	30 000.	0.102	0.164E−01	0.283E−01	0.114E−01	0.272E−01	0.684E−02
	50 000.	0.124	0.131E−01	0.286E−01	0.124E−01	0.273E−01	0.750E−02
4s[3/2]2–	2500.	0.473E−01	0.230E−01	0.246E−01	0.601E−02	*0.238E−01	*0.349E−02
4p′[1/2]1	5000.	0.512E−01	0.246E−01	0.248E−01	0.691E−02	0.243E−01	0.408E−02
696.54 nm	10 000.	0.611E−01	0.220E−01	0.250E−01	0.787E−02	0.245E−01	0.470E−02
C = 0.20E + 20	20 000.	0.801E−01	0.130E−01	0.253E−01	0.892E−02	0.246E−01	0.535E−02
	30 000.	0.967E−01	0.849E−02	0.255E−01	0.959E−02	0.246E−01	0.576E−02
	50 000.	0.119	0.499E−02	0.257E−01	0.105E−01	0.247E−01	0.632E−02
Perturber density = 1.E + 23 m^{-3}							
4s[3/2]2–	2500.	0.555	0.239	*0.284	*0.564E−01		
4p[3/2]2	5000.	0.592	0.261	0.296	0.685E−01		
763.51 nm	10 000.	0.704	0.222	0.302	0.806E−01	*0.290	*0.464E−01
C = 0.33E + 21	20 000.	0.929	0.127	0.305	0.930E−01	*0.297	*0.547E−01
	30 000.	1.12	0.809E−01	0.307	0.101	*0.299	*0.596E−01
	50 000.	1.38	0.454E−01	0.310	0.111	*0.301	*0.661E−01
4s[3/2]1–	2500.	0.559	0.267	*0.257	*0.610E−01		
4p′[3/2]2	5000.	0.599	0.301	0.269	0.747E−01		
738.40 nm	10 000.	0.686	0.299	0.275	0.882E−01	*0.262	*0.506E−01
C = 0.25E + 21	20 000.	0.864	0.209	0.280	0.102	*0.268	*0.599E−01
	30 000.	1.02	0.162	0.282	0.111	*0.270	*0.654E−01
	50 000.	1.24	0.130	0.286	0.122	*0.272	*0.726E−01
4s[3/2]2–	2500.	0.473	0.222	*0.233	*0.517E−01		
4p′[1/2]1	5000.	0.512	0.244	0.244	0.632E−01		
696.54 nm	10 000.	0.611	0.215	0.249	0.745E−01	*0.238	*0.428E−01
C = 0.20E + 21	20 000.	0.801	0.127	0.252	0.862E−01	*0.243	*0.505E−01
	30 000.	0.967	0.830E−01	0.254	0.933E−01	*0.245	*0.552E−01
	50 000.	1.19	0.489E−01	0.257	0.103	*0.247	*0.612E−01

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Table I. *continued.*

Perturbers are:		Electrons		Protons		Ionized argon	
Transition	T (K)	Width	Shift	Width	Shift	Width	Shift
Perturber density = 1.E + 24 m^{-3}							
4s[3/2]2–	2500.	5.51	2.12				
4p[3/2]2	5000.	5.91	2.39				
763.51 nm	10 000.	7.04	2.09	*2.82	*0.671		
C = 0.33E + 22	20 000.	9.29	1.17	*2.98	*0.835		
	30 000.	11.2	0.743	*3.03	*0.928		
	50 000.	13.8	0.422	*3.08	*1.05		
4s[3/2]1–	2500.	5.56	2.35				
4p′[3/2]2	5000.	5.98	2.79				
738.40 nm	10 000.	6.85	2.89	2.58	0.721		
C = 0.25E + 22	20 000.	8.63	1.97	2.73	0.907		
	30 000.	10.2	1.54	2.79	1.01		
	50 000.	12.4	1.26	2.85	1.15		
4s[3/2]2–	2500.	4.70	1.95				
4p′[1/2]1	5000.	5.11	2.21				
696.54 nm	10 000.	6.11	2.03	2.32	0.612		
C = 0.20E + 22	20 000.	8.01	1.18	2.46	0.768		
	30 000.	9.67	0.765	2.51	0.856		
	50 000.	11.9	0.458	2.56	0.968		

the contribution of the interacting levels of like and unlike parentage. They used a quasistatic treatment [41,42] with a ion dynamic correction [30] when needed. They introduced in the formalism a weighting parameter α and found that experimental widths and shifts match with theoretical results for an α parameter lying between 0.5 and 0.6. Our experimental and theoretical results are in agreement with these authors.

Table II. *Measured total Stark FWHM (W_w electron + ion) in 10^{-1} nm taken from noted data sources at given N (in 10^{22} m^{-3}) and T (in 10^4 K). *denote averaged value into 13 500 K and 26 500 K electron temperatures in* [15].

Transit.	λ (nm)	T	N	W_m	Ref.
4s–4p	763.51	1.3	3.8	0.28	This work
		1.38	14.5	1.46	3,4
		1.0	2.0	0.40	5
		1.03	2.0	0.20	6
		1.0	1.0	0.074	16
		1.11	0.4	0.038	14
4s–4p′	738.39	1.3	3.3	0.25	This work
		1.03	2.0	0.18	6
		1.0	1.0	0.070	16
		2.0*	10.0	1.03	15
	696.54	1.3	3.8	0.33	This work
		0.97	1.2	0.11	1
		1.38	14.5	0.80	3,4
		1.00	4.8	0.40	2
		0.97	1.2	0.08	7
		1.30	10.0	0.81	8
		1.65	60.0	4.40	10
		1.11	0.4	0.03	14
		1.35	12.1	1.18	13
		1.19	6.1	0.43*	11
		2.0*	10.0	0.97	15
		1.40	20.0	1.40	17
		1.275	10.0	0.80	9

Generally, our calculated Stark width values (electron + argon ion) agree well (within ±25%) with existing experimental data except W in [5] of the 763.51 nm line which lie above our calculated value up to the factor 2.

It should be pointed out that our calculated Stark shift values (electron + argon ion) agree well (within ±12%) with experimental shift data [12] in the case of the 696.54 nm and 738.39 nm Ar I lines.

5. Conclusion

The found agreement among existing W and d data and their calculated values allow us to recommend the strong 696.54 nm and 738.39 nm Ar I spectral lines as lines with convenient Stark broadening parameters needed in plasma spectroscopy.

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References

1. Popenoe, C. M. and Shumaker, J. B., J. Res. Nat. Bur. Stand. A **69**, 495 (1965).
2. Evans. D. and Tankin, R. S., Phys. Fluids **10**, 1137 (1967).
3. Chapelle, J., Sy A. A., Cabannes, F. and Blandin, C. R. Acad. Sci. B, Paris 264, 853 (1967).
4. Chapelle, J., Sy A. A., Cabannes, F. and Blandin, J. Quant. Spectrosc. Radiative Transfer **8**, 1201 (1968).
5. Bober, L. and Tankin, R. S., J. Quant. Spectrosc. Radiative Transfer **9**, 855 (1969).
6. Tonejc, A. M., J. Quant. Spectrosc. Radiative Transfer **12**, 1713 (1972).
7. Tonejc, A. M., Acinger, K. and Vujnović, V., J. Quant. Spectrosc. Radiative Transfer **12**, 1305 (1972).

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8. Jones, D. W., Musiol, K. and Wiese, W. L., In: "Spectral Line Shapes" Vol. 2, (ed. K. Burnett), (Walter de Gruyter PC, Berlin 1983), p. 125.
9. Iglesias, E., Guimerans, Y., Castell, R., Mandelbaum, D. and Sanchez, A., Acta Cient. Venezoelana **34**, 84 (1983).
10. Vitel, Y. and Skowronek, M., J. Phys. B 20, 6477 (1987).
11. Bakshi, V. and Kearney, R. J., J. Quant, Spectrosc. Radiative Transfer **42**, 405 (1989).
12. Djeniže, S., Skuljan, Lj. and Konjević, R., J. Quant. Spectrosc. Radiative Transfer **54**, 581 (1995).
13. Pellerin, S., Musiol, K., Pokrzywka, B. and Chapelle, J., J. Phys. B **29**, 3911 (1996).
14. Kusz, J. and Mazure, D., In: "Spectral Line Shapes", Vol. 9, (ed. M. Zoppi) (L. Ulivi, Firenze, Italy, 1996). p. 323.
15. Aparicio, J. A. *et al.*, J. Phys. B **31**, 4909 (1998).
16. Schinköth, D., Koch, M. and Schulz-Gulde, E., J. Quant. Spectrosc. Radiative Transfer **64**, 635 (2000).
17. Valognes, J. C., Bardett, J. P. and Vitel, Y., J. Phys. B **26**, 4751 (1993).
18. Griem, H. R., "Plasma Spectroscopy", (McGraw-Hill, New York 1964).
19. Griem, H. R., "Spectral Line Broadening by Plasmas", (Academic Press, New York 1974).
20. Sahal-Bréchot, S., Astron. Astrophys. **1**, 91 (1969).
21. Sahal-Bréchot, S., Astron. Astrophys. **2**, 322 (1969).
22. Sahal-Bréchot, S., Astron. Astrophys. **35**, 321 (1974).
23. Dimitrijević, M. S. and Sahal-Bréchot, S., J. Quant. Spectrosc. Radiative Transfer **31**, 301 (1984).
24. Djeniže, S. and Labat, J., Proc. XVI ICPIG, Vol. 4, Düsseldorf, (1983), p. 488.
25. Skuljan, Lj., M.Sc Thesis, Faculty of Physics (unpublished), Belgrade (1993).
26. Djeniže, S., Skuljan, Lj., Labat, J., Bukvić, S. and Konjević, R., Astron. Astrophys. Suppl. Series **105**, 115 (1994).
27. Djeniže, S. and Bukvić S., Astron. Astrophys. **365** 252 (2001).
28. Djeniže, S., Srećković, A., Labat, J. and Platiša M., Physica Scripta **45**, 320 (1992).
29. Srećković A., Drinčić, V., Bukvić, S. and Djeniže, S., Physica Scripta **63**, 306 (2001).
30. Barnard, A. J., Cooper, J. and Smith, E. W., J. Quant. Spectrosc. Radiative Transfer **14**, 1025 (1974).
31. Rompe, R. and Steenbeck, M., "Ergebnisse der Plasmaphysik und der Gaselektronik", Band 1, (Akademie Verlag, Berlin, 1967).
32. Wiese, W. L., Smith, M. W. and Miles, B. M., "Atomic Transition Probabilities" Vol. II, NSRDS-NBS, (U.S. Govt. Printing Office, Washington D. C. 1969).
33. Ashby, D. E. T. F., Jephcoth, D. F., Malein, A. and Reynor, F. A., Appl. Phys. B, **36**, 29 (1965).
34. Dimitrijević, M. S. and Sahal-Bréchot, S., Phys. Rev. A **31**, 316 (1985).
35. Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V., Astron. Astrophys. Suppl. Series **89**, 581 (1991).
36. Fleurier, C., Sahal-Bréchot, S. and Chapelle, J., J. Quant. Spectrosc. Radiative Transfer **17**, 595 (1977).
37. Bashkin, S. and Stoner, Jr. J. J., "Atomic Energy Levels and Grotrian Diagrams", Vol. 2, (North Holland, Amsterdam 1978).
38. Kurucz, R. L. and Peytremann, E., SAO Special Report, 362 (1975).
39. Lilly, R. A., J. Opt. Soc. Am. **66**, 245 (1976).
40. Sahal-Bréchot, S., Astron. Astrophys. **245**, 322 (1991).
41. Bardet, J. P. and Valognes, J. C., J. Physique **44**, 797 (1983).
42. Bardet, J P. and Valognes, J. C., J. Physique **47**, 1203 (1986).

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НЕБЕСКИ ЗНАЦИ И КОСМИЧКА ТРАГАЊА У ПОЕЗИЈИ ДРАГАНА ДРАГОЈЛОВИЋА

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Резиме: Размотрено је и анализирано песничко дело Драгана Драгојловића *На астралним капијама.*

Драган Драгојловић[1] је истакнута фигура српске књижевности, познати песник и романописац чија су лирска остварења превођена на више од двадесет језика[2] а његов роман, *Под Јужним крстом*, нарочито омиљен у дијаспори којом се бави, у кратком року је доживео четири издања.[3]

Посебну пажњу астрономске јавности заслужује његово рефлексивно-поетско остварење *На астралним капијама*,[4] добрим делом састављено од песама у прози,[5] у коме на самосвојан и препознатљиви начин износи лирско-медитативна запажања о тајанственим и мистичним повезаностима космичког и земаљског са егзистенцијалним и судбинским.

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[1]Рођен је у Пилици код Бајине Баште 11. отобра 1941. У Београду је завршио Економски факултет и магистрирао на њему. Објавио је више од двадесет књига поезије, а осим романа *Под Јужним крстом*, сазвежђем које карактерише звездано небо Аустралије, познати су му и *Докторова љубав* (треће издање, Sezam book, Зрењанин, 2009) и *Не заборави свој дом* («Чигоја», Београд, 2009). Био је Министар вера у владама Радомана Божовића, Николе Шаиновића и Мирка Марјановићаа и амбасадор у Аустралији, а сада је директор Задужбине «Иво Андрић».

[2]У Аустралији, Немачкој, Италији, Македонији, Румунији, Грчкој, Кини, САД...

[3]Драган Драгојловић, *Под Јужним крстом*, Просвета, Београд, 2002; Нолит, Београд, 2003; Богдановић, Београд; 2006, Sezam book, Зрењанин, 2008.

[4]Драган Драгојловић, *На астралним капијама*, Просвета, Београд, 1998.

[5]Као посебан жанр, песме у прози се први пут јављају у *Гаспару ноћи* (*Gaspard de la nuit*) А. Бертранда, 1842. године. Бодлер је под утицајем овог дела написао 1862. године *Мале песме у прози*. Код нас су их писали Дучић и Андрић. То је омиљена форма дадаиста и експресиониста (Кафка, Брехт, Хандке...). *Речник књижевних термина* (друго допуњено издање), Драгиша Живковић, уредник, Нолит, Београд, 1992, стр. 590-591.



Слика 1: *Драган Драгојловић.*

У првом циклусу насловљеном «Пут ка сазнању», Драгојловић започиње продубљено трагање за Тајном, често износећи своју песничку запитаност над чаровитом и многоструко испреплетаном повезаношћу космичких и људских димензија. Велика Тајна којом се Драгојловић бави, да парафразирамо Гетеа, још увек није у домену чуда. У стилу пословичног казивања или филозофског става он подвлачи: «Мудрост је главни ослонац сумње» и додаје «...која трага за Тајном», саопштавајући своје картезијанско опредељење да сумњом и сталним проверавањем можемо доћи до великих резултата, преточено у девизу италијанских физичара: «Проверавати и опет проверавати оно што је већ било проверено» (Provando e riprovando). Картезијански приступ трагању за Тајном, Драгојловић кроз књигу сучељава и упоређује са тајновито-мистичним, платонским и религијским, завршавајући песму у прози *Сумња светог Августина*, филозофско-поетичким исказом: „Ко сумња, тај се искрено моли.“

Вредно је помена да оно што је у почетном приступу назначио, у завршном циклусу, „Старо правило“, сучељавање западњачке филозофије Рене Декарта и Аристотела, и тајновито-мистичног и у основи платонистичког православног истока, своје лирско-интимистичко трагање за спознајом Тајне завршава „старим правилом“: „Непотребно ти је знање које те оставља без Тајне.“ Трагање за великим тајнама је у човековој стваралачкој природи, то је чак неки вид његовог бивствовања, креативна делатност којом се тежи разазнавање тајне и откривање истине. Несустало трагање за Тајном

у непосредној је вези са стваралачком скепсом, која је видан знак мудрости. За многе, сумња је доста често повезана са сазнавањем истине путем патње. Драгојловић апострофира сумњу у смислу што наглашавајући одговор, у суштини продубљује она круцијална, судбинска питања. Сазнање, мудрост, скепса, за њега је снажан душевни доживљај, који је силовито ношен унутрашњом интенцијом у тежњи да се открије и разазна нешто ново, што је у знатној мери независно од субјективне проживљености.

У наредном циклусу, чији наслов „На астралним капијама“ носи цела књига, песник жели да поведе читаоца „кроз дванаест капија небеског Јерусалима, да се на митским изворима“ напије воде и дочарава му слику о времену када је Орфеј „корачао Земљом, а звезде се пењале и силазиле са неба, по звуку његове свирале“. У свом препознатљивом стилу пословица и афористично-мудрих мисли, Драгојловић закључује: „Онај ко разуме своја ограничења, свестан је своје снаге“ и поставља филозофски узносито, људски пркосно и религијски реторично питање: „Можемо ли бесмртност пронаћи у својој смрти?“

Све песме у трећем циклусу, “Граница тишине“, писане су у прози. Песник каже да је из тишине настало време, из тишине која је била сама и у којој се зачињао будући Свет. За песника, тишина је својеврстан увод у настанак Тајне и једну врсту духовног откривања. У праисконској самоћи, тишина није имала мира док се није препознала у људском болу, док нису настали Живот и Тајна. Тишина и умно тиховање за њега, као да отвара незнане путеве ка ономе што је тајновито и вечно магновено. Живот за којим Драгојловић трага на туђим планетама, где стиже само наша душа, „тамо где су се Природа и Случај стваралачки поистоветили са Богом“ па су „заплакала деца“ и настали „Живот и Тајна“. Драгојловић је овде имао у виду чињеницу да је у многим предањима и легендама, Стварању које он апострофира претходила тишина у библијском смислу и поимању; често се сматра да ће и након свршетка времена настати нека праисконска тишина. У основи, Тишина која претходи Речи, баца извесну космичку светлост на вечни дијалог о судбинским питањима.

Вечни астрални простори обавијени су тишином, која оличава сваковрсна догађања у космичким просторима. Вечност, тишина и духовност животно поетским визијама дају величански размах. У сложеном процесу разоткривања недомашних тајни, присутна је неодољива човекова потреба за духовним продорима и напретком. Астрално, вечна Тајна, Свеживот, Тишина, Дух и Духовност, за Драгојловића представљају неку врсту великог поетско уметничког и сведуховног обреда. У души света али и човека надмоћно царује тајновита Тишина, коју настањује демиург, међутим, тамо где се не уважава да у почетку беше Реч, расипају се духовне снаге и енергије до извесне макрокосмичке обнемелости.[6]

[6]J. Chevalier, A. Gheerbrant, *Rječnik simbola* (drugo prošireno izdanje), Nakladni zavod Matice Hrvatske, Zagreb 1987, str. 704

До звезда нисмо доспели. У њиховим језгрима стварају се елементи који граде наша тела, због чега чувени популаризатор и астроном Карл Саган истиче да смо „деца звезда“, а београдски песник Милан Косовић, праунук оснивача Астрономске опсерваторије Милана Недељковића, лирски понесено закључује да смо сви „браћа по Васиони“. Звезде за сада досеже само наша мисао и поетске визије које „дотичу њихова пространства“ и планете са вртовима „у којима ће деца вечности да саде ружичњаке“ и висоравнима „по којима ће нови богови да се играју“.

До звезда стижу наше мисли „које најбрже савлађују даљине“ а песник се пита да ли се „тамо где ћемо сви бити једно“, „граде насеља за наше душе?“, и проповеднички истиче: „Заборављене књиге кажу да је Дух добра у нама, у неистраженим просторима душе. Ко га нађе отвориће му се астралне капије.“

Одбацујући метафизичку тврдњу да су појединости нашег живота „исписане на небесима“, између звезда, Драгојловић лепо закључује да „само мудри могу бити господари и власници своје судбине“, којом не могу да управљају звезде и да „упутство за градњу среће није написано“, јер како каже Бертран Расел, она очигледно не зависи у потпуности од нас самих већ делимично и од спољашњег света.[7] Драгојловић је на песнички начин запитан да ли судбину условљавају догађаји до којих долази слободном и неконтролисаном игром сила изван човека, животним околностима или трансценденталним силама.

У одељку „Гласови других светова“, песник, после трагања за Животом и Тајном по „туђим“ звездама и планетама, које само мисао досеже и „беспућима небеса“ где „ни људска мисао не стиже“, указује да и ту владају „закони коначног“ који управљају и нашим битисањем и истрајавањем. У своме покушају да докучи Тајну, Драгојловић се пита:

Како овладати Коначним
а не ући у смрт
и остати ту где смо стигли
са оне стране чудесног,
овде, где нас све пориче
а ми се поново рађамо.

Коначност је, као што је познато, ограниченост детерминисаности бића у односу на поимање простора и времена, величине, снаге и енергије. У апејронизму, коначност, која обузима Драгојловића, припада скоро свим обликотворним бићима, која се разликују од бесконачног апејрона. У савременој филозофији, која је овом песнику знана, посебно у егзистенцијализму, коначност се узима као важно одређење човека. Међутим, Драгојловићева концепција света и живота, не прихвата да је човек, како егзистенцијалисти тврде, најконачније од свих бића, управо зато

[7]Бертранд Расел, *Освајање среће*, Минерва, Београд, 1964, стр. 160.

што он зна и поима своју коначност. Уз самоупитаност: Како да њоме влада, у помало идеалистичко-метафизичком смислу, он тежи да човек укине, односно превазиђе своју коначност, „како би се у њој одржао“, у смислу опстајања и истрајавања. Драгојловић, као и филозофи егзистенцијалистичког и феноменолошког усмерења, излази из оквира традиционалног поимања коначности, у смислу бесконачја, и истовремено надраста антрополошку детерминисаност, пошто настоји да је мисли *на себи самој и у себи*, као коначност историјске судбине и бити. Руски филозоф Берђајев питање смисла историјског истрајавања доводи у непосредну везу с проблемом *историјског времена*. У делу *Опит есхатолошке метафизике*, он дословце каже. „Историја света, као и историја човечанства, има смисла једино ако ће се завршити.“ Берђајев надаље о коначности размишља не као о космичкој категорији, већ као о отвореној могућности *превазилажења објективације*, односно алијенације,[8] а ми бисмо додали и као могућност креативног заокружења у процесу настајања и развојности.

Берђајев описује живот као непрекидно умирање, непрестану борбу са смрћу путем љубави према свему што живи и налази смисао смрти у томе што је у времену немогућа вечност.[9] Драгојловић се у изведеним стиховима пита: „Како овладати коначним / а не ући у смрт“ и остати овде, „где нас све пориче“, изван „оностраног“, овладати својом судбином и зауздати њене ћуди. Да ли њу одређује човек или је записана у звездама и не може се променити? То је изврстан увод за следећи одељак именован „Астролошке расправе“, где су у прозно-поетској форми песникове лирске медитације о нерастумачивој „међузависности судбине и неба (...) коју знање не може да потврди, а дух необјашњиво разуме“. Планете он уметнички сагледава као „барке у којима се превозе људи из сна у сан, кроз празнину“. Они у планетама, сујеверно занети астрологијом, покушавају „да открију траг којим треба ићи“ да би надокнадили „немоћ која им је дата“.

Симболизам планета, који проистиче из упоредности између небеског, астралног и земаљског, често се злоупотребљава у астрологији, па се у тој упоредној корелацији измишљају и замишљају некакве нарочите везе које не постоје између путања небеских тела и судбина људи у овоземаљским просторима.

Основу хороскопа, Зодијак, песник именује као „круг у коме нема почетка“, што наводи као разлог немогућности да се направи хороскоп Света, пошто тачка његовог рођендана, на Зодијаку не може да се утврди.

Пошто је човекова мудрост и рационално мишљење не призива, астрологија није дошла на рођендан филозофије, коју Драгојловић успешно претаче у продубљену лирско-рефлексивну поетску форму, али су зато људи

[8] *Енциклопедија руске филозофије*, у редакцији Михаила Маслина, Логос-Укронија, Београд 2009, стр. 66.
[9] Исто, стр. 538.

„на рођендан астрологије (...) послали наду“, наду да завире у недосежну и несазнатљиву будућност и унапред сазнају своју судбину и исходиште.

Размишљајући да ли је „људска судбина дело звезда“, песник у „астролошку расправу“ уводи истрајног и неуморног борца против астролошког сујеверја, светог Августина, који пита оне што верују у астралне бесмислице: „а Бог, (...) где је ту његово место?“ „Да ли звезде извршавају Његове налоге?“ И заиста управо црквени Оци, као свети Августин, указују на погубност и бесмисленост астролошких превара. У петој књизи *Старог Завета*, остарели Мојсије саветује свој народ речима [18:10-12]: «Нека се не нађе у тебе ни врачар, ни који гата по звездама, јер је гад пред Господом.» Свети Василије Велики у својим *Канонима* (бр. 65 и 72) астрологе изједначава са убицама, јер убијајући слободну вољу човека, воде у пропаст његову душу. Свети Максим Грк каже: «Ако кретањем звезда добијамо дарове Господње, онда слободна воља наше душе зависи од особености Зодијака и он нас присиљава да водимо порочан или непорочан живот. (...) А тада је наша вера бескорисна. (...) Свако може рећи пред Судијом да га је зли владар Зодијак приморао да чини рђава дела против његове воље».[10] Поклоницима астрологије свети Максим Грк упућује питање: Зашто у *Јеванђељу по Матеју* [16:24] Христ позива ученике речима „ако неко *хоће* да ме следи“ а не каже „ако неко *може*“, односно ако му звезде то допуштају. Драгојловић наводи да Витлејемска звезда није одређивала судбину, већ је била сведок и слушкиња Његовог рођења.

Указујући на ставове светитеља, који је своју паганску младост заменио крстом и мантијом, песник и код њега проналази семе картезијанске сумње у сопствено дело, јер се из списа које пише „рука светог Августина“ „не виде све чињенице и докази“ нити је објашњено „како воља може да мења оно што је уписано при рођењу.“

У овом изузетном лирско-космичком, рефлексивно-поетском делу, Драгојловић поставља читав низ филозофско-егзистенцијалних питања што упућују на сваковрсна промишљања и ту, на самосвојан начин, песник осмишљава и описује полифоне везе и испреплетаности космичког и земаљског, Човека и Универзума.

Поетско-рефлексивни део ове књиге упућен је, поред осталог, и астрономимам, склоним да промишљају крупна, судбинска питања, која аутор на лирски начин захвата. Многи ће се определити за уметникова поетски-разуђена гледишта, пуна симболике и парадоксалних истина, што лирско-визионарски дограђује неке правце истраживања појединих судбинских питања, која задиру и у домен науке о звездама.

Песник Драгојловић, на известан начин резимира своје трагање за Тајном, доводећи у сумњу жељени циљ, уколико нас достигнуто знање остави без

[10]Свети Максим Грк, „Против оних који се труде да помоћу звезда предсказују будућност, и о човековој слободној вољи“, у *Астрологија у светлости православља*, уредници В. Димитријевић, Ј. Србуљ, Светило, Београд 1999, стр. 48.

тајновитости, односно без могућности даљег трагања, преиспитивања и истраживања, без жеље да стално откривамо, спознајемо, сумњамо и проверамо.

ДРАГАН ДРАГОЈЛОВИЋ:

Сумња Светог Августина

Када се помери завеса на прозору старог времена, види се рука Светог Августина како пише. И речи које тврде да су нека истинита предсказања астролога неодвојива и од случаја и од знања. Док у другој руци држи крст види да многи мисле како је људска судбина дело звезда. А Бог, пита се Свети Августин, где је ту његово место? Извршавају ли оне Његове налоге?

Не види се да ли је дан или ноћ. Прозрачна празнина чува слике и мирис даљине у којој се прелама паганска душа са крстом који се успрaвља на обалама римског царства. Свети Августин пише. Да отвори путеве којима ће пролазити Исус Христос после васкрсења. Да своју паганску младост покаже обасјану Витлејемском звездом. Звездом која није одређивала судбину већ је била сведок и слушкиња Његовог рођења.

Повремену тачност астрологије као да оповргава она сама. Из рукописа се не виде све чињенице и докази. Нити речи које говоре како воља може да мења оно што је уписано на рођењу. И да једино Бог увек може да потврди своје моћи.

Ко сумња, тај се искрено моли.

ПОТРАГА ЗА ЖИВОТОМ

На туђим планетама нисмо стигли да плачемо. Тамо је стизала само наша душа.

У прадомовини Хаоса, у епрувету сграђену од времена, невидљива рука сипала је угљеник и азот, кисеоник и водоник, сумпор и фосфор. Добијени су живот и Тајна. Ред је загосподарио Господњом пустињом. Заплакала су деца тамо где су се Природа и Случај поистоветили са Богом.

Дуго смо боравили у ноћи. Млечни пут је отворио врата и Кум празнине просуо је сламу путем којим ћемо проћи. Којим милијарде планета трагају за животом.

Туђе звезде нисмо дотакли. Тамо елементи наше суштине горе у вечном пламену. Ту се крије почетак других светова. Наше око, ни рука их не дотиче. Али мисао дотиче њихова пространства, њихове лепе обале изнад будућих вода. Младе вртове у којима ће деца вечности да саде ружичњаке. Висоравни по којима ће нови богови да се играју. И певају песме које смо писали да бисмо дотакли суштину и лепоту немерљивог, и нашег срца које, као промрзла и немоћна птица, греје своју тугу на светлости Сунца.

CELESTIAL SIGNS AND COSMICAL SEARCHES IN POETRY OF DRAGAN DRAGOJLOVIĆ

Poetical work of Dragan Dragojlović *On Astral Gates* has been considered and analyzed.

Зборник радова конференције "Развој астрономије код Срба VI"
Београд, 22-26. април 2010,
уредник М. С. Димитријевић
Публ. Астр. друш. "Руђер Бошковић" бр. 10, 2011, 1069-1082

ЛИРСКО-ПОЕТСКО И ДОКУМЕНТАРИСТИЧКО ВИЂЕЊЕ АСТРОНОМИЈЕ У „БЛАГОДАРНИКУ" МИЛАНА С. КОСОВИЋА

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Резиме: Размотрено је и анализирано песничко дело Милана Косовића *Благодарник*, које се унеколико уклапа у српску песничку традицију уз окренутост модерном духу певања. Мало је књига које на овај начин спајају поетско и документаристичко, па је она у том смислу особенија и различита, нарочито када је у питању астропоезија.

Милан С. Косовић,[1] песник који је својим делом украсио београдску и српску лирску сцену, необично је поетско-стваралачки улепшао и садржајно обогатио прославу Међународне године астрономије у Србији,[2] својом занимљивом збирком песама *Благодарник*[3] освестрањеном и разноврсним

[1]***Милан С. Косовић***, магистар економских наука, рођен је 10 јануара 1955. године у Београду од оца Слободана и мајке Данице рођене Недељковић. Бави се књижевном и ликовном критиком. Преводи са италијанског и на италијански језик. Идејни је творац и организатор књижевне манифестације "Песнички крчаг" са Милићем од Мачве. Објавио је седам књига поезије: *У сенци которског сата*, 1989. ЗККС, Београд; *Где никад није постојало време*, 1992. Интер-ЈУ прес-Београд; *Хачкар*, 1993, Просвета-Београд; *Бока плаво ћути*, 1995. (са групом аутора - Б. Цветковић-Витић, Н. Павловић, Б. Бојић и Д. Јовановић) Просвета-Београд; *Акобогда*, 1995 - Интерпринт-Београд; *Лирика воде* - Изабране песме о водама, 2002. године, Интерпринт-Београд; *Благодарник* - Песме о Београду, поводом Међународне године астрономије, Интерпринт, Београд, 2009. године. Добитник је и многих књижевних награда за поезију на пример ***Прва награда на Трећим Шумадијским метафорама*** у Младеновцу 1990. године за песму *СУМЊА*; ***Специјална награда*** на Првом Југословенском фестивалу песника Суботица-Палић за песнички подухват 1990. за песму *Јесен на Палићу*, ВСС Суботице и СО Суботице, 1990. год.; ***Награда Савеза културно-уметничких друштава Београда*** на мајским песничким сусретима књижевних клубова Београда 1992. за песму *Мир*.

[2]Види чланак Николе Божића о Међународној години астрономије у овом Зборнику

[3]Милан С. Косовић, *Благодарник*, Интерпринт, Београд, 2009.

додатним садржајима, коју је са разлогом посветио поменутој манифестацији.

Смисао ове поетско-документарне књиге, за астрономе нарочито увећава то што је аутор праунук Милана Недељковића, првог српског школованог астронома; његово постављење 21. октобра 1884. за суплента за предмет Астрономија са метеорологијом, узима се за почетак наставе астрономије код нас;[4] а оснивач је и Астрономске и метеоролошке опсерваторије, 1887. године.

Благодарник је Косовићев господствени, бајословни омаж Београду, водама река које га умивају и заливају, ауторовим прецима и славним београдским личностима, са којима му је породично стабло уско и присно испреплетано, и посебно прадеди, „јуродивом небеснику",[5] „освајачу сазвежђа",[6] који је „звездама посипао / ружичњаке / и воћњаке",[7] и његовој супрузи, прабаби Томанији „чије је срце величине неба" а „загрљај као царска Русија".[8] Ово дело истовремено даје и лирски узносите поетске слике, које осећајно исказују песникову интимну задивљеност чарима неба, којима је живот посветио његов прадеда, а прабаба му у томе свесрдно помагала.

Мото *Благодарника* је у духу народне традиције:

Земаљско је за малена царство
А небеско за далека и довека

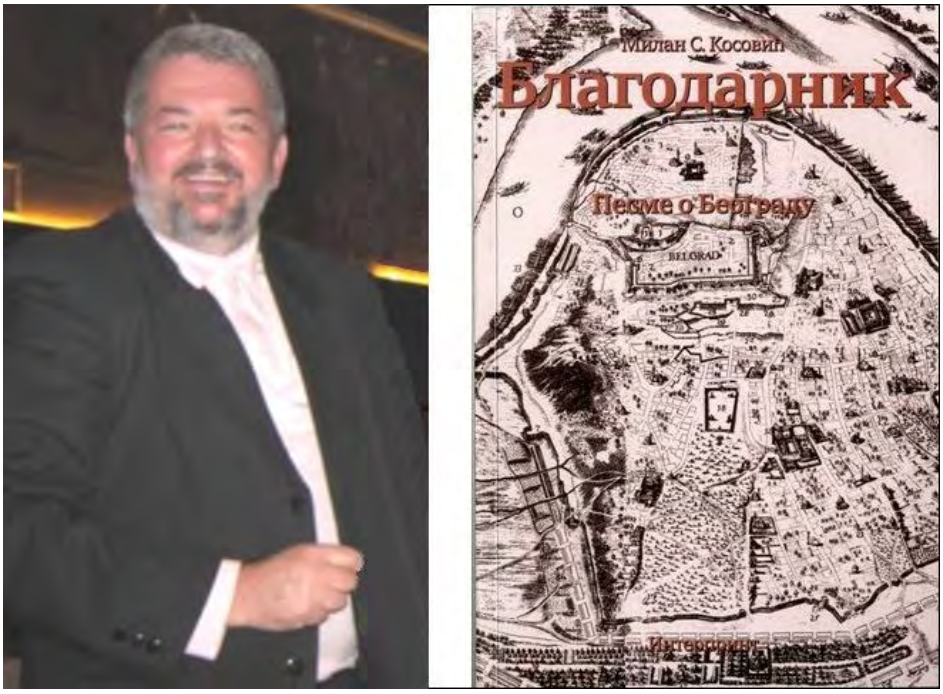
и вишезначно преплиће многослојну и фолклорну симболику озвезданог небеског царства, које пружа вечну славу онима, који су се посветили истраживању његових недохватних дубина и постигнутим резултатима и успесима подигли себи „споменик нерукотворни" како каже Пушкин, и онима који су га добрим делима и „подвизавањем у Господу" заслужили.

Књига почиње надахнутим прологом – *Прошће*. Већ у првим стиховима:

У недоба у поднебесја
Залуташе соколари
Хтедоше све прошће наше да оборе

Попут руског песника Леонида Мартинова,[9] Косовић у духу старо-грчке традиције, која разликује небо, где влада беспрекорни ред, и све је идеално, вечно и непроменљиво, од поднебесја, које се у античким Грчким космоло-

[4]М. Јеличић, „Први српски школовани астроном и метеоролог новог доба", у *Благодарнику*, стр. 13.
[5]Исто, стр. 54.
[6]Исто
[7]Исто
[8]Исто, стр. 56.
[9]М. С. Димитријевић: „Ноћ наоружана звездама – Космичка поезија Леонида Мартинова, *Васиона*, бр. 5, 2003, 158.



Слика 1: *Милан Косовић и насловна страна „Благодарника“.*

гијама обично простирало до прве, месечеве кристалне сфере,[10] где као и на Земљи влада подложност кварљивости, старењу и умирању. У Поднебесја Београда и Србије „светих ратника Манасије“, чије су „босиоком освештане“ воде „благословене“ а „бразде на сазвежђа миришу далека“, не једном су залутали туђински „соколари“ и пустили на свој плен немилосрдне и бездушне челичне птице, означивши да је дошло време „да се Срби на оружје дижу“, како пева Филип Вишњић, и да уједињени добију снагу, коју је везивањем седам прутова у сноп, отац сликовито приказао браћи у народној причи. Али и ако се све пруће – прошће „наше дигло на устанак/ још га не окуписмо / у сабирању нашем земном“, кори песник српску неслогу у одсудним тренуцима, позивајући на саборност, коју према Нестеруковој дефиницији Васионе[11] као „заједништва у Господу“, нуди царство небеско.

[10]Е.Теодосију, А. Даканалис, М. С. Димитријевић, П. Мантаракис, „Хелиоцентрички систем од Орфичких химни и Питагорејаца до цара Јулијана Апостате“, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник М. С. Димитријевић, *Публикације Астрономског друштва «Руђер Бошковић»* Св. 8, Београд 2009, 463-480.

[11]Alexei Nesteruk, *The Universe as Communion, Towards the Neo-Patristic Synthesis of Theology and Science*, T&T Clark, London and New York, 2008.

У првом циклусу, насловљеном као и цела књига, пробраним стиховима опева и слави родни Београд, коме лирско-поетски даје људске особине, стварајући раскошну представу о престоном граду Српског народа, у „црвеној ђенералској униформи од јесењег лишћа“, са орденом који му одсјајем дарују реке које га умивају, иконом Саборне цркве на грудима „као да је походник / Христовог гроба“ и бројаницама „од небеских сазвежђа“,[12] са

Кошавама
И црквама
Са чаршијом
И Патријаршијом
Са звоницима
И далеким видицима
Са псима луталицама
Шареним пијацама[13]

Над капијама песниковог вољеног града су „звезде чувари“ а „Месечина једри ка ушћу / сакривајући се испод / београдских мостова“, док бели коњаник „чека звездопад“.[14]

Београд је за Косовића и „велики расипник“,[15] који своје благородне благодати и богатства дарује захвалним житељима. Зими из његових оџака, уместо варница „долећу звезде“ „попут голубова“,[16] а над Дунавом и Савом месец је плав.[17] Занимљиво је колико је лирских појединости песник уградио у своју велику фреску много вољеног завичаја, престоног Београда.

У *Београдској елегији*[18] он се враћа првим стиховима уводне песме *Прошће*:

У недоба
У поднебесја
Залуташе соколари
Хтедоше да га оборе
Гране да му откину
Лишће покидају
Плодове разметну...

Занимљиво је да је ово објављено 2009, на десету годишњицу последњег од бројних бомбардовања и разарања српске престонице, на коју су туђински

[12]М. Косовић, *Сећате ли се Београда*, Исто, стр. 23.
[13]М. Косовић, *Бео(град)*, Исто, стр. 27.
[14]М. Косовић, *Београдска стража на Великом Равелину*, Исто, стр. 42.
[15] Исто, стр. 23.
[16]Исто, стр. 27.
[17]Исто, стр. 28.
[18]Исто, стр. 29.

силници – соколари опет слали своје челичне грабљивице са смртоносним „даровима“.

Душан Стојковић је у првом од три уводна текста[19] истакао да у збирци „нимало случајно, има седам циклуса“ (укључујући и пролог), подвлачећи симболичко значење броја седам, пошто је међу звездама „некретницама“ толико *луталица* (на грчком *планета* - пет тада познатих, Сунце и Месец). Пошто седам дана одговара и једној месечевој фази, овом броју је одувек приписивана велика важност, светост и симболички и митолошки значај. Између осталог Стојковић помиње седам дугиних боја, светских чуда, смртних грехова. Он, како Стојковић наводи, симболизује и потпуност, савршенство, изобиље, „симбиотички спаја духовно и световно“ и „симболичка је замена за свемир и макрокосмос“. У песми *Београдска елегија*,[20] желећи да „небеском“ Београду да симболичке црте небеског Јерусалима Српског народа, Косовић пева:

Векови пред њим
Векови иза њега
А кратки да прођу као сан,
Преко његових седам кошава
А он само на две реке.
....
Седам светлости код њега станује
А он само на две реке.
...
Бели граде
Седам ће времена преко тебе
А он само на две реке.

Други циклус *Благодарника* именован је „Читује“ и у њему су лирски ламенти над сенима блиских рођака и знаменитих београђана, који су са њим повезани даљим и ближим сродничким везама, јер «Београд је некада био једна велика породица»,[21] како личним примером и документарним смислом и садржајем ове књиге сведочи наш песник. Астрономски најпривлачнија лирска остварења су песме посвећене прадеди Милану и прабаби Томанији Недељковић, и њиховој деци, прерано умрлим кћерима Вукосави и

[19]Душан Стојковић, „Благодарни будни снови“, *Благодарник*, стр. 7.
Јелена Милоградов-Турин, „Необично песничко рухо“, исто, стр. 11.
Милан Јеличић, „Први српски школовани астроном и метеоролог новог доба“, исто, стр. 13
[20]Исто, стр. 29.
[21]Исто, стр. 97.

Видосави, чија су имена уклесана «негде високо на небесима / поред уснулих звезда».[22] и ауторовом деда Саши.

Поетолошки и документаристички је посебно занимљив почетак песме *Деда Саши уместо (венца на дан) опела*,[23] где Косовић бројним алитерацијама и неологизмима, изведеницама полазећи од одреднице *звезда*, као што су *звездарница, звездолики, озвездан, звездохватан*, постиже необичне и допадљиве ефекте, који подсећају на дела оца сигнализма, Мирољуба Тодоровића, као што је *Планета*.[24] Миливоје Павловић у разматрањима на погледе Николе Цветковића на авангарду и неоавангарду, запажа да је далеке 1958. објавио песму под необичним насловом *Звездограм*. Ова сложеница, састављена од две морфеме, као и каснији *Сунцопад*, те *Звездосвитање*, на известан начин слутиле су оно што ће донети Тодоровићева *Звездалија* или, визија *планетарне културе* будућег родоначелника сигнализма.[25]

Звезде у звездарници
Међ звездоликим облацима
Озвезданим небом
Сазвежђима далеким
Тамо међ звезданим годинама
Тамо су звезде
У звездопадима
У трептају твојих очију
И сазвежђу твоје звездохватне душе

Песме *Звездарница*[26] и *Београдска опсерваторија*,[27] посвећене оснивачу ове институције Милану Недељковићу, «јуродивом небеснику», «освајачу сазвежђа» који покушава да ухвати «звезде за ноге» и њима посипа «ружичњаке и воћњаке победоносне», а «сада се негде далеко одмара / изван ове галаксије», због њиховог многослојног астрономског значаја и важности, пренећемо на крају у целини.

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[22]М. Косовић, *Успаванка за Вукосаву и Видосаву*, Исто стр. 52.
[23]Исто, стр. 53.
[24]*ЗАМКЕ најзад звездарима и звездочацима*
звездачима и звездознанцима што
звездовозима, звездоскопима, звездозорима
звездају звездоравнима
незвездомерним
Мирољуб Тодоровић, *Планета*, Просвета, Ниш, 1995.
[25]М. Павловић, *Књижевно-теоријски погледи Николе Цветковића на авангарду и неоавангарду*, Научно-стручни скуп „Стваралаштво Николе Цветковића“, Јагодина, 1. јун, 2007.
[26]Исто, стр. 54.
[27]Исто, стр. 55.

У песми *Београдска опсерваторија*, Косовић на потпуно својствен и оригиналан начин гради једно ново виђење и лирско описивање звезда. Оне трепере «као деца која су много вољена», а када се у камен уреже чувено име, он «одјекује / свом господственошћу / звезда у изгнанству», што као једно од могућих исходишта, гради слику знамените особе, звезде међу људима, која се сада «негде далеко», у «изгнанству» одмара.

Трећи циклус «Небесима и небеским телима», небески песник Милан Косовић, приноси као лирски дар Астрономији и астрономима, «за душу» њеном оснивачу и првом посленику у Србији, прадеди Милану Недељковићу, у част Међународне године астрономије. Прву песму, *Београдским звездама*,[28] посветио је «небеским светиљкама», које «мазне, трепераве, крхке», «стидљиво дрхте» над његовим многовољеним градом. Лирски им дајући карактеристике, грациозности, љупкости, непостојаности и слабости, што је све у супротности са њиховим правим особинама, Косовић жели да им и песнички захвали што ките и украшавају ноћно небо његовог родног и завичајног Београда, пружајући им нежност и пажњу, као «многовољеној деци». Сазвежђа над песниковим градом су «срмена» и време их, како астрономски исправно а лирски надахнуто каже, «претаче», споро али неумитно мењајући њихов изглед.

Исказујући свој лирско-емотивни протест што за разлику од звезда, које га украшавају сваке ведре ноћи, Месец му повремено ускраћује своје дарове, песник каже:

Месецу не верујем
Он дође па нестане
Не одриче се неба
И звездоликих корака
То жрвањ небеског млина
Звездано брашно меље[29]

«Жрвањ небеског млина звездано брашно меље». Колико је песничке слојевитости у овој поетској слици чудесне лепоте. Млин може бити и време, које чини да Месец «дође па нестане», а звезде у експлозијама нових и супернових «меље» у «звездано брашно» од кога смо саздани. А и Месец, који изгледом потсећа на воденичарски камен, «меље» на своме путу ликове звезда преко којих његов лик прелази, појава што је астрономи зову окултација. Млечном путу, који ствара сједињени сјај звезда наше Галаксије, лепо пристаје поетска слика просутог звезданог брашна.

Као својеврсну прокламацију Лотреамоновог и потом и Миљковићевог (*Песме ће писати сви*),[30] Грамшијевог (*Сви су људи филозофи*) Бетовеновог

[28]Исто, стр. 63.
[29]М. Косовић, *Месец над Београдом*, Исто, стр. 64.
[30]Бранко Миљковић је, на оригиналан поетски начин, препевао Лотреамонову мисао истичући да тамо где је «било срце стајаће сунце / и неће бити у људском говору

(*Сви ће људи бити браћа*) и Селимовићевог вида (*Кунем се мастионицом и пером да је сваки човек увек на губитку*) песник понесено и свечано, своја емотивна, интимистички лирска осећања преноси осталима: «А небо волеће сви». Додајући широкогрудо и дарежљиво: «И ни у чијем поседу оно неће бити». За разлику од Марине Цветајеве, која славећи нашу животодавну звезду каже: «Сунце је моје / ја никоме нећу да га дам. / Ни на час, ни на зрак, ни на вид. / - Било ком. Било кад».[31] Ако се сетимо Косовићевих соколара, који му на завичај шаљу немилосрдне, смртоносне грабљивице, које са неба уништавају и разарају, јасно је зашто своју објаву ставља, као и Бетовен братство међу људима и Миљковић љубав према поезији, у будућност (Селимовићев став везан је за садашњост у смислу јесте, било је и биће да је сваки човек вазда на губитку). И Косовићево певање је у знаку духовне слободе и слободарства уопште; он се као и Миљковић залаже да ће истина и слобода *присуствовати у свим речима* и то управо на оним местима *где је песма најлепша*.

Бајковито-чаровиту поетску слику о Милану Недељковићу који седи на Месечевом српу, са ногама које висе у празно,[32] песник као да је пренео из народне скаске, Земљин пратилац је, као и песникова сазвежђа, *срмолик*, не само по бледо сребрнастом сјају, него и по филигранским украсима од његових кратера, које су му минуциозно и систематски попут најбољих небеских кујунџија урезали астероиди и болиди.

Астрономски посебно занимљива и прожета небеским симболима је песма *Халејева комета, Ђото, прадеда и песник*[33]

Чињеницу да су сва тројица видели овај објекат, који се појављује једном у просечном људском веку, сваких седамдесет и шест година, Милан Косовић користи да између њих лирски сатка поетску нит, везу којом постају «три звезде на једној путањи» и «браћа по васиони». Изврнута слика да је он своме прадеди постао брат, престаје да буде необична ако се уклопи у често коришћени слоган. «Сви су људи браћа.» А да смо, како песник каже «сви браћа по васиони», астроном би могао да допуни, да је то тако пошто смо деца исте звезде, која је умрла у експлозији, да би животодавним хемијским елементима од којих смо изграђени, обогатила до тада стерилни међузвездани облак из кога су настали Сунце, Земља и ми, њено звездано потомство.

Кроз целу књигу лајтмотивски се провлачи и особени песников однос према води, која тече рекама што свеобухватно грле, штите и умивају град који му је у срцу.

таквих речи / којих ће се песма одрећи / поезију ће сви писати.» Ова антологијска песма завршава се гласовитим стиховима:

Хоће ли слобода умети да пева
Као што су сужњи певали о њој

[31]Марина Цветајева, у *Модерна руска поезија*, приредиле Милица Николић и Нана Богдановић, Нолит, Београд, 1961.

[32]М. Косовић, *Венери - звезди Даници*, Исто, стр. 66.

[33]Исто, стр. 70.

Нисам никада сазнао
Како се пале звезде
А знам како се вода воли,[34]

Каже Косовић и упозорава Дунав: «Месец ми се дави у твојој пени.»

У студији *Вода и снови*, велики феноменолог Гастон Башлар описује воду као «изокренуто небо на коме звезде добијају нови живот.»[35] Ликови звезда се купају и огледају у њој, што песник лирски описује да само вода може да их загризе.[36] Милоградов-Турин је с разлогом истакла «као лепу игру речи»,[37] и скренула пажњу на поетолошки занимљиву, четвороструку испреплетану алитерацију (белу, белог, бео; воду, воду, вода; Белог града, Београда, зборим, збори):

Зборим воду
Белу воду
Белог града
Збори вода Београда[38]

Животна стварност се манифестује у најразличитијим облицима, и то знатно шире него што песничка, и уопште књижевна форма може да искаже. И ако документарност унеколико остаје изван текста књижевног дела, ипак поједини уметници успевају да је угради у песничко ткиво, како би представе о свету и животу биле целовитије и стварносно убедљивије. Зато се догађа да уметничко-поетски текст буде оплемењен садржајима документаристичке природе, понекад у облику записа, мемоарских појединости, писама, фотографија и сл. Спретно уграђивање документаристичких елемената у књижевно-поетске структуре, доприноси целовитијем захватању суштинских аспеката животне реалности.[39] Завршни део књиге под симболичним насловом, који је скоро и сам песма за себе:

Између две реке,
И звезданог неба
Стихови памте град
И песниковог претка.

Милан С. Коссовић је овде уградио и неколико веома занимљивих документаристичких фрагмената, назначавајући чак и изворе, научну и

[34]М. Косовић, *Реке не падају с неба*, Исто, стр. 69.
[35]Цитирано према Душан Стојковић, *Благодарни будни снови*, у М. Косовић, *Благодарник*, стр.7.
[36]М. Косовић, *Похвала води*, Исто, стр. 75.
[37]Ј. Милоградов-Турин, *Необично песничко рухо*, у М. Косовић, *Благодарник*, стр.11.
[38]М. Косовић, *Београд над водом*, Исто, стр. 44.
[39]Станиша Величковић, *Документи и прича*, Градина, Ниш, 1998, стр. 10.

стручну литературу, новинске чланке и др.[40] То, поред осталог, повећава вредност и смисао појединих докумената; а заједно са текстуалним и визуелно-фотографским прилозима, успоставља извесну кореспонденцију са стиховима у почетном и средишњем делу књиге. Прилог под насловом «Јуродиви небески звездар», је у основи студијско-мемоарског и породично-фактографског карактера. Веома је корисно што Косовић при том, из породичног сећања износи детаље, нове и за оне који су добри зналци Недељковића – *небеског звездара*, занимљиве свима који ће се бавити историјом настанка Астрономске опсерваторије.[41]

У тексту «Београд је некад био једна велика породица» Милан Косовић указује на често јавности непознате везе између читавог низа значајних београдских породица које су изнедриле знамените личности од Томе Вучића Перишића, Петра Добрњца, Симе Лозанића, Стевана Христића, до савременика, Александра и Војислава-Вокија Костића, Борислава Пекића... У средишњем делу овог прегледа, посвећује одговарајућу пажњу Недељковићима, и при том објављује и неке породичне фотографије, а завршава га одељком родослова Христића и Трпезића.

У *Благодарнику* се остварује извесна синтеза лирских партија и појединости, преко студијско-мемоарских до чисто фактографских. Поред оних, уметнички најуспелијих песама, овде су значајни и истраживачки напори које је Косовић уложио у реконструисању породичних структура интелектуално најкреативнијег дела Београда. С друге стране вредно је то преплитање поетског, студијског, публицистичког и документарно-фактографског. Све ово показује да је аутор књиге, и поред узлета у небеске сфере, доста солидно ослоњен на животну и историјску стварност, са можда притајеном намером да покаже како је његов поетско-имагинативни свет, колико вероватан толико и истинит. Косовићева породично-генеалошка истраживања узајамних веза успешно потврђују чињеницу да је Београд некада доиста био *једна велика породица*.

Благодарником, благу и благородном дару дарованом астрономима у славу Међународне године астрономије, посвећене овој лепој науци, и свога прадеде, са којим ће, како песник објављује, 2134. године дочекати Халејеву комету, Милан Косовић оставља звездани траг међу астрономима, љубитељима ове науке, траг космичких чари и надахнућа, који ће својим сјајем указивати, како се надахнуто, плодоносно и лирски могу присно, многоструко и вишезначно преплитати, спајати и допуњавати поезија и астрономија.

[40]М. С. Косовић, *Извори*, у *Благодарнику*, стр. 137-139.

[41]Посебно је драгоцено писмо Стевана Стојановића Мокрањца, које показује широке комуникације научника Недељковића, са овим великим музичким уметником. Вредно је помена да су готово сви истински велики људи били брижни за напредак „нашег народа, развијајући му укус за лепо и узвишено, за склад и хармонију“.

МИЛАН КОСОВИЋ

Звездарница

Јуродивом небеснику – прадеди Милану Недељковићу

Посадио је звезде на
Небу
На иконама и на
Таваници
Иселио се
Из своје собе
Међ облаке
Градоносне
Као освајач сазвежђа
У свечаном поретку
Одличја Светог Саве
И албанске голготе
На кишној кабаници

После је
Звездама посипао
Ружичњаке
И воћњаке
Победоносне

Сада се негде
Далеко одмара
Изван ове галаксије
Нема винограда са чокотима
Прекривених звездама
Спава Звездара стара

Београдска опсерваторија

Ухватити звезде за ноге
Прадеди Милану Недељковићу

Никада се не може починути
Са чувеним именима
Урезаним у камен
Који одјекује
Свом господственошћу
Звезда у изгнанству

Док носе свој умор
Попут тешког пакета
Чија празнина одјекује
Као морска шкољка
С ким ће поделити терет
Неисповеданог мрака

Далеко од брзих струја времена
Као деца која су много вољена
Трепере звезде
Ловцима бесмртности
Победничком светлошћу

Људи непозвано, бахато
Улазе у животе других
Док небо расеца јато голубова
Њихова прошлост се гули као кожа

Звезде нису препредењаци
Треба заронити испод њих
И ухватити их за ноге

Београдским звездама

Дахом ишчиле
У напону непролазног
Још стидљиво дрхте
Небеске светиљке
Мазне трепераве крхке

Ноћас испустише уздахе
Док срмено сазвежђе
Претаче време
Круне се пространства
Дном свемира
Свраћају често до мене

Гледам их као налет свитаца
Што коритом река
Посребрују планете
Некој заруделој души
Бескрајном васионом
Попут успаванке долете

Пре налета кошава
Испод београдских мостова
Метеоролошких извештаја
Да се ноћас не зебе
Све од мог прозора
До бескраја
Док се у зору
Врате опет у себе

Астрономија

Шта још тражиш овде
Још једно вече трчи
Ишчекујеш непотковану ноћ
Звезде нуде себе
Беле патуљке

Чекаш повратак племена птица
Црвене џинове галаксије
По млечном путу сазвежђа
Где се љубав мери
У светлосним годинама

Позајми ми
Степенице до неба,
Крадљивче муња,
За још једну непроспавану ноћ
Метеорских трепавица

Не знам како се гради свемир
Какав то неимар
Исписује немир
И каква је то љубав
Од свих љубави вратоломнија
А тако једноставно зову је
Астрономија

LYRICALLY-POETICAL VISION OF ASTRONOMY IN „BLAGODARNIK“ (THANKFULNESS) OF MILAN S. KOSOVIĆ

Poetical work *Blagodarnik* (Thankfulness) of Milan S. Kosović has been considered and analzyed.

Зборник радова конференције "Развој астрономије код Срба VI"
Београд, 22-26. април 2010,
уредник М. С. Димитријевић
Публ. Астр. друш. "Руђер Бошковић" бр. 10, 2011, 1093-1124

„С ГЕОМ НА РЕДУТУ" ПОД ЗВЕЗДАМА

МИЛАН С. ДИМИТРИЈЕВИЋ

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Резиме: Размотрено је и анализирано лирско-поетско стваралаштво десет савремених бугарских песника Евгеније Маринчеве, Рајча Русева Рајсна, Илијане Илијеве, Милче Цветкова, Катје Маринове, Улјане Паскалеве, Ангела Ангелова, Јорданке Брзинске Дандан, Зинаиде Чаушеве, Маје Митове и Петка Недјалкова, са нарочитим нагласком на космичким мотивима у њиховом стваралаштву.

На скупу „Развој астррономије код Срба V" обухватили смо лирска остварења, надахнута небеским мотивима, плејаде даровитих бугарских песника окупљених око литерарног клуба „С Геом[1] на редуту", уз већи број фотографија документарне природе. Њихове стихове смо препевали на српски, а уз свакога од њих појединачно, уследила је кратка белешка о понуђеном лирско-поетском остварењу. Неке допуњене фрагменте понудили смо нашим књижевним часописима, који су то прихватили и објавили.[2]

[1]Гео Милев (1895-1925) је знаменити бугарски песник. Ларпурлартиста, модерниста уз склоност ка експериментисању. У каснијем периоду, Милев је еволуирао ка марксистичким схватањима и погледима на уметност, у оквиру часописа *Пламък* (Пламичак). У поменутом часопису објавио је револуционарну поему *Септември*, због које је касније прогањан. Он је врло значајан представник књижевне левице, која је тада била присутна и на нашим просторима. У мају 1925, због својих прогресивних схватања и делања, убијен је од стране бугарске полиције.
Објавио је више збирки песама, а афирмисао се и као врстан преводилац класичне и модерне поезије, укључујући ту Бајрона, Гетеа, Мајаковског и друге. Дела: *Жестокият пърстен*, *Иконите Спят*, *Антология на жълтата роза*, *Антология на червената роза* и др. *Енциклопедија Лексикографског завода 5*, Загреб 1961, стр. 193.

[2]М. С. Димитријевић, „Митско-поетска космогонија Маје Митове", *Луча*, **XVIII**, бр. 2-3, Суботица 2009, 45-48.
М. С. Димитријевић, „Савремена бугарска поезија", *Успења*, III, бр. 9, Лесковац 2009, 26-27.

Неко време потом, наставио сам да преводим њихове стихове, које сам читао на заједничким окупљањима у Софији,[3] Пловдиву[4] и Мелнику,[5] где су се одржавале „Песничке вечери“. У таквим приликама, или после њих, добијао сам нове, објављене и необјављене стихове, шире и песника који не припадају клубу „С Геом на редуту“, а преводио сам оне, који су умени нашли посебан одјек, а нарочито остварења надахнута чарима и лепотама неба.

Овде су представљени нови препеви, настали између два скупа, који ће, надамо се, нашој астрономској и стручној јавности па и шире, пружити прилику да се суочи са једним другим, не научним, већ распеваним лирским виђењем неба и појава на њему, које истражујемо.

На почетку ове мале збирке лирско-поетских остварења, је осам песама талентоване поетесе, која се остварила и као надарени ликовни уметник, чија су дела присутна и у иностраним галеријама.[6] Њена ликовно-стваралачка концепција види се и из начина како визуелно организује и осмишљава поједине песме, на пример у облику амфоре, уз коришћење наглашенијих графичких елемената, а сваки ред је центриран, тако да читалац поред лирског, посматрајући допадљиве фигуративне облике, има и ликовни доживљај.

Овој поетеси основно и најважније надахнуће пружа слојевита и вишезначна симболика Земљиног пратиоца, кога лирски осликава у најразличитијим видовима од округлог Месеца и његове светлости, преко питања упућених Луни до „математике“ у доба када је пун. Он јој „осветљава (...) мисли“, а када проникне у њих; одговара јој на „на необична питања“, сведок је романтичних љубавника и „сабира два тела и две душе у једно“. О њему каже:

Наш стари гласник,
помилова ме нежно
и рече ми,
пожелећеш ме.
Пољуби ме вљздушасто
и напусти.
Отишао је код следећих заљубљених.

Маринчева у своје стихове уноси научне појмове и симболе, попут бисекције угла, симетрале, тригонометријске зависности и логаритмовања;

[3]Јул 2008, март, септембар-октобар, новембар 2009.
[4]Септембар 2009.
[5]Октобар 2009.
[6]М. С. Димитријевић, „Речитост сликарства, поезије и неимарства Евгеније Маринчеве“, *Зборник радова конференције „Развој астрономије код Срба V*, уредник М. С. Димитријевић, *Публикације Астрономског друштва „Руђер Бошковић“*, Св. 8, Београд, 2009, стр. 772-773.

па је чини се показала како се може стваралачки спојити математика и поезија. У певању Евгеније Маринчеве, Земљин сапутник се повезује и са симболиком сна (*Треба ми сан*), па и несвесног, узетих као део ноћног живота. Тај ноћни живот и Луна, посебно када је у питању њенаа светлост, елементи су који припадају незнаном и тајновитом (*и пусти Месец да проникне у твоје мисли*), јер духовни и мисаони свет, посебно када је у питању љубав, јесте у великој мери повезан са имагинативним; и то са маштовитим које егзалтира.[7] У целини гледано, светковина Месеца у њеном интимистичком певању израз је унутрашњих стања, која се метафорички изражавају кроз његову лепоту, светлост и чаровитост када је пун.

Познати бугарски песник Рајчо Русев Рајсн, за кога „ноћ као древни владар седи / високо и катедрално“[8] заступљен је са пет песама. Понајвише је лирско-симболички осмишљена прва, под насловом *Путујуће позориште.* За Русева, Земља је „велики циркус“, који диже „своју небеску шатру / у славу Мудрог који има укус / за тај драги и страшан театар“. Песник долази у „звезданим кочијама“, да би одиграо своју улогу, а на крају, Месец који све то прати седећи“на танком облаку“, каже:

Хвала господо, дођите нам опет –
Радоваћемо се таквој срећи!

Док другде Земљин сапутник симболизује време које пролази, овде је у непосредној вези са „великим циркусом“, уз напомену да се у осталим приликама повезује са водама, вегетацијом али и човековом судбином. Месечево божанство овде је у знаку сценско-театралног, на путу до сазнања о сопственој вредности.

У песми *Дођи зоро*, песник је призива да га од мрака лекује. У њој, која је увек млада, и никада не умире, види радосни симбол буђења у коме налази спасење, а звезде му показују могући пут и исходиште.

Показујте, да се не изгубим,
не падајте звезде, јер закасних.

Илијана Илијева, велики мајстор хаику поезије,[9] овенчана је бројним књижевним наградама. У њеним кратким строфама, писаним допадљиво лапидарним стилом, присутни су небеско-космички мотиви и симболи.

[7]Ж. Шевалије, А. Герберт, *Рјечник симбола*, Загреб 1987, стр. 409-410.
[8]М. С. Димитријевић, „Катедрално озвездање космичке ноћи у поетском стваралаштву Рајча Русева Рајсна“, *Зборник радова конференције „Развој астрономије код Срба V*, уредник М. С. Димитријевић, *Публикације Астрономског друштва „Руђер Бошковић“*, Св. 8, Београд, 2009, стр. 769-771.
[9]М. С. Димитријевић, „Хаику васељена Илијане Илијеве“, *Зборник радова конференције „Развој астрономије код Срба V*, стр. 780-782.

Снежне пеге
у осветљеном сунцем
блату – иде пролеће.

Месец вршидбу
намеће
дан се смањује.

Поетеса описује љубав као грех који је „пут за двоје у звездани прах“ и пита се:

Боже – ако је љубав грех – шта је онда мржња
....
Ако је јабука узрок греха –
Да ли је грех пред свима пут кроз звездани прах.

А своме вољеном, поетеса жели да да на дар цео Космос.

Илијева показује да су скоро све истинске формуле света – поетске. У песми *Ајнштајнов и-мејл* она тражи „научно доказану лаж“ и сликовито открива да се скоро све догађа у сфери духа са мноштвом симбола, доводећи у везу формулу за релативност, љубав и осећања. Наш знаменити песник Бранко Миљковић је тврдио да се Ајнштајн може препевати, а Илијева открива да се љубав може лирски изјавити уз помоћ Теорије релативности и теорије вероватноће, које се догађају у просторима духовности, храбро истичући да „баш тамо где се прелази у нови ред има нешто апсолутно“.

Прилог краси и пола туцета песама астронома-поете и уваженог научника Милче Кирилова Цветкова, једне од најистакнутијих личности овог књижевног клуба, који стваралачки организује и осмишљава његову делатност.[10] Своју Катју он воли „Увече, када изгреју звезде“, „у Јутро, када Месец нестаје“ и Дању, када она „заслепи Сунце пламено лепотом“.

У песми *Пред звезданим вратима*, Милчо описује песнички сусрет, који је организовао на Астрономској опсерваторији у Софији, једне снежне фебруарске ноћи 2008. године, наглашавајући да „Астроному с лиром машта даје моћ“. Песници су отворили „звездана врата Опсерваторије“

И стоје на прагу Васионе бездна,
Загрљени певају и слушају звезде.

Песник пита „Ко с гитаром пева звезда серенаду?“ и у тај круг укључује судбоносну самотност на свету, а све то опет повезује атмосфера вечери, млад месец и „тамна, тамна ноћ“. У хладовитом зимском дану у сали види „заснежене поете“, који седају тихо, очарани астралним пространством и „певају о звездама куплете“. Из целине певања Милче Цветкова зрачи

[10]М. С. Димитријевић, „Распевани астроном и лирски визионар Милчо Кирилов“, *Зборник радова конференције „Развој астрономије код Срба V*, стр. 765-769.

животворност и непосредна веза са оним дневним, људски постојаним али и небески узноситим.

Цветков надахнуто пева о „наранџастом небу“, које види у јутарњем тенутку, заједно са метафоричном претставом ветра који му дарује коња и рашчупаним птицама. „Овога јутра небо је наранџасто као ћивот било. / у коме није злато већ љубав.“ Његова вољена поистовећује се са тим пролећним небом, па је, као и те васионске просторе, види сву наранџасту.

Зелено писмо Лорки асоцира на чувену песму *Романса месечарка*, из циклуса *Циганси романсеро* (1924-1927). Наш песник у самом наслову истиче *зелено* и песму завршава апострофирањем верзалом поменуте боје. Често се цитирају Лоркини стихови „Зелено, волим те зелено“,[11] где он помиње велике звезде од иња, што је све могло да има одјек у Милчовим стиховима. Ова два песника обузета су зеленим, понајвише зато што оно оличава истовремено живот и смрт, „у пролећном зеленилу живота и оловном зеленилу смрти“.[12] Он у своје певање укључује и познатог бугарског песника Рајча Русева Рајсна, који му је братски дао писмо за шпанског лиричара са многим питањима. А кључна се појављују у завршном делу песме:

И зашто фламенко је розе?
И зашто нам крв је црвена?
Само то те питам Лорка,
Знам да је све друго ЗЕЛЕНО!

Фламенко, који у себи садржи нешто од краљевског достојанства, помпе и поноса, добио је розе боју. А крв, која у извесном смислу претставља Сунце, ватру, и такође, краљевско достојанство, симболизује суштину живота, његова животна начела, снагу и подмлађивачку силу, а такође носи у себи и нешто од црвене соларне енергије.

Поента је на зеленом, које претставља мешавину плавог и жутог, али и комбинацију неба и земље, те је у том смислу мистично и тајновито као и астрални простори у које је Милчо загледан.

У песми *Антиастро* Милчо саопштава да су му дојадиле формуле и срачунавања далеких звезданих пространстава; питања о црним рупама су му преко главе, као и све што се односи на планете Венеру, Марс, Сатурн, Јупитер и слично. Он препушта радознале астролозима да им, ако то они желе, сачине „астралну кућу и хороскоп“, па хуморно-иронично додаје:

И на истину та лаж ће да вам личи,
ко на ТВ-у биће логично и тип-топ.

[11]Федерико Гарсија Лорка, *Неверна супруга*, Удружење издавача и књижара Југославије, 1996, стр. 7.
[12]Ц. К. Купер, *Илустрована енциклопедија традиционалних симбола*, Просвета – Нолит, 1986, стр. 17-18.

Песник би радије да одгонетне „зашто су облаци бели и очи зелене“? Уместо астрономије, њега емотивно-еротски зазива питање ко води љубав у животно-сензуалној летњој ражи и зашто Она чека увек баш њега.

Цветков пева и „рињој“, „светлоокој“, „блиставој“ Луни, разбијаној од метеорита, што му плиму мужевне „снаге даје и увећава“. У обузетости Луном, која у извесном смислу оличава женску премоћ, као царица небеска, песник је у пуном заносу достиже „дању“, по светлу. У наставку се пита да ли је Луна измишљена од месечара и да о њој песници „праве стихове и пишу поеме“. Она која има власт и премоћ над плимом и осеком, над водама и годишњим раздобљима, очарава уметнике а сматрало се да у чаровитом смислу има утицаја и на будућност. У последњој строфи, Луна је за песника *света икона*, којој се моли тражећи пут до раја.

Селено –Васељено, Камино, Камино!
Месечина по друмовима ми без краја.

Попут Миткета, јунака из *Коштане*, који види друмове под месечином, тако и наш песник, обузет замамним чарима Луне, доживљава прочишћену афектацију небеског после слетања авиона.

Катја Маринова[13] са химничним усхитом велича з р н о, које храни, и жели му да нарасте „велико,/ као Сунце.“ У њеној лирско-поетској васељени је и мрав, који се са љубављу брине о зрну и „оносветски зрикавци“. Поетеса је доста солидно упозната са етимолошком основом назива зрикавца, па зато песму без наслова започиње речима „Оносветски зрикавци засвираше. / Кренуше са белим коњима / по белим пољима наших душа...“ Зрикавац се понекад именује као „божји коњ“ на пример на руском северу,[14] али он је и оносветски, када су у питању разастрта поља душе. У сличном тону, она завршава песму, помињући зрикавце и њихову свирку, „да би могле / наше препорођене душе / да напусте храмове“. Храмови су једна врста микрокосмоса и претстављају могуће место за пребивалишта божанске природе,[15] па зато поетеса и указује на тај духовни аспект.

У песми означеној бројем „3“, развија се једна врста паралеле између мрава и њихове многобројности[16] и више пута апострофираног зрна и зрневља, које такође упућује на мноштво, али поетеса зрну, у неким моментима, придаје и космичка значења, па ту надовезује и напред поменуте зрикавце, који без зрачне снаге Сунца „нису могли да живе / да би свирали.“ Она особину многобројности мрава доследно и са пуно истанчаности остварује у корелацији са зрневљем, под којим мрави сагињу леђа и подчињавају му се, али и брину о њему са љубављу.

[13]М. С. Димитријевић, „Вечно препорађање неба и земље у стиховима Катје Маринове“, *Зборник радова конференције „Развој астрономије код Срба V*, стр. 779-780.
[14]Александар Гура, *Симболика животиња у словенској народној традицији*, Београд, 2005, стр. 387.
[15]Ц. К. Купер, *Илустрована енциклопедија традиционалних симбола*, стр. 50.
[16]А. Гура, исто, стр. 383.

Поетеса Улјана Паскалева успешно негује хаику песничку форму и лирски је обогаћује небеско-космичким сликама. Посматрајући димњак, који у ноћи наизглед додирује Месец, она ту поетску визију претаче у хаику тростих:

Високо небо –
Месец још млад
пробада димњак.

На занимљив и лирско надахнути начин Улјана Паскалева гради космичко – поетску слику љубавног заноса, који води на „седмо небо“, „Шестокраки зраци“ из „кадифених“ очију њеног драгог, чаробно милују „њену ауру“ и разлиставају овоје њене душе, тако да је остао само један атом

Који ангелогласно запева,
разбуди јој све ћелије
и одапе их право горе,
где начини од њих ново Сазвежђе...

Она пева и о особеној врсти „космичког сливања“ помињући „небески звездолет“, који доводи у непосредну везу са собом и својом нутрином. Под шекспировским насловом „Сан мајске ноћи“ и она се обраћа зрикавцима, који започињу свој концерт: „Шумска вила / је слушала, / и претворила се у цвет.“ Цвет овде оличава женски принцип и посудасти облик, који је у лирској вези са шумском вилом. Поента ове песме је у знаку анђела на небу што „у дугу се разлиста“. Дуга, поред осталог, симболизује преображење, као и небеску славу; она је мост између овог света и небеског раја; а у односу на све претходне космичке симболе, она у завршници може да претставља чаровити престо Бога неба.[17]

На Ангела Ангелова, професора на Факултету музичке уметности у Пловдиву, овде ћемо се осврнути у једном помало неуобичајеном лирско-мемоарском тону. Срео сам га у Пловдиву, заједно са поетесом Јорданком Брзинском Дандан, када сам са Милчом Цветковим путовао на Рожен, због организовања Седме бугарско-српске астрономске конференције. Са њима смо обишли знаменитости овог древног и славног града, античког Филипополиса и престонице кнежевине Источне Румелије, због чијег је уједињења са Бугарском, краљ Милан 1885. неславно заратио са нашим суседом. Ангел нам је испричао низ пикантних и занимљивих појединости, које су ми помогле да темељитије дочарам лепоту и необичност пловдивских културно-историјских споменика и занимљивости српским учесницима, које сам на путу за поменуту конференцију провео кроз овај град.

У Ангеловој лирици, љубавни занос и жена и њене чари су средишње теме, којима песник често даје небеско значење.

[17]Ц. К. Купер, *Илустрована енциклопедија традиционалних симбола*, стр. 39.

да бих те имао
залепио сам на небо
звезде
које је неко
скинуо
да бих те имао
широко сам отворио
двери
свих Васиона.

Описујући љубавно спајање са својим „сунашцем“, и надолазећи врхунац каже:

Страхујеш од урагана који се ближи
(нас двоје смо му у оку)

а сада види два сунца на небу.

Узносита пловдивска поетеса, Јорданка Брзинска Дандан, коју сам упознао заједно са Ангелом у овом граду а са њом сам суделовао и на Мелничким поетским вечерима, у песми *Отвори прозор*, крајње лапидарним стиховима пева:

Љубе се
сунце и земља.
Зачињу пролеће.

Ветар је дунуо
вест да разнесе.
Отвори прозор.

Прозор се отвара зраку и васколикој светлости Сунца, али и светлости Земље и у том смислу симболизује свеколику способност примања и пријемчивости; он је својеврсно отворено око простора у коме се зачиње пролеће и вазноси ветар.[18]

Поетеса је као и њена песма о зрачно отвореном прозору, окренута универзалним симболима који означавају једну врсту првобитног савршенства. Њен поетски „Незавршени круг“ је свеукупни симбол потпуности и целовитости.[19] Он скоро да нема почетка ни краја и као такав укида време и простор у име васпостављања љубави.

[18]Ж. Шевалије, А. Герберт, *Рјечник симбола*, Загреб 1987, стр. 536.
[19]Ц. К. Купер, *Илустрована енциклопедија традиционалних симбола*, Просвета-Нолит, Београд 1986, стр. 79.

у ходницима мисли
ноћ се мота
на љубав
са тобом игра

Круг који симболизује циклично кружење око ње, „описује срећу“ у смислу бескрајног кретања и неомеђености.

Зинаида Чаушева[20] обликује песму од бројних питања, која понекад имају и реторско-поетски карактер. Песму *Небо од питања* почиње допадљивом сликом о летњој роси, служећи се овом истанчаном симболиком; јер роса је нека врста небеског благослова, [21] па у том смислу она отвара питање:

Окупана у летњој роси,
да ли сам прочистила душу
до следећег лета.

Роса се овде показује као животворна милост, која прочишћава душу. У наставку, она се обраћа питањима љубави, захватајући оно што је дубока човекова нутрина. Доброта јој је штит за опстајање, нарочито у тенуцима дубоке усамљености. При том поставља питање шта ако је срећа само илузија, док су бол и патња тегобна свакодневица. Људскост коју истиче поетеса, управо се доводи у непосреднију везу са обличјем душе изражене у знамењима.

У средишњем делу песме, она помиње врапца, коме је помогла да полети („Зар не спасих у себи изгубљену људскост?“). Врабац се у словенској народној традицији појављује у знаку брачне и љубавно-еротске симболике. У неким фолклорним текстовима, он се повезује и са народним играма, посебно у руским божићним песмама и плесовима.[22]

Неко тајновито небо саздано од бројних и сваковрсних *питања* испуњено је тугом; а поменута роса у почетним стиховима у завршном делу песме доводи се у непосреднију везу са кишом која напаја земљу, како би се родио нови живот. „Вода је свака киша, / вода од летње росе, у којој се окупах.“

Симболика росе је у многим традицијама блиска симболици кише. То је поетеси Зинаиди знано, Међутим она у наведеним стиховима као да призива неку врсту бисерне росе божанског порекла. Јер њена роса не заборавља далеке и неостварене снове. То је небеска роса, која је сва у знаку непрекидне обнове.

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[20]М. С. Димитријевић, „Антологијски стихови Зинаиде Чаушеве поетесе сунца и љубави“, *Зборник радова конференције „Развој астрономије код Срба V*, стр. 790-791.

[21]Ж. Шевалије, А. Гербрант, *Рјечник симбола*, стр. 566.

[22]Александар Гура, *Симболика у животиња у словенској народној традицији*, Београд 2005, стр. 445.

Песма под симболичким насловом *Деца у замку под звездама* Маје Митове је антологијска по својој вредности, веома слојевита и вишезначна[23] па би у том смислу захтевала студиозну анализу скоро сваке слике, песничке синтагме и полифоно разуђене симболике. Полифонију овде помињемо у смислу вишегласја присутних у појединим космичким појавама, потом у слојевитом погледу на свет поетесе Митове. Песма у овом погледу отвара својеврстан унутрашњи дијалог и могућност промишљања о најразличитијим стварима, укључујући ту распоред и композицију појединих целина, које воде ка поенти песме.[24] Наш је утисак да ма како био целовит и обухватан студијски приступ песми *Деца у замку под звездама*, скоро увек ће, због њене свестране отворености, бити могућности за доградњивање и даље развијање њених лирских визија и представа а да се при том не саопшти и она последња и дефинитивна реч и одредница.

При замишљеном повратку у детињство и напуштени велелепни, свенебески и људски замак, поетеса би да у љубавном заносу склони све вреже и лијане са улаза и да ускочи у «пролаз за двоје». При том би оживео онај старински, древни намештај, са својим чаробним мирисима, скривен под «загорело бело». Ово сивкасто белило у поетском и ликовно-визуелном смислу има изузетно значење, а поетеса га је употребила на најбољи начион, како то чине велики, у много чему недостижни, сликари попут Клода Монеа (*Ефекти магле*, сивобеличасти дим парњача на станици Сен Лазар) и Саве Шумановића (на пример *Шидски друм*).

Поетеса патину минулог времена метафорично види као «рђу година», коју жели да претвори «у прах напуштен од тишине». У бочицу, која путује безвременом, убациће смрвљене часове - и тако збрисати протекло време, на свом путу ка детињству. А потом, протрљаће крик у коприви да на величанствено поетски начин «поткује травњак на прагу». Особена флора попут коприве, врбе, травњака са својом вишезначном симболиком, обогаћује дух овог певања. А ту је и галоп разиграним бескрајима.

[23]Вишезначност и семантичка основа на којој овде инсистирамо је категорија такозване *Нове критике*. По мишљењу Виљама Емпсона вишезначност се односи на различита и сваковрсна значења одређеног израза у речнику, али и „на све, чак и најсуптилније вербалне нијансе, које омогућавају различите реакције на један те исти део језика [*piece of language*]. – William Empson, *Seven Types of Ambiguity*, 1930.

[24]Појам полифоније у књижевности увео је Михаил Бахтин у анализи дела Достојевског. „Појам полифоније је у тесној вези с појмом недовршеног дијалога у коме никада не бива изговорена последња реч.“ – М. Бахтин, *Estetyka twórczości słownej*, 1941, у *Problemy literatury i estetyki*, наведено према књизи Ана Бужињска, Михал Павел Марковски, *Књижевне теорије XX века*, Службени гласник, Београд 2009, стр. 173.

Галопираћемо њеним разгранатим бескрајима.
И на реци ћемо разседлати плаво.
А чим јутро спусти беле завесе,
стазе ћемо обавити тајнама.

Стазе обасјане звездама, којима се поетеса кретала са својим садругом, скрива од дневне вреве обавијајући их тајновитим. Она их завештава гласнику-претечи да их објављује када им «месечева кандила» што украшавају небо, опет дарују мистичну светлост ноћи. Поетеса жели да се добош којим гласник објављује вест да је она зауздала и покорила време и опет постала дете, чује и у оном другом свету – сада и овде, извештавајући о њеној победи.

На крају, поново се враћа замку, уочавајући при том магичну звездану спиралу којом ће «сићи двоје деце». Замак детињства је својеврсна склонитељска небеска кућа, која се имагинативно остварује звезданом спиралом што може да оличава свеукупност и вечност. У поетској спирали је присутно бесконачје, као и могућност враћања у безвременост, која оличава свевременост, младалаштво и детињство.

Структура ове песме, њена оригиналност, лирска осмишљеност, врло прикладне стилско изражајне појединости те садржај и мотивске преокупације, произилазе из дубоко проживљене потребе поетске реинкарнације песничког бића и поетесиног трансмодерног враћања и реверзибилности. Даровита уметница овде полази само од унутрашњих нагонских импулса за које тражи суптилно и танано поетско рухо и заодевање у лирске визије, које далеко надмашују ону јужносрбијанску, балканску, миткетовску *жал за младост*.[25] У овој песми Митова врло вешто прожима и преплиће оно што је дух модерног поетског израза, са традиционалним, на моменте архаичним, подижући све то на виши ниво општељудске и универзално драматске представе о пролазности и изминућу скоро свега на овом свету и у животу. Она мајсторски бира појединости којима ће песнички и уметнички оваплотити слику минулог детињства са призивком да се оно оживотвори у младалачки замишљеном и велелепном небеском замку под астралним сводовима.

Преостају нам даља студиозна преиспитивања вишедимензионалности и модерне, скоро додекафонске музичко поетске осмишљености песме Маје Митове *Деца у замку под звездама*.

Пред читаоцима је и песма без наслова (*Као таласи године пролазе)*, истанчаног песника-астронома Петка Недјалкова, професора Софијског универзитета, који посебно велику пажњу поклања беспрекорној рими и математички прецизној организацији песме. Због особитости његове поезије и професионалне окренутости звездама, овде смо га, као астронома-песника

[25]Бора Станковић у нашироко познатом делу *Коштана* са играњем и певањем, у најелементарнијем смислу, али дубоко људски и истинито изражава поменуту жалбу.

уврстили мада не припада песничком клубу „С Геом на Редуту“. Недјалков живот и његове недаће и ударце, лирско-поетски претставља као пловидбу по немирном, узбурканом мору. Недјалков је започиње лепим поређењем „као таласи године пролазе“... Таласи су, као што је познато, у сталном и непрекидном кретању, и као такви, назначавају ток промена и илузија.[26] Године бесповратно пролазе: „Нас двоје, док нас бриге ломе, газе / сами претварамо живот нам у Ад.“ Ад је место недоокучиве патње, па то претварање живота у паклену ситуацију и има продубљену психолошку и етичку утемељеност. У тај контекст укључује се својеврсна конфликтна ситуација људске психе... Урањање у таласе указује на раскид са уобичајеним; а само храбри и одважни имају снаге да се изборе са валовитим ударима судбине и да њихов налет дочекају грудима. А то је у знаку борбе за егзистенцијални опстанак и истрајавање: „А затишје је увек санак сваке буре / и морски закон је – да стењеш тишином.“ Као научник и песник, он се лирски обраћа морским законима. А симболика тишине, коју овде помиње у извесном смислу, надовезује се на тишину о којој пева у раније објављеној песми *Буђење*.[27] Астроном-поета, када га са вољеном вода заврти у своје „спирале – нежне млечне путе“, дочаравајући небо, украшено сјајем далеких звезда наше Галаксије што видимо као раскошно – чаробну траку названу тим именом, жели да им се душе „усмере на горе па да / стигну у други – звездани океан“.

Пошто смо у претходном периоду остварили увид у доста широк и обухватан круг савремених бугарских песника, у чијем смо узноситом певању препознали низ астралних симбола,[28] за ову прилику издвојили смо, према личном афинитету, једанаест књижевно-поетских стваралаца, од којих је већина присутна и у ранијем представљању,[29] уз придруживање нових.[30] Међу њима постоји извесна мотивско-тематска блискост, по линији односа према животворним појединостима које уносе у своје стихове, клонећи се апстрактних лутања; уз настојање да изворно оваплоте своје аутентичне песничке доживљаје. Поетски израз им је оплемењен суптилнијом симболиком, и то не само када су у питању космичке преокупације, већ и наизглед ситне, али занимљиве лирске појединости попут математичких формула и симбола, теорије релативности, љубавне преданости, сићушних мрава, кастањета, певања цврчка и сл. Песничка форма им је врло разнолика, од лирске

[26]Ц. К. Купер, Исто, стр.169.

[27]М. С. Димитријевић, «Поезија науке и наука поезије Петка Недјалкова», *Зборник радова конференције «Развој астрономије код Срба V*«, Београд, 2009, стр. 282-286.

[28]М. С. Димитријевић, „Савремена бугарска поезија; Клуб песника „С Геом на Редуту“ и чаровитост лирско-космичке инспирације“, *Зборник радова конференције „Развој астрономије код Срба V*, уредник М. С. Димитријевић, *Публикације Астрономског друштва „Руђер Бошковић*“, Св. 8, Београд, 2009, стр. 759-791.

[29]Евгенија Маринчева, Рајчо Русев Рајсин, Илијана Илијева, Милчо Кирилов Цветков, Катја Маринова, Зинаида Чаушева, Маја Митова, Петко Недјалков,.

[30]Улјана Паскалева, Ангел Ангелов, Јорданка Брзинска Дандан.

дескрипције, преко интимистичког певања, до сажетих хаику стихова. Песнички израз им је у знатној мери однегован, понегде лирски истанчан, са дубљим емотивно-сазнајним означењима. Поред стилске неуједначености, већина овде присутних песника доследно гради своју поетску визију света, трагајући за новим и релативно мало обрађиваним темама, које обликују у сагласју са својом концепцијом света и живота. Ови и други препеви, уз самоназначене опаске и коментаре, у даљој перспективи могу да представљају добру основу за један мали избор из њиховог стваралаштва.

Овде понуђена остварења једанаест бугарских песника, дају јасну слику не само о њиховим поетским дометима и умећу, већ и о разноврсним лирским могућностима за надахнуто поетско описивање неба и чаробних појава и објеката који га украшавају, надахњујући не само астрономе, него и песнике, сликаре, писце, филозофе и људе који уживају у његовим лепотама.

ЕВГЕНИЈА МАРИНЧЕВА

Округли Месец

Ове вечери кривац за моју несаницу
је
округли Месец.
Он осветљава моје мисли,
мада то нема смисла,
само ти си у мени.
Али нека се и Месец увери –
видеће само тебе.
И да ли знаш?
Није Он крив!
Крив си ТИ!

На Месечевој светлости

Када вечерас легнеш,
затвори очи,
и пусти Месец да проникне у твоје мисли.

Одговориће ти на необична питања –
ко сам ја,
зашто те надахњујем,
зашто ти дајем своју љубав,
зашто сада...
и зашто на такав начин.

Немам више питања

Упитала сам Месец
зашто и од када је преузео све моје.
Одговорио ми је, да је стар,
и од када се сећа, тако је.
Да питам звезде.
Оне ме одведоше Сунцу,
које ми шапну:
Питај своје срце!
Више
немам
питања.

Пун Месец

Видела сам ... пун је Месец.

Наш стари гласник,
помилова ме нежно
и рече ми,
пожелећеш ме.
Пољуби ме ваздушасто
и напусти.
Отишао је код следећих заљубљених.

А ја остадох,
ослушкујући таму...

Пун Месец

Треба ми сан...
а он не долази.
Уместо њега – идеш Ти –
најлепша приказа у пустињи
мојих осећања.
Протежем руку, да те додирнем
али ти нестајеш,
остављаш ме саму усред пешчане
пустоши...
Не љутим се.
И без тога сан не долази.
Зато се опет јавља
следеће чудесно привиђење.
Потпуна копија првог.

Математика у доба пуног Месеца

Округли пуни Месец сабира
два тела и две душе у једно.
Недостају
бисекција угла, симетрале,
висине и диференцијали,
медијане, интеграли, лимеси и
тригонометријске зависности.
Решења су
у потпуности у области недозвољених
вредности,
зато што се логаритмује скуп –
нешто апсолутно забрањено!
Нова лема:
Неопходан и довољан
услов:
Скуп се логаритмује
само
по времену спајања
и **јединствено**
у време пуног Месеца.

НЕШТО,
ШТО МИ ДАЈЕ КРИЛА И ЧИНИ МЕ СРЕЋНОМ,
КАДА МЕ НАСМЕЈЕШ –

Сећање,

Да љубиш мој смех.

Лекција из љубави

Страх ме је.
Да ћу бити у белој димензији,
И да ћу желети
Да ти кажем,
Да те волим.

Да ли ћу то урадити.

Учитељ треба да је принципијелан и строг.
Каква иронија...

Једино Бог даје лекције из Љубави!

РАЈЧО РУСЕВ РАЈСН

Путујуће позориште

Месец на танком облаку седи,
На пут смо се, брате, макли.
У звезданим кочијама до мене си ти
Са маском из прошлог спектакла.
Идемо кроз ноћ и велики циркус
Дићи ће своју небеску шатру.
У славу Мудрог што има укус
За тај драги и страшан театар.
Све ће да бљесне на сцени опет.
Не мари што умор те обузе!
Гледаћеш таленте и лепи свет
Чудеса и аплаузе.
А после ће нам прићи Месец –
Наш поштовалац највећи
„Хвала, господо, дођите нам опет
Радоваћемо се таквој срећи!“

Ту смо завршили улогу своју.
Одавде надаље је јасно,
Хеј види над дрветом звезду моју,
А твоја је она десно.

***

МАЛА БУГАРСКО, мајко Бугарско!
Од мале ране највеће су боли.
Мало по мало сви су те издали,
мало по мало сви су те крали.
Мало по мало – Бог да не види
а и Рогатог да не увреди.
Дан да надмудри. Ноћ да превари.
Зар нема таквих? Зар ја сам једини.
Тебе убијају, ја се не огласих...

Мајко Бугарско, мајко Бугарско!
Рекли су: нема те. Беше – су рекли.
Звезде се пале на место свећа.
Ко те убијао? Ко ли те се сећа?

***

ЗА МЕНЕ СИ КАО ИЗМИШЉЕНА.
Као идеја. Као знак.
Истинскија но у другој истини,
Коју ја само сада знам.

Тамо могу да направим све.
Да те преобразим у жену, у цвет.
У чашу вина. Или птицу
После у онај знак опет.

Или да те претворим у стих.
У песму: И ко да ме сневаш,
да чујем, без да знаш то ти,
и саму себи како певаш.

***

ДОЂИ ЗОРО, од мрака ме лечи!
Дођи дане, од таме ме спаси!
Показујте, да се не изгубим,
не падајте звезде, јер закасних.

Немој стазо, ти да ми кривудаш!
Ако паднем, ја сам ћу устати.
Нећу вама, ни смеха ни суза.
Под звездама тражим.
Он је тамо.

***

ДАН И НОЋ СУ НОГАВИЦЕ ДВЕ
од панталона на времену.
Навлачи га да голо не иде,
Када путује кроз Васиону.

Земља је зато час црна, час бела –
зависи којом је ногом рита!
И ја, да му се неби видело,
Да је двоного и без копита,

ситно кривудам и напред гурам.
А синоћ се сетих зашто !
Зато што обе ноге
У један отвор турам!

ИЛИЈАНА ИЛИЈЕВА

Хаику

****

Месец вршидбу`
намеће
дан се смањује.

****

Ледени висуљак
гледа прозор
наопако.

****

Клик! И галеб
ми је у објективу.
Остао је лет.

****

Снежне пеге
у осветљеном сунцем
блату – иде пролеће.

Из збирке Пижо и Пенда[31]

Једна мува
кружи над сунцокретом
до заласка сунца.
Страшило до изласка
гледа звезде.

[31]Пижо и Пенда су имена две мале фигурице направљене од белог и црвеног конца, које се традиционално налазе на мартеници, малом украсу којим се Бугари дарују првог марта, и стављају га на одело. Према старом веовању, када носе црвено и бело, желе да умилостиве Баба Марту да скрати зиму и брже донесе пролеће.

Грех је пут за двоје у звездани прах

тако је – да, то знају сви
тако и премудри старци
у светим Божјим књигама написаше
или су написали да не бисмо знали –
да не би питали – Боже – ако је љубав грех –
шта је онда мржња –
да ли је љубав давање новаца на зајам
и ако је јабука узрок греха –
да ли је грех пред свима пут кроз звездани прах
шта је открио Њутн, да му свако верује без сумње
а све је љубав између Њега и Жене
и не проклија у мисао – рана – из насеља

Ајнштајнов имејл

ако не могу да напишем најлепшу песму за тебе
да ли ћеш ми опростити
ти сигурно - да
не знам да ли ћу и себи ја
желим цео космос на дар да ти дам
само једним додиром
нека буде случајност у теорији вероватноће
у формули за релативност Ајнштајна слово ненађено
ако бих знала његов имејл молила бих га сваки пуни час
за једну научно доказану лаж
да тамо где текст прелази у нови ред
баш тамо има нешто апсолутно

А вулкани су ујутру тихи

После Сатурна, Меркура и Онтарио – Ири
да одемо и на планински врх?
Има чуда у Руанди – жена је Гахинга.
Мухабура има мужеван дух.
Није Вихрен[32] нема језера да ме смири,
али два пут је већи од Олимпа
а вулкани су ујутро толико тихи
да може на њима да се дрема.

[32]Највећи врх на планини Пирин у Бугарској

Не реци не мили, купих ждребе с кобилом
На вашару код Великог Конарета[33] -
преврнух све, дисах прашину и трње –
ал продадох бабине дукате!
Тако нема ништа да нам клепеће успут –
Да нам се причини ко ланци роба.
Јер сам бела жена на твојим грудима
у Африци у црном добу.

МИЛЧО ЦВЕТКОВ

Волим те

Волим те Увече
када изгреју звезде,
и када дуги дан прође,
као црно вино опијају очи те,
када си ти, када у мене дођеш.

Волим те у Јутро,
кад Месец нестаје
када бели дан започне
а ти ме тераш, изгараш, не стајеш
и тло ми се под ногама миче.

Волим те Дању
кад заслепиш Сунце пламено
лепотом, и нема класа и сламе
што међу нас не буде овршано
после љубавне наше помаме.

Волим те Ноћу
јер тада сам он
кога ћеш чекати упркос и потопу
што стиже на коњу а не чује се звон
и преобраћа те у Калиопу.

Волим те Упркос
волим те чак
волећу те и кад Земља нестане
док срце не пукне, нек види свак
да љубав никад не престане.

[33]Село у Бугарској

Волим те Толико
волим те тако
и свесрдно те молим
ово запамти
и не заборави
обожавам да те волим.

Волим те.

Пред звезданим вратима

Софија, Астрономска опсерваторија,
Млад месец, 6.02.2008, 22:23

Ко отвара лако звездана врата ту?
Ко с гитаром пева звезда серенаду?
Ко то плаче сам, самцијат на свету?
Те сузе радости, дају ми награду.

Вече. Млад је месец. Тамна, тамна ноћ.
Кад је тако црна, боље сјаје звезде.
Астроному с лиром машта даје моћ,
а надања нова у души се гнезде.

И упркос ветру, тога зимског дана,
Улазе у салу заснежене поете,
седају тихо, погледа задивљена,
слушају и певају о звездама куплете.

Витешки успеси бљеште сад у тами,
свако је заштитник када тражи дама,
заклетве до неба кад смо с Женом сами,
и од смрти веће истине нам нема!

И стоје на прагу Васионе бездна,
загрљени певају и слушају звезде.
Ту је стало време, и све ишчезава,
астро-поетична маштања нам језде.

Наранџасто небо

Овога јутра наранџасто је небо.
Значи поклон од ветра је коњ, не кобила.
Гледам твоје очи и не сањам то,
већ уздишем, како лепа си била!

Овога јутра сам ветар, и дувам од вечери.
Зато иду као рашчупане птице.
Овога јутра од љубави, не од страха треперим,
и маштања су ми опет простртa на жице.

Ово пролеће неочекивано, тако дуго ишчекивано,
долете са последњим поривом и летом.
Чим не затвори врата, значи чекаш ме,
и не притискам звоно, већ горе идем трком.

Овај дан, у тај час, у овом животу мислим сада,
колико ретко из твога бокала сам пио!
Овога јутра небо је наранџасто, као ћивот било,
у коме није злато већ љубав. И будим се. Осана!

И видим те наранџасту! Катја[34].

Зелено писмо Лорки

Драги Лорка,
Од мене имаш писмо,
просто ти га носим, јер за друго нисам.
Брат ми га, Лорка, Рајсн[35] даде,
не одбиј ме, гомилу ми питања зададе.

Прво да те питамо зашто,
у Шпанији расту маслине?
Грану, две откидох, не сто,
а плаветнило неба сине!

Ако их окренеш, погледај, Лорка:
Као сребрне струне беласају.
Зашто у Севиљи и на Мајорки,
Кастањетама звече и таласају...

[34]Катја је песникова супруга
[35]Рајчо Русев Рајсн, песник и ауторов пријатељ

И зашто фламенко је розе?
И зашто нам крв је црвена?
Само то те питам, Лорка,
знам да је све друго ЗЕЛЕНО!

Антиастро

Доста ми је да говорим уз формуле,
да вам рачунам колко су звезде далеко,
Зашто постоје црне рупе и сјајне флокуле,
на та питања нек вам одговори други неко.

Зашто је Венера врело и загушљиво место,
да ли на Марсу постоје канали и пирамиде.
Како да на Сунцу нема дана, где је несто,
Да ли се све опет врти, а људи то не виде.

Одакле Сатурн има прстене јарке?
Што Јупитер краси црвена пега?
Има ли Титан смарагдне арке?
Зауставите другог - питајте њега.

Уживаћете у његовој астролошкој причи.
Сачиниће вам астралну кућу и хороскоп.
И на истину та лаж ће да вам личи,
ко на ТВ-у биће логично и тип-топ.

Од мене, како ниче нада после кише тражи.
Зашто постоје облаци бели и очи зелене,
ко се све додирује као луд у летњој ражи,
и зашто она увече чека мене.

Луна

Луни Цандевој

Достигох Луну дању – по светлу.
Видех да је риђа, светлоока, блистава.
Макар је од разних метеорита разбита,
плиму ми снаге даје и увећава.

Да ли је измишљена од месечара,
и за њих бледи сјај ноћу ствара.
За њу не само поете безбројне
Праве стихове и пишу поеме.

У природи има врста таква,
што сваки Лунин следи дах.
Од ње зависи будућност је каква
Дал' дишемо, или постајемо прах.
Као штит, забит у етар пред нама,
прва је мета и жртвеник пламен,
све бриге и злобе нам она склања,
што проби је преби небески камен.

Загледан у тебе о света иконо,
на коленима молим пут до раја.
Селено –Васељено, Камино, Камино!
Месечина по друмовима ми без краја.

31. 10.2007 NYC (после слетања)

КАТЈА МАРИНОВА

****

Оносветски зрикавци засвираше.
Кренуше са белим коњима
по белим пољима наших душа.
Свирали су,
да би их чули.
Повлачили су струне
између нас и небивствовања,
да би опседнули ветар.
Ко их чује,
ко осети подстицај
у гривама коња,
срећан је.
Од коњске гриве до растрзане душе
растојање је два педља.
У њима је тело,
зазидано у ћутање.
Оносветски зрикавци засвираше
да би могле
наше препорођене душе
да напусте храмове...

3.

Мрави кренуше.
Полако и сигурно преузеше
тврђаве,
у којима зри зрно.
То, з р н о,
расло је је велико, велико...
Велико,
као сунце,
без кога зрикавци
нису могли да живе,
да би свирали.
То, з р н о,
очекиваше мраве,
зато – да би настао хлеб –
неко је требао да се побрине
о њему са љубављу.
И мрави знадоше,
да су на овој земљи,
да би стварали
нове и нове мраве,
који ће сагињати леђа
под з р н о м!
Нове и нове мраве
који ће се –
подчињени великом закону –
бринути о з р н у
са љубављу.
Мрави знадоше.
И чинише то.
Мрави су се одрекли свега ,
што су други
створили,
зато што је створено било лет,
а о н и су лазили.
Користили су несавршенство
оних закона,
који су давали власт
онима који лазе, забринутима,
предназначенима
да се са љубављу брину
за з р н о.

УЉАНА ПАСКАЛЕВА

НА ПУТЕВИМА ХАИКУА
ХАИКУ КАМЕНЧИЋИ

Изгреви

***

Бледи месец,
Дегаове балерине
прогоне ноћ.

***

Високо небо –
месец још млад
пробада димњак.

***

Ветар воли маглу,
испарења вајају
најдражи лик.

***

Небески знаци –
багремове гране
најдражи поклон.

Сазвежђе

Из кадифених му очију,
са благим мирисом кафе,
излазили су дуги шестокраки зраци,
који су чаробно миловали њену ауру
и разлиставали један по један
безбројне ланене овоје
њене Душе...
На крају је од ње остао
само један атом,
који ангелогласно запева,
разбуди јој све ћелије
и одапе их право на горе,
где начини од њих ново Сазвежђе....

Космичко сливање

Када појашеш небески звездолет,
таласи у мени и ван мене су једно,
а ја сам бамбусово стабло.
Срела сам те по спирали,
и спознала твој сјај,
бесмртна сам, миг – бескрајан,
у лаву ти се увијам
зали ме с Нилом, но прездравих,
а семе од Сиријуса у мени
расцвета се у лотос...

Сан мајске ноћи

Белонога и боса,
на прстима –
у росу загазих.
Била сам корњача –
Са људским лицем.
Загрли ме ветар,
пољуби ме пчела,
заволе ме киша,
зави ме трава...
Сунце ми листиће осуши,
буба мара ми постаде капица
паук ми колевку испреде.
Јабуков цвет
Од олује ме сакри.
Мајски ме бумбар
на плес позове,
љубоморан је багремов цвет.
Префињено зрикавац
концерт ми започе –
ненадмашни Маестро.
Шумска вила
је слушала,
и претворила се у цвет.
Несташан облак.
Даждоносним смехом нас зали,
одозго.
Анђео на небу –
у дугу се разлиста.

АНГЕЛ АНГЕЛОВ

Да бих те имао

обојио сам коња
зелено

да бих те имао
залепио сам на небо
звезде
које је неко
скинуо

да бих те имао
широко сам отворио
двери
свих Васиона

да бих те имао
чудовиште зелено(око)

Заљубљујем се

сунашце моје
сјајиш
сјајиш ми у срдашцу
изгревам и ја
грејем зраком на лицашцу ти
затвори очи
затвори
(да би ме Видела)
отвори душицу
отвори
(да бих се Улио у Тебе)
осећаш
осећаш лепршање лептирастих крила
(то сам ја)
страхујеш
страхујеш од урагана који се ближи
(нас двоје смо му у оку)
а сада види два сунца на небу

Месечев зрак

Месечев зрак додирује
огледала мојих језера.
Планина сам.
По брежуљцима ми
ка теби језера теку.
Огледају се,
додирнута зрацима Месеца

ЈОРДАНКА БРЗИНСКА ДАНДАН

Отвори прозор

Љубе се
сунце и земља.
Зачињу пролеће.

Ветар је дунуо
вест да разнесе.
Отвори прозор.

Незавршени круг

Према заласку
идем и осмехујем се

у ходницима мисли
ноћ се мота
на љубав
са тобом игра

јавно
сунчев над гласић
просипа кокице
спуштају се у дубину

из бразде дугог ишчекивања
изливена радост сестре
мама он је добро
добро је мама

око мене
описује срећу
незавршени круг

ЗИНАИДА ЧАУШЕВА

Небо од питања

Окупана у летњој роси,
Да ли сам прочистила душу
до следећег лета?
Да ли ћу те још волети,
ако ми твоје очи не узврате с љубављу?
А зар ми није доброта
штит за опстајање
пред оштрим ножевима дана?
И чему све када тебе нема,
а сваки дан јечи од самоће?
Шта очекујем ако је срећа илузија,
а бол ми је свакодневица?
Када сам помогла врапчету да полети
Зар не спасих у себи изгубљену људскост?
Небо је испуњено тугом.
И тамо је код послања –
проливена киша да напоји земљу,
а у њој нов живот да се роди.
Тако да буде!
Вода је свака киша,
вода од летње росе
у којој се окупах,
у жељи да те додирне
Роса, која не заборавља,
моје сањање,
тако далеко,
тако неостварено!

МАЈА МИТОВА

Деца у замку под звездама

Када опет будемо деца
свратићемо
у напуштени замак.
Склонићемо лијане са улаза.
Ускочићемо у пролаз
за двоје.

Оживеће древни намештај,
заривен под прегорело бело.
Расковаћемо рђу година
У прах напуштен од тишине.
И убацићемо у бочицу
часове разбијене на мрве.
Непорасла одела из сандука
нагнуће се над колевком
коња врана.
И дивље ће копита полудела
да поткују травњак на прагу.
Протрљаћемо крик у коприви.
Савићемо, препознаћемо је.
Галопираћемо њеним разгранатим бескрајима.
И на реци ћемо разседлати плаво.
А чим јутро спусти беле завесе,
стазе ћемо обавити тајнама.
Завештаћемо их гласнику-претечи.
Да им објављује путеве под новим
месечевим кандилима. А добош да му одјекује
и у оном другом времену.
Са вешћу, да ће у замак
по звезданој спирали
сићи двоје деце.

ПЕТКО НЕДЈАЛКОВ

***

Као таласи године пролазе,
Једна за другом – без повратка назад.
Нас двоје, док нас бриге ломе газе,
сами претварамо живот нам у Ад.

Но нема како – сем да се дубоко гњурнем,
Грудима удар да чекам – ко таласолом.
А затишје је увек санак сваке буре
и морски закон је - да стењеш тишином.

И нека, када нас заврти вода
У спирале си – нежне млечне путе,
да се не гаси љубав наших тела,
да душе опет са надом полете.

За миг застали – на катарци тог брода
што је од таласа бесних љуљан,
поново да се усмере на горе па да
стигну у други – звездани океан.

„WITH GEO ON THE REDOUTE" UNDER THE STARS

Lyracally-poetical creativity of contemporary bulgarian poets Evgenia Marincheva, Raicho Rusev Raisyn, Iliana Ilieva, Milcho Tsvetkov, Katya Marinova, Uliana Paskaleva, Angel Angelov, Jordanka Brzinska Dandan, Zinaida Chausheva, Maja Mitova and Petko Nedjalkov, and cosmical motives in their verses were analyzed and considered.

Зборник радова конференције "Развој астрономије код Срба VI"
Београд, 22-26. април 2010,
уредник М. С. Димитријевић
Публ. Астр. друш. "Руђер Бошковић" бр. 10, 2011, 1125-1132

КОСМИЧКЕ ИНСПИРАЦИЈЕ СТРАТОСА ТЕОДОСИЈУА

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Резиме: Размотрено је и анализирано песничко дело Стратоса Теодосијуа *Универзалне инспирације*..

Евстратије – Стратос Теодосију[1] успешно и плодотворно истражује астрономске идеје и замисли филозофа, писаца и песника старе Грчке, и њихов утицај на наше поимање Универзума; са посебним акцентом на пресократовске мислиоце, чија су дела дошла до нас само у фрагментима.

[1]Др Ефстратиос Теодосију је астроном и ради као ванредни професор Историје и филозофије Астрономије и Физике на Универзитету у Атини. Његова подручја научног рада су посматрачка астрономија, сателитска спектрофотометрија Ве звезда и историја и филозофија астрономије. Објавио је више од 150 научних радова у међународним часописима и зборницима радова са конференција, око 300 чланака у грчким часописима и 15 књига о историји и филозофији астрономије и физике. Ефстратиос Теодосију и Милан С. Димитријевић су били координатори грчке и српске стране билатералног пројекта „Астрономија: Историја и Филозофија" (2004-2008) потписаног између Астрономске опсерваторије у Београду и Физичког факултета атинског Универзитета, а током вишегодишње успешне сарадње (први сусрет на XI Међународној школи за младе астрономе, Хвар 1980, сарадњу започели боравком аутора у Атини 1998, први заједнички прилог 2001: M. Dimitrijević, E. Theodossiou, *Calendar of the Greek Orthodox Church*, 5th Hellenic Astronomical Conference organized by the Hellenic Astronomical Society 20 - 22 September 2001, Fodele Crete, Hellas, Book of abstracts, 2001, стр. 171.),објавили су већи број заједничких радова (на пример: E. Th. Theodossiou, V. N. Manimanis, M. S. Dimitrijević, E. Danezis: 2006, "Nicephoros Gregoras: The greatest Byzantine Astronomer", *Astronomical and Astrophysical Transactions* **25** (2006), 105-118; E. Danezis, D. Nikolaidis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, A. Antoniou, E. Theodossiou: „A new model for the structure of the DACs and SACs regions in the Oe and Be stellar atmospheres", *Publications of the Astronomical Society of Japan* **59**, (2007), 827-834; M. S. Dimitrijević, E. Th. Theodossiou, P. Z. Mantarakis: 2008, "Milutin Milanković and the reform of the Julian calendar in 1923", *Journal of Astronomical History and Heritage* **11** (2008), 50-54.

Више пута је походио Београд и био радо виђен гост и учесник конференције „Развој астрономије код Срба V и VI„. На овој Конференцији, све нас је пријатно изненадио када је, слушајући остале песнике – учеснике, изразио жељу да нам, на грчком и енглеском понуди „космичке“ стихове из прве збирке песама *Универзалне инспирације*[2] и представи нам се као још један астроном-песник.

Предложио сам му да изабере и пошаље три песме са преводом на енглески, да би их препевао, укључио у Зборник и српским астрономима приказао њој непознати вид стваралаштва, ове ренесансно-свестране личности, познате грчкој јавности по веома успешним наступима на телевизији, у серијалима где на занимљив и допадљив начин представља астрономију што нас приближава звездама, укључујући и разне видове њеног присуства у култури, уметности и обичајима. Веома је активан на стручно-популаризаторском пољу, често присутан и у другим медијима, а у широку палету његових интересовања улазе и Византијски ствараоци, грчко просветитељство, и различита филозофска питања и проблеми у космологији, астрономији и физици, као и однос науке и религије. Такође је бескомпромисан и истрајан борац против астролошког сујеверја.

Са енглеског, користећи као додатну помоћ и грчки оригинал, препевали смо три Стратосове[3] песме. У првој, *Божанска светлост* или *Химна астрономима*, лирски понесено, химничним и узноситим језиком, слави астрономе, за које је Земља мала пошто уз помоћ телескопа слободно тумарају „по једва видљивим небеским градовима“, а преко дана се, проучавајући животодавно Сунце и његов „вечни бескрајни пут“, купају у „божанској светлости“. Понесени проучаваоц величанствених домета античке грчке културе, Стратос лирски слави Сунце, које даје живот и топлоту; земљу озелени, а зору чини хомеровски рујнопрстастом, бога Хелиоса, који на блештаво сјајним двоколицама прелази по небу „свој велики, бескрајни пут“.

[2]Стратос Теодосију, *Универзалне инспирације* (на грчком), Публикације Диаволос, Атина, 2010.

[3]У Грчкој, људи имају два имена, по једно на свакој од две варијанте језика које су у употреби. Катаревуса је китњасти, церемонијални језик, који користе Црква, адвокати, пригодни говорници... Теодосијуово име на њему је Ефстратиос, српски Евстратије. Друга варијанта је Димотики – народни, која се користи у свакодневном говору, када га зову Стратос. Слични примери су Константин – Коста, Еманоел – Манос, Хараламбије – Бабис, Георгије – Јоргос. За разлику од научних радова, где се потписује Катаревуса варијантом, Теодосију је на своју прву збирку песама ставио Димотики име Стратос, да би подвукао присност са читаоцима, са којима жели да подели своја лирско-поетска астрономска промишљања.



Слика 1.



Слика 2: *Стратос Теодосију*.

Следећа песма, *На Опсерваторији*, такође је насловљена као *Химна* – сада – *астронома посматрача*. Стратос поетски истиче како у павиљону са телескопом цео дан влада мир, да би ноћу оживео, купола му се отворила а телескоп управио „ка звездама на небу / величанственим световима“. Астроном-песник, „без гласа, запањен“ стоји „задивљен славом небеса“, тражећи стваралачко надахнуће, извориште мисли и разрешење сумње у звездама, које припадају боговима, „трепере и ћуте“. Стратос у њима налази и подстицај за дан који наступа, јер „ноћи са слутњом језде у дневну инспирацију неку“.

Последњу песму, Стратос насловљује „Тајанственој Селени“. Дата је у два паралелна дела, тако да су на левој страни четворостихови, а на десној двостихови, померени тако да се могу укомпоновати у целину. Овај лирски запис може се читати као кохерентно остварење, али и сваки део посебно. И овде Стратос налази надахнуће у старим грчким митовима, легендама и фолклору. Наводећи њена различита грчка имена: Селена, Селана, Хтонија, Мена, Титанис, Хеката, Феба, рођачке везе са другим древно-грчким олимпијским бесмртницима, песник је узносито понесен и задивљен „бледом лепотом“ Луне, која „наоружана белином“ светлости што јој дарује брат Хелиос – Сунце, разгони таму ноћи, истичући да је мера времена, чије су ћерке Часови – Хоре а ујутру је следи богиња Зоре – Еос (Еја).

Судећи по овим песмама, Стратос Теодосију је једна врста химнода – певача химни сличних онима у античкој Грчкој, и то нарочито онда када помиње митолошке личности и богове. Из његових стихова избија свечани тон, који је сав у славу онога о чему пева. Ту су присутни култни и хијератски елементи. Ова карактеристична хорска лирика у појединим моментима као да захтева једну врсту музичке пратње. Вредно је помена да он у тај свечани химнички дух и тон уноси модерне елементе и када је у питању форма стиха, као и њихова спретна и самосвојна композиција у погледу унутрашњих повезивања, преплета и прожимања.

Стратос Теодосију се у напред истакнутим песмама показује као добар зналац митолошких и култних предања, у која уноси извесну разиграност, која даје ритам и мелодиозност његовом певању. Песма *Тајанствена Селена* недвосмислено показује да Теодосију, поред осталог, припада и групи такозваних учених песника (poeta doctus), или су му они блиски, нарочито када је реч о грчким песницима Александријске школе и хеленистичке епохе. У том смислу, његова поезија је веома складна по форми и у техничким појединостима. Скоро у целини његовог певања присутне су митолошке алузије и паралеле, уз наглашену ерудицију, која из њих зрачи. За пуније разумевање поменутих, и других, његових стихова, потребно је шире познавање грчке митологије, класичних извора и традиције.

Збирком песама *Универзалне инспирације,* Евстратије – Стратос је преточио своју стваралачку обузетост и задивљеност достигнућима античке грчке цивилизације и астрономским лутањима телескопом по чарима и лепотама неба „наоружаног звездама“, како каже песник Леонид Мартинов,[4] у лирско-поетско остварење, којим нам се приказује и као даровити и истанчани песник химничних стихова. Митолошки и култни аспекти су веома присутни у његовом певању, па тај модерни поетски глас и израз, заоденут митским и астралним визијама, богати савремено песништво.

[4]М. С. Димитријевић: „Ноћ наоружана звездама – Космичка поезија Леонида Мартинова, *Васиона*, бр. 5, 2003, 158.

СТРАТОС ТЕОДОСИЈУ

Божанска светлост
(Химна астронома)

Ми мали пролазни смртници,
када гледамо светло-дајућег Сунца
вечни, бескрајни пут,
у божанској се купамо светлости!

Као астрономи, о Боже, каква част!
Када посматрамо, за нас вечне,
Безбројне, звездосјајне,
спиралне путање...
Земља је мала за нас,
ми слободно лутамо
једва видљивим звезданим градовима.

На Опсерваторији...
(Химна астронома – посматрача)

Уточиште астронома младих
Опсерваторија сива.
Цео дан остаје у миру,
а ноћу постаје жива.

Тешка се купола окреће,
и мали отвор се шири.
Ка звездама на небу далеко
величанственим световима вири.

Без гласа запањен стојим
задивљен славом небеса.
И ноћи чекам и бројим
да видим звездана места.
Вишебојна светлости игра,
звезде трепере и ћуте.
Да ли ћу ... телескопом кад мерим,
разорити астралне путе.

Боговима припадају звезде,
а мисли и сумње човеку.
Ноћи са слутњом језде
у дневну инспирацију неку.

Тајанственој Селени

О тајанствена Хтоњанка[5]
Селена[6] моја и Феба,
Дете Хипериона,[7]
Ћерка богиње Теје.

[5]Богове подземног света Грци су именовали као Хтонске. Њима је владао мргодни бог Хад и његова краљица Персефона. Термин Хтонски богови такође је употребљаван за богове земљорадње. Међу њима су, између осталих, Хипнос, бог снова, Никс, богиња ноћи, Онири, демони снова и Хеката, буквално „одаљена“, богиња магије, вра̨бине, ноћи, Месеца, духова, вештичарења и магијског призивања духова мртвих. Она је једино дете Титана Перса и Астерије, од којих је добила моћ према небу, земљи и мору. Идентификује се са низом других божанстава укључујући Селену-Месец, Артемиду, арголидску Ифигенију, беоћанску нимфу Херкину и другим. Пребивала је на «гробницама» и местима «где се пресецају два пута». Артур Когерел, *Речник светске митологије*, Нолит, Београд, 1998, стр. 226. Aaron J. Atsma, *Theoi Greek Mythology; Exploring Mythology in Classical Literature and Art*, http://www.theoi.com/greek-mythology/underworld-gods.html

[6]Селена, латински Луна, била је богиња Месеца, односно Месец персонифициран у божанско биће. Била је ћерка Титана Хипериона и Теје, а сестра Хелиоса Сунца и Еос (или Еја) Зоре. Називају је такође Феба, као сестру бога Сунца Хелиоса који се зове и Феб. Описују је као веома лепу богињу, са дугим крилима и златном дијадемом, а Есхил је назива „око ноћи“. Као и њен брат Хелиос по небу путује у кочијама које вуку два бика, или јаше на коњу, мазги или бику. У класично доба Месец су поштовали само варвари, а касније Селена је поштована као божанство и поистовећивана са Хекатом, Артемидом или Изидом. У народним веровањима је поистовећивана са магијом и разним болестима. Драгослав Срејовић, Александрина Цермановић-Кузмановић, *Речник грчке и римске митологије*, Српска књижевна задруга, Београд, 1992, стр. 378, Исто, http://www.theoi.com/Titan/Selene.html

[7]Хиперион је био најпре епитет и име бога Сунца, Хелиоса, а касније један од Титана, бог светлости, један од синова Урана (Неба) и Гее (Земље) и отац небеских светлости, Еос (Еје) - Зоре, Хелиоса – Сунца и Селене - Месеца. Супруга му је била Теја, дама етера – сјајног небеског плаветнила. Име му значи „гледајући одозго“ или „онај који иде горе“, од грчких речи *хипер* и *ион*. Био је један од четири браће Титана, који су са Хроносом сковали заверу да кастрирају свога оца Урана. Када је Уран (Небо) дошао супрузи Геи (Земљи), Хиперион, Криос, Којос и Јапет су се поставили на четири стране света и ухватили и држали оца док га је Хронос – Време кастрирао. У овом миту, четири Титана су персонификација великих стубова, који у блискоисточним космогонијама држе раздвојене Небо и Земљу. Као отац Сунца и Зоре, Хиперион је несумњиво био Титан – Стуб истока, а његова браћа, Којос, Криос и Јапет, персонифицирају север, југ и запад. Титане, синове Урана и Гее, са власти је скинуо Зевс и бацио их у таму Тартара, који Хезиод описује као празнину која се налази испод темеља свега, где су корени земље, мора и неба. *Речник грчке и римске митологије*, стр. 485, исто http://www.theoi.com/Titan/TitanHyperion.html

Твој брат Хелиос,
нуди ти своју светлост.

На колима са два коња
на небесима „лелујаш“.
Ти си мера времена
светлошћу пуниш ноћ и дан.
.
Еос, твоја лепа сестра
следи те ујутру.

О богињо наоружана белином...
Мена[8] и Титанка,
отерај сместа
таму ноћи.

Ти си славна жена.
Хеката ти је име.
Хоре[9] су твоје четири кћери
Пандија[10] ти је посвећена.
Зову те Селана
Као Хтонији ти се моле.

Али ја сам... Селено задивљен,
Твојом бледом лепотом.

[8]У грчкој митологији Мена се јавља као име богиње, која управља лунарним месецима и понекад се поистовећује са Селеном. Познате су и педесет Мена, ћерке Селене и Ендимиона, које представљају педест лунарних месеци четворогодишње Олимпијаде, основне јединице у античком грчком мерењу времена. Исто http://www.theoi.com/Titan/Menai.html.

[9]Хоре или Часови су биле божанска бића која управљају сменом годишњих доба и „брину да чокот расте и жито зри“. Управљале су окретањем небеских сазвежђа помоћу којих се мерила година. Такође су чувале капије неба и цео Олимп, и окупљале звезде и сазвежђа на небу. У грчкој митологији постоји више врста Хора, а као родитељи се углавном спомињу Зевс и Темис, али према неким изворима, четири Хоре које персонификују годишња доба, потекле су од Хелиоса и Селене. Касније су Хоре схваћене као алегоријске фигуре, као персонификација годишњих доба, неких од месеци, или часова. Исто стр. 491, исто http://www.theoi.com/Titan/Selene.html.

[10]Атички фестивал у старој Грчкој о чијем карактеру има доста несугласица, али је према некима био посвећен богињи Месеца, чија је једна од многобројних кћери Пандија, по другима атичком краљу Пандиону или самом Зевсу, *Dictionary of Greek and Roman Antiquities,* ed.William Smith (1870), Стр. 861, http://www.ancientlibrary.com/smith-dgra/0868.html.

МИЛАН С. ДИМИТРИЈЕВИЋ

COSMICAL INSPIRATIONS OF STRATOS THEODOSSIOU

Poetical work *Universal Inspirations* of Stratos Theodossiou was considered and analyzed.

Зборник радова конференције "Развој астрономије код Срба VI"
Београд, 22-26. април 2010,
уредник М. С. Димитријевић
Публ. Астр. друш. "Руђер Бошковић" бр. 10, 2011, 1185-1189

ПЕСНИЧКИ ДЕКОНСТРУИСАНА ЛИРСКО-СОНЕТНА КОСМОГОНИЈА У ИЗВРНУТОМ ОГЛЕДАЛУ

Поетски дар Петковићевом уздарју

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Резиме: Анализирано је певање Ђорђа Петковића *Геини астралци*.

Ђорђе Петковић већ више година континуирано и доследно обликује деконструисане сонете са репом и с акростихом у огледалу.[1] У том смислу он је на трагу нових, модерних стремљења у уметности и стваралаштву. Временски гледано то се ситуира у авангардне и постмодерне токове у уметности, што се углавном односи на последње деценије прошлог миленијума и почетак новог. При том он следи тенденције постструктурализма и деконструкције Жака Дериде, уз аспекте асиметричног концептуализма, трансавангарде и технолошког постмодернизма, посебно када је у питању *акростих у огледалу*.

Сонет је, као што је познато, веома сложен и деликатан песнички облик, који се састоји од 14 стихова.[2] Ђорђе Петковић се већ неколико деценија

[1]Ђ. Петковић, *Деконструисани сонети са репом и с акростихом у огледалу*, Зборник радова конференције «Развој астрономије код Срба IV», Београд, 22-26 април 2006, уредник М. С. Димитријевић, *Публикације Астрономског друштва «Руђер Бошковић»*, бр. 7, 2007, стр. 593-601.
Ђ. Петковић, *С Београдске звездарнице*, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18-22 април 2008, уредник М. С. Димитријевић, *Публикације Астрономског друштва «Руђер Бошковић»*, бр. 8, 2007, стр. 723-728.

[2]Сонет је један од најзначајнијих и «најраширенијих метричких облика из италијанске књижевности», веома строг у композицији и то тако што се први део састоји од два катрена од по четири стиха са обгрљеним римама (abbaabba) и од два терцета од по три стиха са римама (cdecde) или (cdccdc). *Речник књижевних термина*, Институт за књижевност и уметност у Београду, Нолит, Београд, 1992, стр. 801 (друго допуњено издање); Тања Поповић, *Речник књижевних термина*, , Logos art, Београд, 2007, стр. 683.

бави сонетном формом, као и акростихом. Негује га тако што му почетна слова стихова, читаних одозго на доле, представљају неку посвету или име личности. А он то све сагледава и у *огледалу*, тако што додаје једну врсту наставка у обрнутом поретку, с тим што се у другом делу најпре појављују терцине, а потом катрени; а име или посвета исто тако у другом случају почиње одоздо ка првој терцини, као у замишљеном огледалу. Осим два сонета у овој оригиналној и самосвојној Петковићевој песничкој форми, у средишњем делу, почев одозго наниже и одоздо навише, додаје се по један стих у смислу особеног *репа*.

У средишту овог вида Петковићевог певања, увек су присутне космичке теме и мотиви. Тако у првом захвату, деконструисане сонете са репом и акростихом у огледалу, посвећује организаторима конференције, потом знаменитим песницима сигнализма Мирољубу Тодоровићу и Миливоју Павловићу, аутору *Беле књиге*, као и небеском сликару Сретку Дивљану.[3]

У наредном захвату, Ђорђе Петковић се определио да, као и у претходној прилици, сачини одговарајућу поетску публикацију, коју је у астралном духу насловио *С Београдске звездарнице*.[4] За основу овог свог певања, узео је односно „деконструисао“ стихове из антологије песама о космосу *Космички цвет*.[5]

За VI Конференцију „Развој астрономије код Срба“[6] Петковић је надахнуће нашао у *Зборнику* са претходне, у коме је представљен један део савремене бугарске астро поезије, настале у оквиру клуба песника „С Геом на Редуту“.[7] Као подстицај послужио му је обухватан прилог уредника поменутог *Зборника*, озрачен лирско-космичким визијама бугарских песника. Овај најновији прилог Ђорђа Петковића је сав у знаку уздарја Милану и Милчи Кирилову Цветкову.

Занимљиво је да је Петковић за наслов свога певања узео слојевити и вишезначни симбол: песник Гео (Милев) – Геа земља, на чијој се травнатој површини, која лиричарима даје антејску астралну снагу, одржавају састанци. Песнички сусрети остварују се у познатом софијском парку, који

[3]Ђ. Петковић, *Деконструисани сонети са репом и с акростихом у огледалу*, Зборник радова конференције «Развој астрономије код Срба IV», Београд, 22-26 април 2006, уредник М. С. Димитријевић, *Публикације Астрономског друштва «Руђер Бошковић»*, бр. 7, 2007, стр. 593-60.

[4]Ђ. Петковић, *С Београдске звездарнице*, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18-22 април 2008, уредник М. С. Димитријевић, *Публикације Астрономског друштва «Руђер Бошковић»*, бр. 8, 2007, стр. 723-728.

[5]М. С. Димитријевић, *Космички цвет, антологија песама о космосу*, Просвета, Београд, 2003.

[6]Београд, 22-26. април 2010.

[7]М. С. Димитријевић, *Савремена бугарска поезија, клуб песника «С Геом на Редуту» и чаровитост лирско-космичке инспирације*, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18-22 април 2008, уредник М. С. Димитријевић, *Публикације Астрономског друштва «Руђер Бошковић»*, бр. 8, 2007, стр. 759-791.

носи име овог легендарног поете, чији је карактеристични лик препознатљив и присутан широм Бугарске.

У првом сонетном певању Петковић узима Милчове песме *Сиријус* и *Поклон* (посвећену аутору овог текста); и на основама „деконструисаних" појмова из поменутих стихова, гради своју лирски понесену представу, повезујући Витошу са Авалом, вазносећи „идеале с обе стране Сиријуса", најсјајније звезде, уводећи и „виртуелну њиску" тајновитог „Трачког коњаника". У своје певање Петковић хуморно-иронично спаја астрономе и бугарске комите од којих Васиона тражи да је признају за своје светилиште стиховима:

Васиона иште преко сателита
Од астрокомита да је светилиште.

Наредна песма је надахнута стиховима *Ти, Песма зрнима, Питагорино огледало* и *Месечева птица* поетесе Маје Митове. У певање бугарске уметнице он преплиће разуђене асоцијације на српске мотиве, јунаке и имена. При том, на основу Мајине подстицајне поетске речи, о болести слетелој са Птичјег месеца – ванземаљским грипом осећања, Петковић хуморно истиче:

Месечева птица са грипом у кљуну
Истискује куну да јесте ништица.
Ту јалове звезде од помоћи нису,
Оне су на вису Војводе Пријезде.

У *Песми зрнима* Маја призива Коњаника да златником на жетелачком пешкиру, откупи песму зрна на њеним грудима „Бар – за још једну ноћ", а Петковић је то престиховао стављајући акценат на емотивно-еротске елементе:

Ето, с твога зрна овај сонет ниче,
....
А падоше петли испред коњаника,
Вештица их чика на брезовој метли.

Овде се Ђорђе служи појединостима из српске народне традиције, према којој се петао у неким веровањима појављује као демонска животиња,[8] што донекле важи и за коња, који се везује за чудовишта доњег света.[9] Вештице

[8]Ш. Кулишић, П. Ж. Петзровић, Н. Пантелић, *Српски митолошки речник*, Нолит, Београд, 1970, стр. 233.

[9]Према фолклорној традицији, коњ је једна од «најмитологизованијих» животиња (...) оличава везе са светом натприродног, оносветским, и истовремено је атрибут

се у српској митологији замишљају као старе и наопаке жене које наносе зло људима.[10] Петковић овде има у виду укорењени страх од вештица, који нагони људе да се штите од њих

Следећи сонет посвећен је песмама *Ноћ као древни владар* седи и *Београд*, Рајче Русева Рајсна. Петковић се и овде лирски поиграва Рајчовим стиховима:

Дал нека звезда на тебе гледи?
Ту цигару да палим стално.

Полазећи од њих он пева:

У томе је сазвежђу „С Геом на Редуту“
Рајчо сјајну слуту – Месечеву прећу,
Ангажује да се пали цигарета,
....
Јер је она света, ако с раком зна се.

Ова два песника полазе од обичне животне појединости – паљења цигарете, што упућује на „светост“ дуванског дима и канцерозно нестајање. Овде постоји извесна асоцијативна веза између певања „С Геом на Редуту“ и стихова Милована Витезовића, када се наспрам „звезданог реда“, стрпљиво, у шљивару „жижи“ цигара.[11]

У четвртом сонету „деконструисани“ су стихови Катје Маринове, која понесено пева о хлебном зрну, мравима који га носе „да зрно оплоди земљу“, о ралу, које нам коз рад „узвиси душе“. Поетеса овде указује на мрава и његову плодоносност и плодотворност. А у словенској симболици мрава посебно је важна многобројност, која се иначе користи у неким обредним приликама, веровањима и фолклорним текстовима.[12] Мариновој је свакако било познато да се мрав појављује у различитим народним умотворинама, на пример у пословицама и загонеткама, па му је зато обратила изразитију пажњу.

Петковић отворени свет види као царство мрава, полуиронично наглашавајући да је планета високо уздигла главу, уз ироничну инвективу „усправила се после хербицида“, па и он види мрава, како „потрбушке/ озрачен са крушке знак је заборава“. Испрва полуироничан став прераста у помало саркастично истицање свеколике угрожености хербицидима, који осим на људе делују и на царство мрава. Свестан чињенице да је у сваком

епских ликова, везаних за култ мртвих, *Словенска митологија – Енциклопедијски речник*, Zepter Bookworld, Београд, 2001, стр. 280-283.

[10]*Српски митолошки речник*, стр. 64-65.

[11]Милован Витезовић, *Певање српско*, «Дневник», Нови Сад, 1992.

[12]Александар Гура, *Симболика животиња у словенској народној традицији*, Београд, 2005, стр. 383

човеку појединцу садржан космос, он у митском духу помиње антејско живљење „с потковицом претка“, и закључује: „Ако јесмо свемир што у нама скрива / Зрно изазива унутрашњи немир“. При том он у смислу сагледавања поетског света у *огледалу,* наведене стихове у завршној строфи попут огледала изокреће у првој, почетној, и тако складно заокружује ову поетску целину.

У завршном сонету обраћа се стиховима Петка Недјалкова, научника-астронома, који „плави небески круг“ садева у пола стиха, како каже Петковић, налазећи упориште у стиху: „Пијан до плавог наступа дан“ (*Јутро*)

Следећи свој, на моменте еротско-поетски, набој, Петковић у парадоксалном смислу указује на жељу песника-научника да „немоћ претвори у моћ“.

Недјалков скреће пажњу на „три мале смрти“, а то су: болница, затвор и туђина. Суочен са овим, Петковић пева: „Виђен у туђини – на своме остати свој“, где наглашава важност очувања идентитета, после чега помиње озраченост, број у затвору и глину. У тим и таквим смртно драматичним околностима: „Космос нам је шанса, али такође клон“, односно опасност да нас тамо чека слична судбина.

У завршној строфи Петковић се присно обраћа рођаку по „именослову“, Петку. Уз самоиронично запажање да и од њега тражи да буде „нов к’о ђаче прваче“, на крају он спретно доводи у сплет експресивно са импресивним сводом, уочавајући „да слободу не остварује свет“.

Из симболичко осмишљених и унутар себе испреплетаних *Геиних астралаца*, зрачи изразитији хуморно-иронични поглед на свет и став Ђорђа Петковића, који на моменте прераста у сарказам. То је упадљива новина у односу на раније деконструисане сонете са репом . У овим стиховима као и у ранијем певању, Петковић је на линији бранковско-стражиловске ритмичности и складне мелодиозности, уз смело, лудистичко поигравање појмовним представама и симболима. Пријатно изненађује Петковићева одважност да доследно пева „сонете са репом и с акростихом у огледалу“, али овога пута имајући у виду плејаду бугарских песника, које продуховљено позива у своју лирску космогонију.

POETICALLY DECONSTRUCTED LYRICALLY-SONETIC COSMOGONY IN OVERTHROWN MIRROR

Deconstructed sonnets with tail and acroverse in the mirror of Djordje Petković are analyzed.

Зборник радова конференције "Развој астрономије код Срба VI"
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уредник М. С. Димитријевић
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ДРУГА ЛЕТЊА ШКОЛА ИЗ АСТРОНОМИЈЕ

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Резиме: Представљен је комплетан пројекат Друге летње школе из астрономије, одржане у Београду од 29.09. до 01.10.2008. године.

1. УВОД

Порекло Универзитета у Београду везује се за 1808. годину када је у Србији први пут основана Велика школа. Данас у свом саставу има 31 факултет и 11 института. Током два века постојања, Универзитет је имао огроман допринос нашем културном, научном, образовном, политичком и економском животу.

Већ од 1886. године астрономија се активно изучава на Катедри за астрономију и метеорологију. Годину дана касније почиње са радом Астрономска и метеоролошка опсерваторија. Обе институције, Астрономска Обсерваторија (АОБ) и Катедра за астрономију, дале су током јубиларне 2008. године допринос прослави два века постојања бројним активностима, међу којима је и Друга летња школа из астрономије. Развој идеје о оваквој врсти едукације у области астрономије дат је у раду Ковачевић и Димитријевић (2008).

Друга летња школа је поставила за циљ теме везане за фундаментална истраживачка поља у астрономији, које су презентовали водећи стручњаци, доводећи учеснике до самих фронтова најсавременијих истраживања.

2. ОБРАЗЛОЖЕЊЕ НАУЧНО-НАСТАВНОГ САДРЖАЈА ШКОЛЕ

Највећи део квантитативних информација које имамо о Космосу долазе из спекторскопских посматрања. Фотојонизована плазма је присутна у многим асторфизичким феноменима, од H II региона и планетраних небула, што је обележје почетног и крајњег стадијума звездане еволуције, па све до јонизованог међузвезданог и међугалактичког медијума и гаса фотојонизованог изворима високих енергија у АГЈ и квазарима.

Интерпретација њихових комплексних емисионих линија захтева познавање многобројних атомских процеса, који су изузетно осетљиви на физичка својства емисионог гаса и поље зрачења јонизујућег извора. Поред емпиријских студија посматрања, из којих се добијају неке основне информације, примена нумеричких кодова је често есенцијална за разумевање ових извора. Звезде су непрозрачне, тако да није могуће посматрати њихову унутрашњост директно, већ само индиректне методе дозвољавају да се измери унутрашња температура, притисак, заступљеност елемената итд.

Са друге стране, можемо директно посматрати у објектима попут остатака супернових, промењену заступљеност хемијских елемената, услед термонуклеарних процеса у унутрашњости звезде, што је постало доступно непосредном изучавању када је у експлозији нове или супернове одбачен омотач. Истраживања активних галактичких језгара (АГЈ), односно квазара и других типова квазистеларних објеката се експлозивно развијају више од четрдесет година. Углавном скоро све што знамо о њима потиче од студије њихових спектара, на различитим подручјима таласних дужина.

Космологија је такође изузетно напредовала током задње две декаде, користећи веома велике телескопе (било да су на Земљиној површини или у свемиру попут Хабловог свемирског телескопа) и њихов брзи дигитални систем за процесирање слика, или спектрограма (нпр. који су анализирали линије H I Lα [O II] 13727, [OIII]II4959,5007 Hα). Осим тога, савремена истраживања су фокусирана на дизајн, имплементацију и архивирање веома великих посматрачких програма. Један такав пример је SDSS (Sloan Digital Sky Survey) који је направио огромне каталоге астрономских објеката.

Ове виртуелне колекције гига, тера и могуће ускоро петабајта омогућиле су нова открића кроз интеграцију и кроскорелацију добијених података.

Због свега изложеног, при конципирању програма школе и избору предавача, желели смо да полазницима буду приказане могућности спектроскопије за истраживање и разматрање астрономских проблема, са посебним акцентима на спектроскопију и моделирање звезданих атмосфера, проучавање спектара топлих звезда и звезданих омотача са емисионим линијама, истраживање АГН и приказивање великих база података о астрономским објектима и спектрима, као што је то SDSS (Sloan Digital Sky Survey).

3. ОРГАНИЗАЦИЈА И РАД ШКОЛЕ

Друга летња школа из астрономије одржана је од 29. 09. до 01. 10 .2009. год. у Београду. Покренута је на иницијативу аутора овог рада.



Слика 1: *Учесници Друге летње школе из астрономије на тераси зграде Математичког факултета. Фото: др Миодраг Дачић, виши научни сарадник АОБ.*

Институције-организатори летње школе су Астрономска Опсерваторија у Београду, Математички факултет у Београду и Природно математички факултет у Новом Саду, а њено одржавање је помогло и омогућило Министарство за науку и технолошки развој Републике Србије. Научни организациони комитет је пројектовао наставни план и рад школе и одабрао предаваче. Ово тело је радило у следећем саставу: копредседник комитета др Милан С. Димитријевић, научни саветник Астрономске Опсерваторије у Београду, копредседник доц. др Тијана Продановић, Природно математички факултет у Новом Саду, коподредседник др Лука Ч. Поповић, научни саветник Астрономске Опсерваторије у Београду, коподпреседник проф. др Jiři Kubát, Astronomical Observatory, Ondřejov, Czech Republic, и чланови: проф. др Жарко Мијајловић, и проф. др Дејан Урошевић, Математички факултет у Београду. Локални организациони комитет је обезбедио

логистичку подршку целом пројекту и био је у саставу: доц. др Анђелка Ковачевић Математички факултет у Београду, мр. Еди Бон научни сарадник Астрономске Опсерваторије у Београду, др. Миодраг Дачић, виши научни сарадник Астрономске Опсерваторије у Београду, мр. Наташа Гавриловић научни сарадник Астрономске Опсерваторије у Београду, доц. др Драгана Илић Математички факултет у Београду, мр. Јелена Ковачевић научни сарадник Астрономске Опсерваторије у Београду, др. Зоран Симић виши научни сарадник Астрономске Опсерваторије у Београду, мр. Бранкица Шурлан Математички институт у Београду.

Циљ ове иницијативе је трострук: прво као место за дискусију између дипломираних студената универзитета са територије бивше Југославије и истакнутих научних радника из области астрономије. Затим, развој академске сарадње и дебате међу самим студентима и као треће летња школа је допринела Европској димензији високог школства, повезујући студенте и професоре са територије Балкана.

Летњу школу је похађао укупно 21 студент, а дошли су из Србије, Републике Српске, Чешке, и Марока (детаљнија расподела учесника је дата у Табели 1).

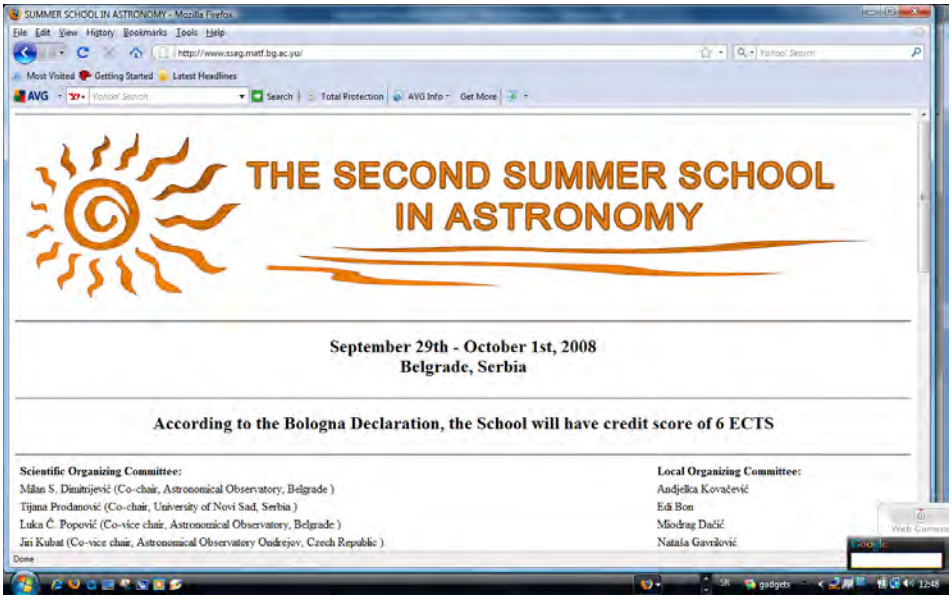
Табела 1: *Расподела учесника Друге летње школе из астрономије по институцијама.*

Научна институција	Број професионалних астронома	Број студената
Астрономска опсерваторија у Београду	7	
Математички факултет у Београду	5	6
Природно-математички факултет у Новом Саду	1	5
Математички инситут САНУ	1	
Универзитет у Бања Луци		5
Карлов Универзитет у Прагу		2
Масариков Универзитет у Брну	1	2
Астрономски институт Чешке Академије наука	1	
Универзитет у Атини	3	
Универзитет у Вашингтону	1	
Универзитет у Инфрану, Мароко		1

Скуп су свечано отворили проф. др Неда Бокан проректор Универзитета у Београду и др Милан С. Димитријевић, научни саветник АОБ. Укупан број учесника са радом из наше земље је 11 а из иностранства 16.

Скуп предавача су сачињавала истакнута имена са 7 признатих светских и домаћих инситутција: др Милан С. Димитријевић, научни саветник АОБ, др Лука Ч. Поповић, научни саветник АОБ, проф. др Emmanouil Danezis, др Evaggelia Lyratzi, др. Antonis Antoniou, Department of Astrophysics, Astronomy & Mechanics, Faculty of Physics, University of Athens, Greece, проф. др Jiří Kubát, Stellar Department Academy of Sciences of the Czech Republic, проф. доц, др Jiří Krtička, Ústav teoretické fyziky a astrofiziky Přírodovědecká fakulta MU Brno, проф. др Желько Ивезић (Željko Ivezić), University of Washington, Department of Astronomy, USA. Велики допринос школи дали су и млади истраживачи са Астрономске опсерваторије, који су одржали практичне вежбе студентима: мр Еди Бон, мр Јелена Ковачевић и мр Наташа Гавриловић.

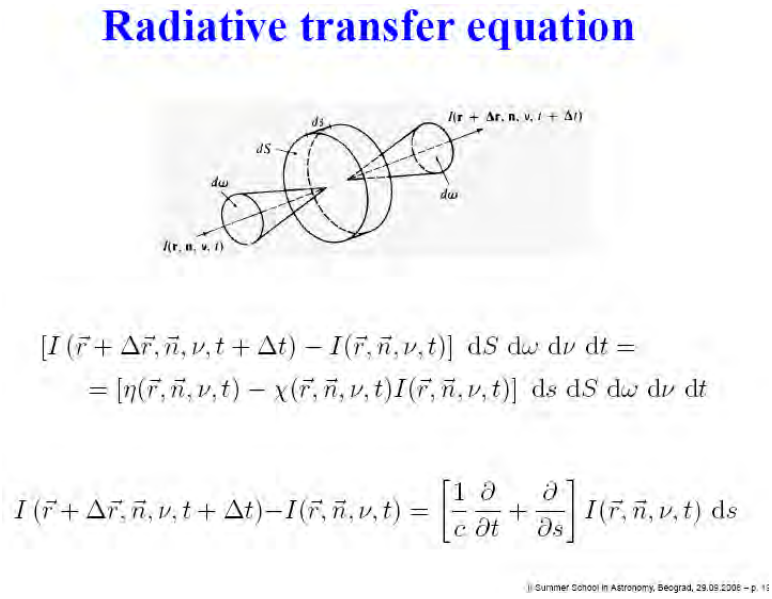
Сви детаљи о програму предавања и организацији школе налазе се у дигитализованом облику као ДВД презентација коју су уредили др Милан Димитријевић и др Анђелка Ковачевић, а за штампу припремили др Милан Димитријевић и Тања Милованов (Димитријевић, Ковачевић, 2009).



Слика 2: *Почетна страна званичне интернет презентације Друге летње школе.*

Школа је трајала три дана. Методологија рада састојала се из предавања за којима су следиле студентске радионице у којима су они групно и/или појединачно радили на теоријским и практичним задацима уз помоћ предавача.

Први радни дан био је посвећен феноменима у Звезданим атмосферама и ветровима. Специфично је разматран проблем моделовања звезданих атмосфера врућих звезда. Основно питање је ако бисмо имали спектар звезде да ли можемо добити из њега њене физичке параметре. Међутим, директно решавање је веома тешко и зато се приступа инверзном проблему, да се за дате звездане параметре изведе модел звезде и наравно поређење са посматрањима. Описани су параметри зрачења (специфични и средњи интензитет, флукс, тензор притиска), његове интеракције са материјом, једначина преноса зрачења, равна и сферна геометрија модела атмосфере. Разматрана је дифузиона апроксимација и интерпретација у домену вероватноће. Детаљно је разрађен појам термодинамичке равнотеже (локалне, статистичке), затим моделовање конвекције и на крају су описани програмски кодови за моделовање звезданих атмосфера.

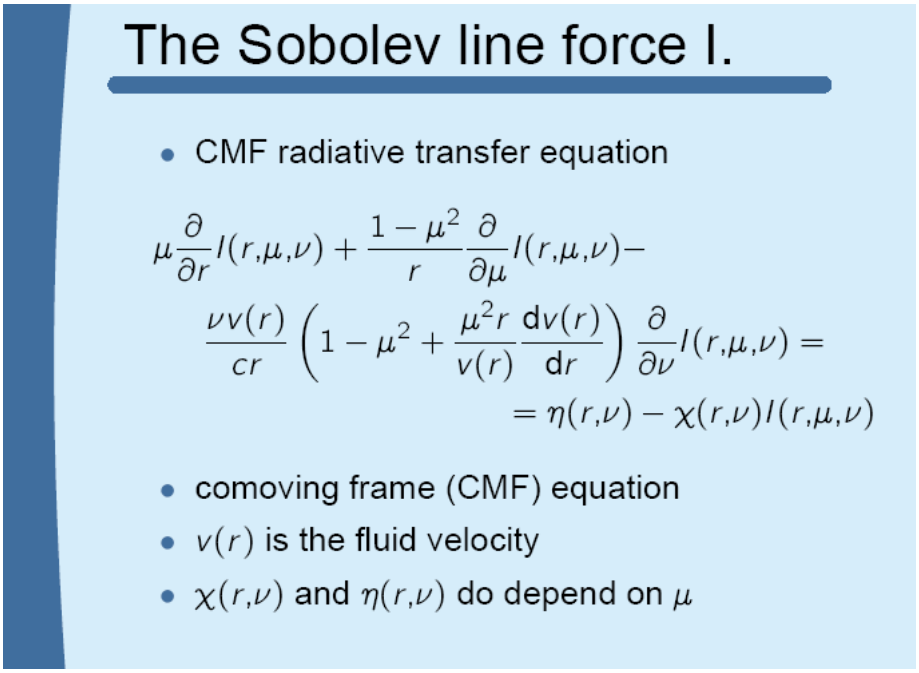


Слика 3: *Слајд са предавања др Јиржи Кубата (Jiří Kubát) о моделовању звезданих атмосфера*.

Организована је на крају дана научна радионица у којој се дискутовало о конкретним проблемима везаним за поменуте феномене.

У другом дану, студенти су се упознали веома детаљно са специфичним и комплексним профилима линија у спектрима врућих звезда са емисионим линијама и квазара. Наиме, у случају таквих звезда појављују се спектралне линије које не одговарају ни једној познатој апсорпционој линији код звезда истоветног спектралног типа (то су дискретне апсорпционе компоненте - ДАК, Bates & Halliwell, 1986). Међутим, касније је показано у радовима Данезиса и сарадника (Danezis et al., 2003), да то нису непознате

апсорпционе линије, већ спектралне линије истог јона и исте таласне дужине као и непомерена спектрална линија али померене у односу на њу за одговарајуће Δλ, пошто потичу из другачијег региона који ротира и веома брзо се креће. Дато је објашњење одакле проистичу ДАК (Danezis et al. 2006): ако ти региони ротирају веома брзо и споро се крећу радијално, добијене линије имаће велике ширине и мале помаке и као резултат, оне се преклапају међу собом, као и са непомереном спектралном линијом и зато се зову сателитске апсорпционе компоненте - САК. Ови феномени су могући и у спектрима Активних галактичких језгара. Danezis et al. 2003, су предложили модел којим се може објаснити комплексна структура густих региона врућих емисионих звезда и неких АГЈ, где се појављују САК или ДАК. Дата је аналитичка форма модела и дискутоване и демонстриране особине поментуог модела.

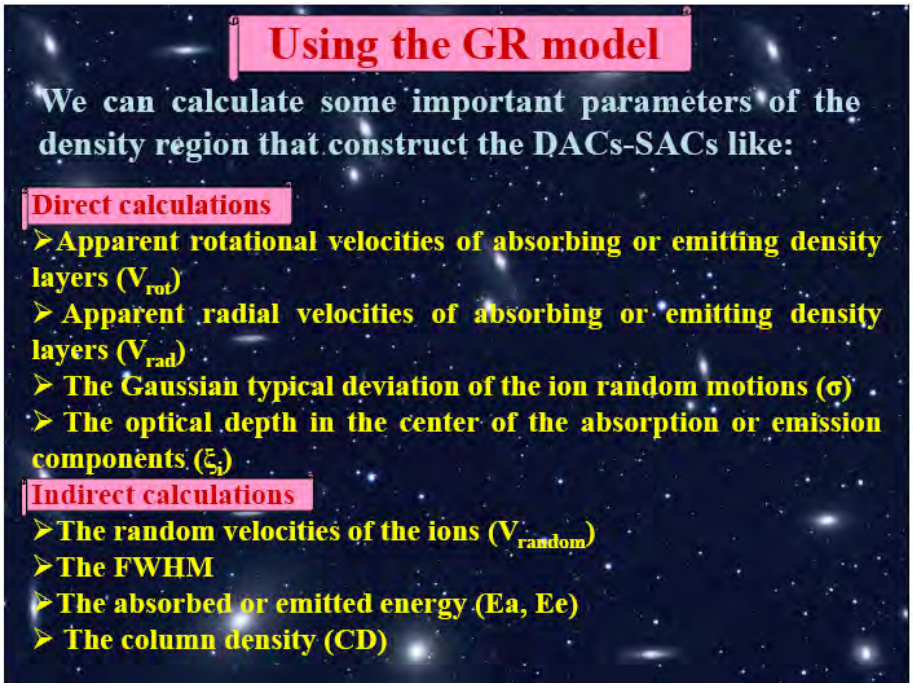


Слика 4: *Слајд са предавања др Јиржи Кртичке (Jiří Krtička) о звезданим ветровима.*

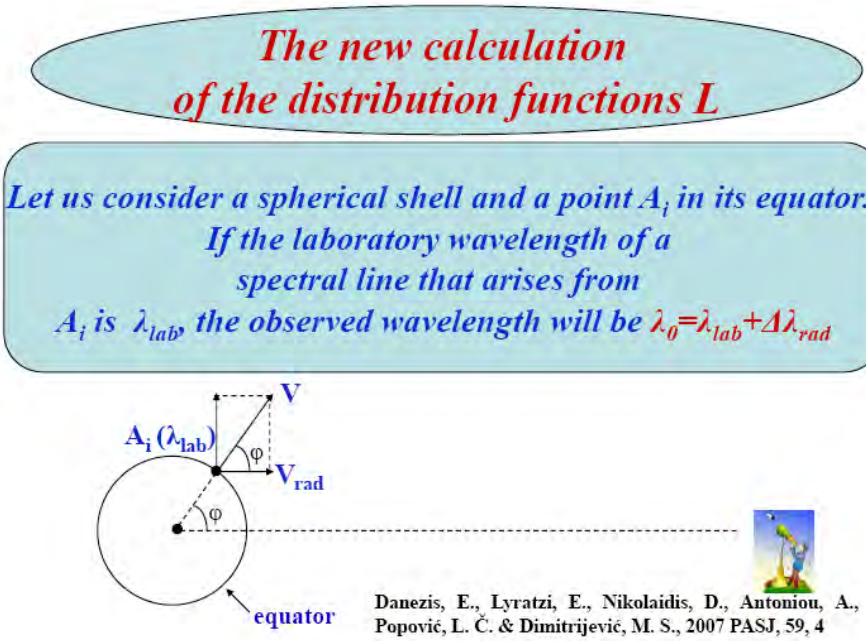
Др Милан С. Димитријевић дао је свеобухватну слику о ширењима спектралних линија у астрофизичким плазмама са посебним освртом на Штарково ширење (ширење изазвано интеракцијом са наелектрисаним честицама која доводи до Штарковог ефекта, односно цепања и померања атомских енергетских нивоа сразмерно јачини електричног поља. Уколико овај ефекат линеарно зависи од јачине електричног поља (код водоника и

водонику сличних јона) познат је као линеарани Штарков ефекат, односно квадаратични, ако је зависност квадратна (што је случај код атома и јона који нису водонику слични). Са развојем компјутерске технологије и ванатмосферске спектроскопије показала се потреба за подацима за параметре Штарковог ширења огромног броја спектралних линија, који могу да се организују и у базе (нпр. Феникс код за моделовање звезданих атмосфера укључује стално растућу базу атомских података за више од 500 милиона прелаза, где ће се, када су доступни, укључивати и подаци о Штарковом ширењу).

Штарково ширење је значајно у истраживањима астрофизичких, лабораторијских, ласерски произведених плазми, као и за истраживање инерцијалне фузије и у плазменим технологијама. Ово ширење може бити важно у астрофизици за моделовање у огромном опсегу температура и електронских густина (у односу на услове у лабораторијској плазми), од неутронских звезда (ефективна температура у атмосфери од 10^6 до 10^7K), преко белих патуљака, врелих звезда, па све до екстремних услова за радио рекомбинационе линије, које потичу из међузвезданих облака H I (T=50K) и H II (T=10000K), код којих је Ne = 1-1000 cm^{-3}.



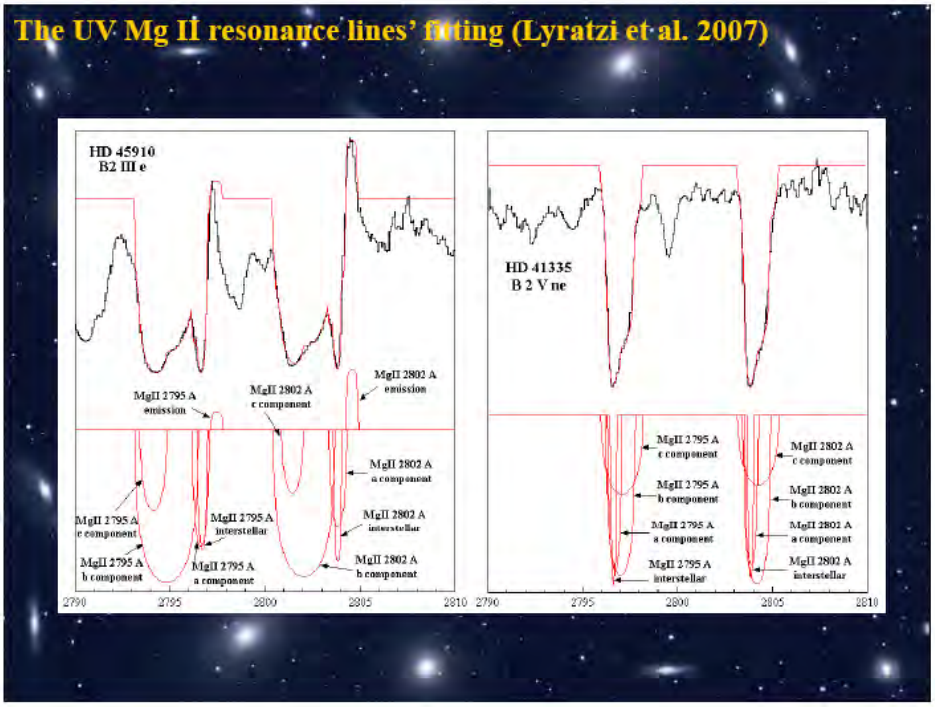
Слика 5: *Слајд са предавања проф. др Емануела Данезиса (Emmanouil Danezis) о ГР Моделу, којим се помоћу растављања комплексног профила линије на* ***Гаусовске*** *компоненте и анализе утицаја* ***ротације*** *области из којих линије потичу, могу одредити важни параметрио области згушњења из којих САК и ДАК потичу.*



Слика 6: *Слајд са предавања др Антониса Антониуа (Antonis Antoniou) о новом приступу у моделирању САК и ДАК..*

Веома интерсеантна је била Отворена лабораторија у којој су студенти били упознати са компјутерским програмом који фитује спектралне линије врућих емисионих звезда и квазара, коришћењем ГР програма.

У међузвезданим молекуларним облацима, типична електронска температура је око 30 К или мања, и типична електронска густина је 2-15 електрона по cm^{-3}. У таквим условима, слободни електрони могу бити захваћени (рекомбиновани) јоном у чијој су близини, на неку веома удаљену орбиту са главним квантним бројем (n) од неколико стотина и који се потом каскадно деексцитује на енергетске нивое n-1, n-2,...зрачећи у радио домену. Такви удаљени електрони су слабо везани са језгром и због тога на њих могу знатно утицати и веома слаба електрична микропоља, па последично, Штарково ширење може бити значајно. Оно може имати утицај и у соларном спектру јер ширина спектралне линије расте са повећањем главног квантног броја горњег нивоа. Штарково ширење у астрофизици је значајно за: дијагностику звезданих плазми, одређивање заступљености елемената, моделовање звезданих спектара, истраживања хемијске стратификације, боље калибрисање спектралне класификације, разматрање нуклеарних процеса у звезданим унутрашњостима, преноса зрачења и одређивање непрозрачности звезданих атмосфера.



Слика 7: *Слајд са предавања др Евангелије Лирадзи (Evaggelia Lyratzi) о коришћењу ГР модела*

DMVL manual

Software requirements: Windows 95 or higher.
Installation: In order to install the DMVL software, copy the DMVL folder directly to C:\

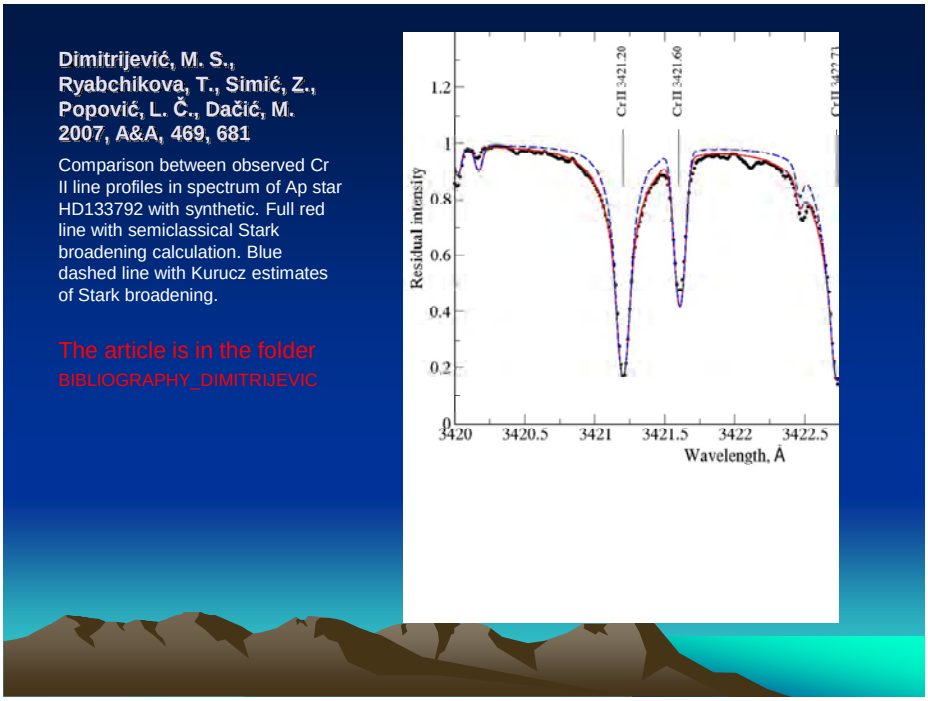
1. Preparation of Data with *sdiapp* software

With **sdiapp** software we can prepare the data of spectra that we want to study with DMVL software. The spectrum should be in ascii format as a **.txt** file. The preparation of data requires:

a) Red shift correction (in case of galactic spectra)
b) Normalization of spectrum
c) Cutting off the spectral range that we will study

Double click on **sdiapp.exe** (C:\DMVL\ANIMALS) in order to open **sdiapp** application. The window of Figure 1.1 opens.

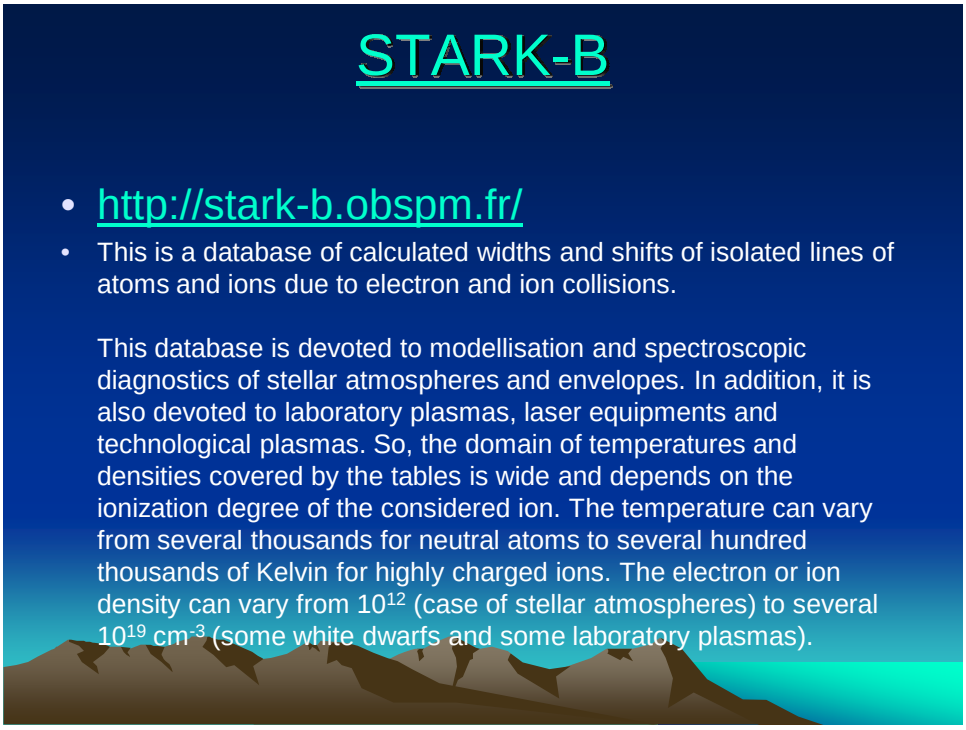
Слика 8: *Детаљ из упутства за употребу ГР програма, који је коришћен у отвореној лабораторији.*



Слика 9: *Слајд са предавања др Милана С. Димитријевића о Штарковом ширењу.*

Године 1926, Henry Russel је објавио у Astrophysical Journal рад са анализом Fe II спектара. Одредио је 61 енергетски ниво на основу 214 Fe II спектралних линија, и закључио да су све линије од астрофизичког значаја сада класификоване. Међутим, деведесетих година прошлог века било је познато 675 енергетских нивоа али још увек 50% појединачних спектралних карактеристика астрофизичких спектара високе резолуције било је без објашњења њиховог порекла, што указује на комплексност астрофизичких спектара и потребу за великим бројем података, које често није једноставно добити.

Дат је опис семикласичног пертурбационог теоријског метода за одређивање Штарковог ширења профила линија који је алтернатива квантно механичком прилазу са употребом јаке спреге, нарочито у случају комплексних спектара, тешких елемената или за прелазе између виших енергетских нивоа, када је метод јаке спреге практично неприменљив у строгом облику. Са друге стране, такође приказани, једноставнији Модификовани Семиемпиријски метод (MSE – Dimitrijević and Konjević 1981, Dimitrijević and Kršljanin 1986) може бити користан за звездану спектроскопију која зависи од веома екстензивне листе елемената и прелаза, за моделовање плазме, пошто захтева мање података и за велики број линија има релативно добру средњу тачност.



Слика 10: *Слајд са предавања др Милана С. Димитријевића о STARK-B бази података.*

Резултате за параметре Штарковог ширења, које су добили у току тридесетогодишње сарадње, Димитријевић и Силви Сахал-Брешо са Париске опсерваторије, сада организују у базу података STARK-B. За добијање података уношених у базу, основа је програмски код који даје процену електронског и јонског ширења изолованих спектралних линија неутралних атома и јона, коришћењем семикласичног приступа Sahal-Bréchot (1969ab, 1974), који је побољшан (видети Dimitrijević и Sahal-Bréchot (1984)).

Исцрпан преглед о истраживањима спектралних линија вангалактичких објеката дао је др Лука Ч. Поповић. Профили линија могу обезбедити информације о геометрији, брзини гаса итд. различитих вангалактичких објеката. У Универзуму разликују се апсорпционе (звездани спектри, апсорпциона материја, квазари итд) и емисионе линије (емисионе маглине, вруће звезде, супернове, активна галактичка језгра). У уводу су објашњени појмови прелаза у атомима и јонима, процеси зрачења на различитим таласним дужинама и одговарајући облици спектралних линија и континуума. Описане су рекомбинационе линије са посебним нагласком на водоникове код Lyman серије у ултраљубичастом делу спектра, које су најјаче изражене линије у већини спектара квазара. Такође је објашњена хиперефина структура HI линија. Описани су параметри линија, помак и

ширина, као и природан и колизиони процес њиховог ширења. Код Доплеровог ширења линија две компоненте су значајне: термално ширење и турбуленција. Термално ширење је контролисано расподелом термалних брзина и обликом профила линија.



Слика 11: *Слајд са предавања др Милана С. Димитријевића, са подацима о историји конференција о спектралним линијама.*

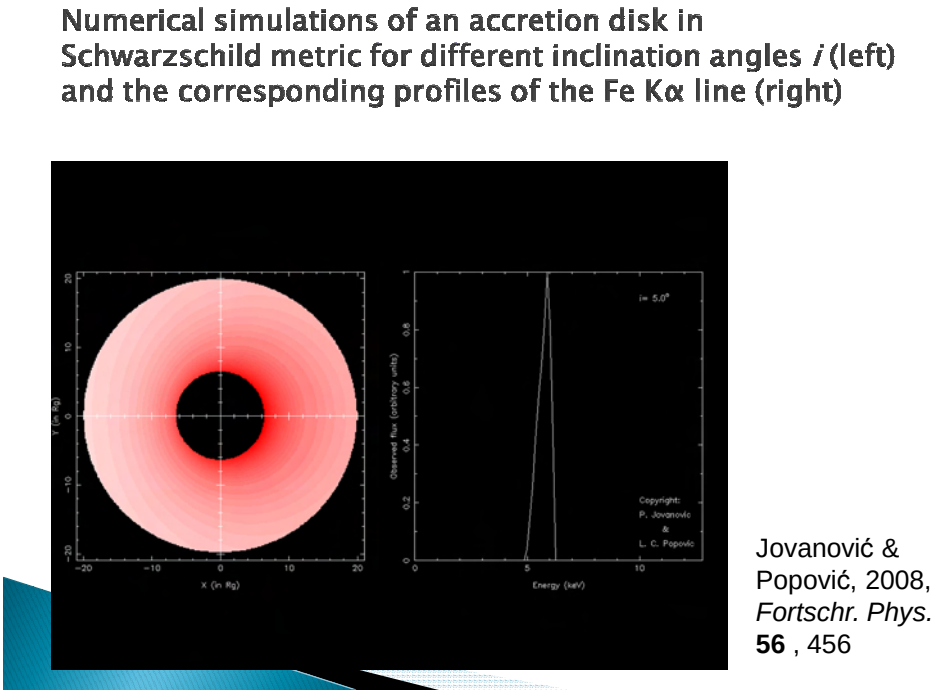
Турбуленције се јављају због хаотичног кретања на скалама мањим од слободног пута фотона. Све то утиче да је профил линије Гаусовска функција. Конволуцијом Гаусовског и Лоренцовог профила добија се Фохтова (Voigt) функција, што је права репрезентација профила линије. Што се тиче ротационог ширења линије (које је последица Доплеровог ширења уских површина на привидном диску звезде) оно не утиче на еквивалентну ширину линије.

Потом, објашњена је детаљно појава апсорпционих линија код квазара. Наиме, светлост са удаљених квазара интерагује са гасовитим компонентама између и унутар галаксија готово кроз целу историју Космоса (унутар опсега црвеног помака од 0 до 5). Та светлост региструје сваку такву интеракцију у облику апсорпционих линија. Имајући у виду опсег црвеног помака у коме се ово дешава, могуће је детаљно изучавати космичку еволуцију, укључујући еволуцију у интензитету ултраљубичастог позадинског зрачења и космичке хемијске еволуције.

Квазари показују неколико типова апсорпционих линија, рефлектујући на тај начинј различиту структуру међугалактичког простора. Те линије су познате као "Lyman-alpha forest" које настају због присуства малих облака ван галаксија, "damped Lyman-alpha" које настају због густих облака у дисковима галаксија и "strong and weak Mg II absorption" које настају због интеракције у халоу галаксија.

Затим је детаљно описан феномен Активних галаксија (квазари, Сејферт 1, Сејферт 2, блазари, итд). Сматра се да 10% од укупног броја галаксија припада овом типу. Оне су 10^4 пута веће луминозности од обичних галаксија, са малом запремином (10^3 парсека), зраче у опсегу од гама до радио таласа, имају јаке и понекда веома широке емисионе линије. Активна галактичка језгра су готово увек заклоњена честицама прашине. Према важећем моделу АГЈ, прашина у торусу или око диска заклања неке линије у правцу оптичког, ултраљубичастог и X континуума, који производи супермасивна црна рупа, као и широке емисионе линије.

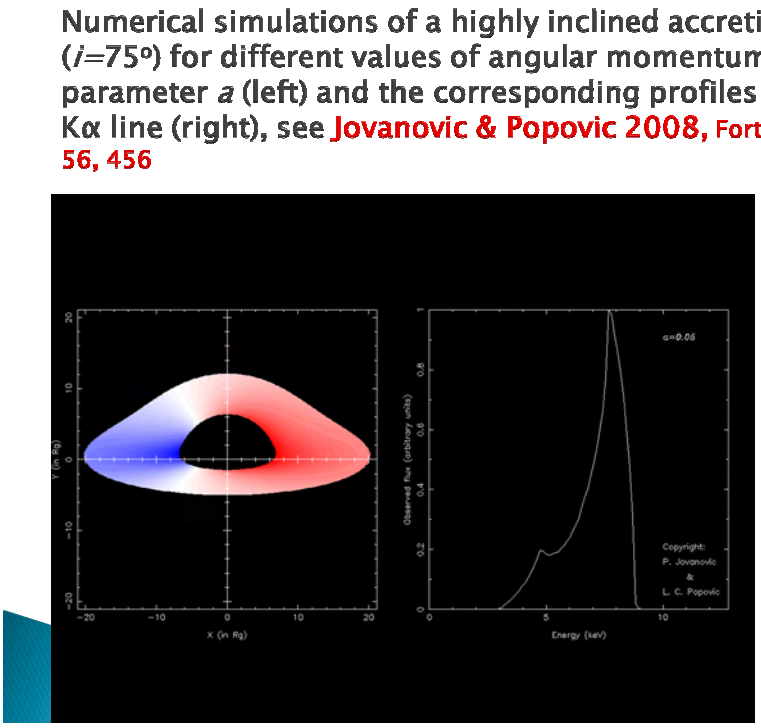
Код оваквих објеката, АГЈ немају широке емисионе линије и зову се АГЈ тип 2. Унификациони модел имплицира да и тип 1 и тип 2 имају исту генералну структуру - централни део је супермасивна црна рупа коју окружује акрециони диск, али да заклањање централног региона зависи од оријентације торуса који га окружује. Постоји неколико типова линија, код квазара, видљивих у ултравиолетном делу спектра: широке (Лајман алфа), уске апсорпционе (на мањим таласним дужинама крила линија CIV) и широке апсорпционе (на крилу веће таласне дужине код линија CIV) и слично у оптичком делу спектра код Hα и Hβ. Оно што је интересантно, да плазма која окружује масивну црну рупу утиче на АГЈ: тако што омогућује појаву X зрачења и Fe K α линија. Широка емсиона Fe K α линија која има асиметричан профил (уски плави пик и широко црвено крило) је посматрана у бројним АГЈ типа 1. У неким случајевима ширина ове линије одговара трећини брзине светлости, имплицирајући да емитер ротира релативистичком брзином. Зато је она највероватније настала у веома компактном региону у близини црне рупе АГЈ и може дати неке информације о условима под којима се налази плазма као и о просторно временској геометрији у близини црне рупе. Имајући у виду да је та плазма у јаком гравитационом пољу и има високу температуру, поставља се питање каква је геометрија АГЈ. Ова линија настаје када је плазма под утицајем јаког X зрачења тако да је једна од две K љуске (n=1, n је главни квантни број) електорна у атому (или јону) гвожђа одбачена а потом долази до фотоелектричне апсорпције X зрака.



Слика 12: *Слајд са предавања др Луке Ч. Поповића.*

Уопштено говорећи, у случају супермасивне црне рупе у АГЈ, маса и спин су одговорни за неколико ефеката који могу бити детектовани код Fe Kα линија (Јовановић и Поповић 2008). Угаони моменат или спин централне супермасивне црне рупе је својство метрике простор времена. Јовановић и Поповић (2008) су показали како то утиче на посматране профиле линија предпостављајући да се Fe Kα емисиони регион протеже између следећих вредности унутрашњег и спољашњег радијуса: Rin = Rms и Rout = 20 Rg. Анализирали су два случаја инклинације акреционог диска (35° и 75°) у Шварцшилдовој и Керовој метрици. Овде је приказан други случај када је диск под великим углом. Профили линија су шири него у првом случају, управо због већег нагиба. У случају Керове метрике, црвени пик линије је више угњежден у своје плаво крило (као и у првом случају) и то потврђује да се овај ефекат појављује управо због угаоног момента. Значи, угаони момент централне црне рупе значајно утиче на облик линије што подржава предпоставку да Fe Kα настаје у акреционом диску близу ње (Ballantyne & Fabian,2005). Типичан спектар у X домену састоји се из следећих компоненти: континуум од 0.1 до 100 KeV, који има компоненту са равнијим спектром и компоненту са спектром у облику степеног закона, и промене су од неколико делова часа до неколико дана. Fe Kα линија је први пут потврђена посматрањем Сејферт 1 галаксије MCG-6-30-15 (Tanaka et al.,

1995). За њу је карактеристично да се, ако настаје у релативистички ротирајућем диску АГЈ, шири због кинематичких ефеката и њен облик се мења због Доплеровог ефекта и гравитационог црвеног помака. На крају је дат закључак уз низ примера да је свега трећина Сејферт 1 галаксија са релативистичиким Fe Kα, неке од ових линија могу бити емитоване из млаза (jet), као у случају објекта 3C120, где апсорпција у њеном плавом крилу индукује постојање млаза у том региону.



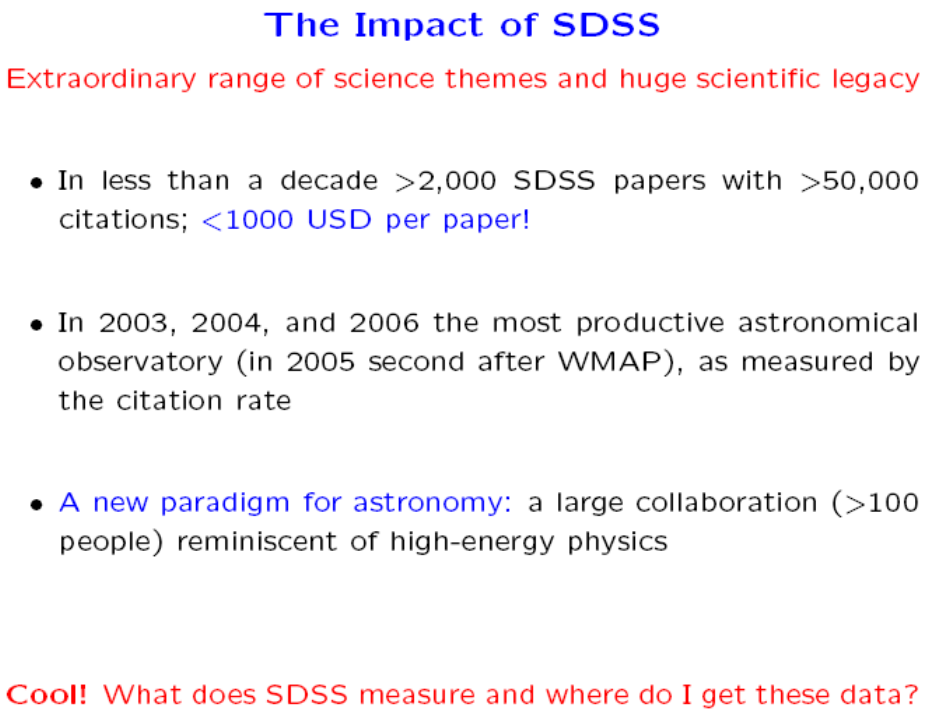
Слика 13: *Слајд са предавања др Луке Ч. Поповића.*

У протеклих неколико година астрономски подаци су се организовали у јавним терабајтним базама података, док се у наредном периоду од нове генерације посматрачких програма очекују петабајтне структуре. Основни циљ предавања проф. Жељка Ивезића био је да фамилијаризује слушаоце са садашњим посматрачким програмима, а посебно са SDSS, као и да их мотивише на сопствена истраживања.

Огромни телескопи попут Keck, Very Large Telescope, Gemini (10м) су посебно значајни за детекцију слабих објеката (могу детектовати објекте који су 100 милиона пута слабији од оних, који се могу детектовати људским оком). Сви посматрачки програми обухватили су преко милијарду објеката.

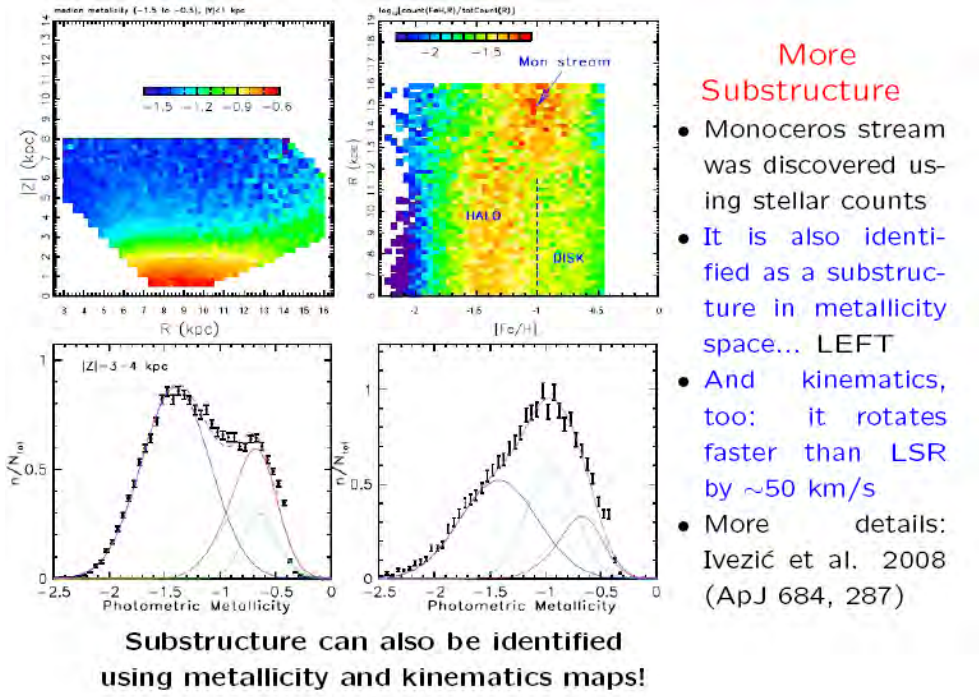
Оптички посматрачки програми као што су они Паломарске опсерваторије (први 1950 до 1957. и други 1985 до 1999) били су

фотографски, у два опсега, са астрометријском тачношћу од 0.5 лучних секунди, и фотометријском од 0.2-0.4 mag, а произвели су каталог USNO-B који има 10^9 објеката.



Слика 14: *Слајд са предавања проф. др Жељка Ивезића.*

Међутим, велики пробој је начињен дигиталним посматрачким програмом SDSS, који је био у 5 опсега, m<22.5, астрометријске тачности мање од 0.1 лучне секунде, фотометријске тачности 0.02 mag, а покрио је 1/4 неба, и више од 10^8 објеката (не у Галактичкој равни). Овај пројекат начинио је слике преко 100 милиона звезда и исто толико галаксија и одредио је спектре за 1 милион галаксија, 100000 квазара и 100000 звезда. Укупна количина података је преко 20 терабајта (више него што је у библиотеци америчког конгреса). Овај пројекат утицао је на развој астрономије: за мање од декаду направљено је више од 2000 радова са више од 50000 цитата. Постоји неколико интерфејса за добијање података из SDSS (www.sdss.org): Catalog Archive Server (CAS) (претраживач SDSS каталога слика и спектара), Spectro Query Server (претражује спектре по положају или по спектралним или фотометријским параметрима), Imaging Query Server (претраживач каталога слика, функционише слично предходном), Imaging cross-ID (унакрсни претраживач каталога слика других посматрачких програма) и SQL претраживање, итд.



Слика 15: *Слајд са предавања проф. др Жељка Ивезића.*

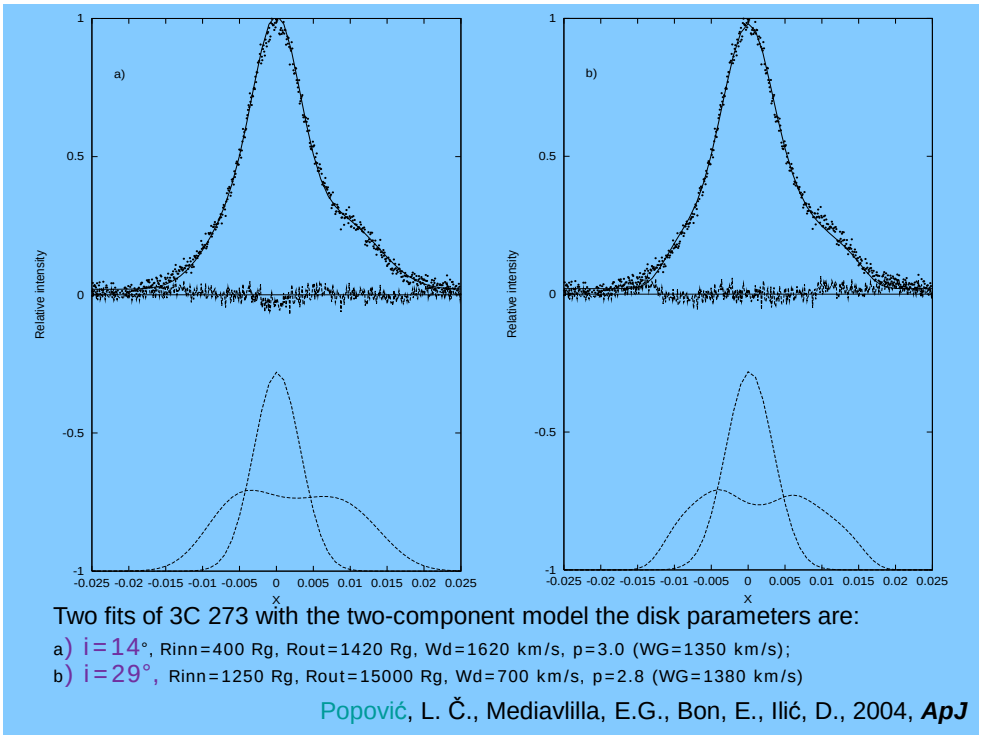
Надаље су приказани неки од научних резултата добијених на основу података SDSS посматрачког програма. У оквиру нашег Сунчевог система, овај програм је обезбедио статистички значајан узорак посматрања малих тела (преко 100 000 малих тела је посматрано), снимљене су слике у пет боја. SDSS је каталогизовао око 100000 малих тела која раније нису била детектована. Добијена је побољшана расподела астероида из главног астероидног појаса по величини, јер су вршена мерења на објектима чији је дијаметар мањи од 1 км (што раније није било могуће) и откривена је промена у нагибу ове дистрибуције за вредност дијаметра од 5 км. Такође је добијена процена вероватноће судара од 1 у милион година са астероидима чији је дијаметар већи од 1 км. Осим тога, откривена је јака корелација између боје и позиције, за стеновите објекте S типа у унутрашњем делу појаса и карбонатне астероиде C типа у његовом спољашњем делу, као и да динамичке фамилије имају различите боје. Унутар одређене хемијске класе астероида, различите нијансе боје одређују њихову старост, тако да се SDSS боје могу користити за датирање ових објеката.

У спољашњем делу Сунчевог система SDSS је открио 2 тела Нептунових Тројанаца, око 50 објеката у Кајперовом појасу, међу којима је најинтересантнији објекат 2006SQ372 који има велику полуосу од готово 800 AJ. Симулације су показале да је овај објекат био избачен релативно скоро из Оортовог облака према унутрашњем делу Сунчевог система.

Спектри звезда покрили су опсег таласних дужина од 3800 Å до 9200 Å, са резолуцијом од 1800 и S/N>4 по пикселу. SDSS је детектовао 95% од свих до сада познатих С патуљака, и први познати Т патуљак (Adelman et al. 2007). Звездани спектри добијени овим програмом су довољног квалитета да дају тачну процену звезданих параметара као што су ефективна температура, гравитација, металичност и хемијска структура. Овако процељени параметри су показали добру корелацију са мерењима добијених на основу слика.

SDSS је радио и дисекцију структуре наше Галаксије, одређујући специјалну расподелу звезда, расподелу металичности и звездану кинематику. Оно што је квалификовало SDSS за овакву студију је: тачна фотометрија (обезбеђује процену растојања и [Fe/H]), огроман број посматраних звезда (мале случајне грешке при одређивању бројчаних густина), огромна површина посматраног неба, 10 000 квадратних степени, и лимит магнитуда од m<20.5 (што даје добро запреминско покривање). Као што је познато, конструкција модела халоа и диска Млечног пута захтева $\rho(z \mid R = Rsun)$ фит суме двоструких експоненцијалних и степеног закона профила. Али различити модели могу да произведу исти фит. Зато је неопходна огромна површина неба да би се направио коректан модел и SDSS задовољава тај услов. Начињена је тродимензиона мапа звездане бројчане густине (око 50 милиона звезда је посматрано). Анализа је била заснована на фотометријским растојањима и зато је била независна од модела. Потврђен је двокомпонентни експоненцијални диск модел али је за хало лоше одређен модел степеног закона због постојећих подструктура у њему и ипак недовољног покривања неба. Локализована је значајна густина објеката у правцу Вирго. Више детаља о овоме може се видети у Jurić et al. 2008. Мапирање металичности у нашој Галаксији показало је исте компоненте (јасну поделу на диск и хало) као што су добијене на основу бројчане густине. Кинематичке карактеристике су корелиране са металичношћу: звезде богате (диск) металима ротирају, сиромашније (хало) звезде су на случајним веома ексцентричним путањама. Традиционални двокомпонентни модел диска предвиђа корелацију између металичности и ротационе брзине али на основу мерења SDSS то није потврђено. Кинематичке мапе и оне које приказују металичност омогућиле су детектовање Моноцерос подструктуре (Ivezić et al. 2008). Ефекат гравитационог сочива (галаксија која својом масом утиче на дисторзију облика галаксија у позадини због гравитационог савијања светла) је мали ефекат реда 1% али се може детектовати на статистички значајном скупу галаксија. На основу овог ефекта се може проценити маса галаксија у позадини као функција растојања од центра галаксије сочива. Очекивање је да је за изотермалну сферу савијање приближно r^{-1}. На основу SDSS мерења, утврђено је да је савијање $\propto r^{-0.8\pm0.2}$ због чега је добијена процена масе $\propto L^{-1.0\pm0.2}$.

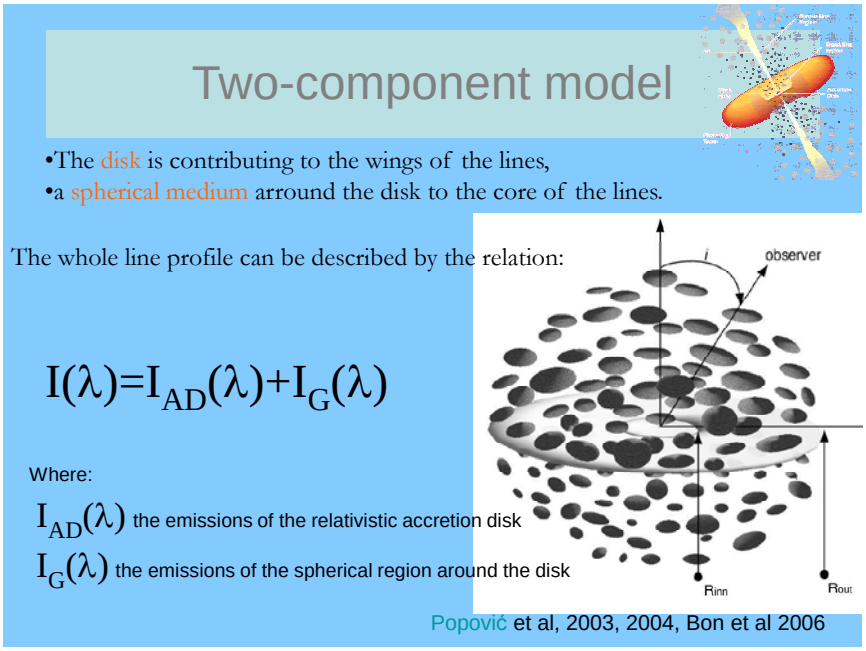
Еди Бон је дао детаљан увид у модел широколинијског региона код АГЈ и разматрао начине поједностављења овог модела, како редуковати број неопходних параметара и одредити њихове домене.



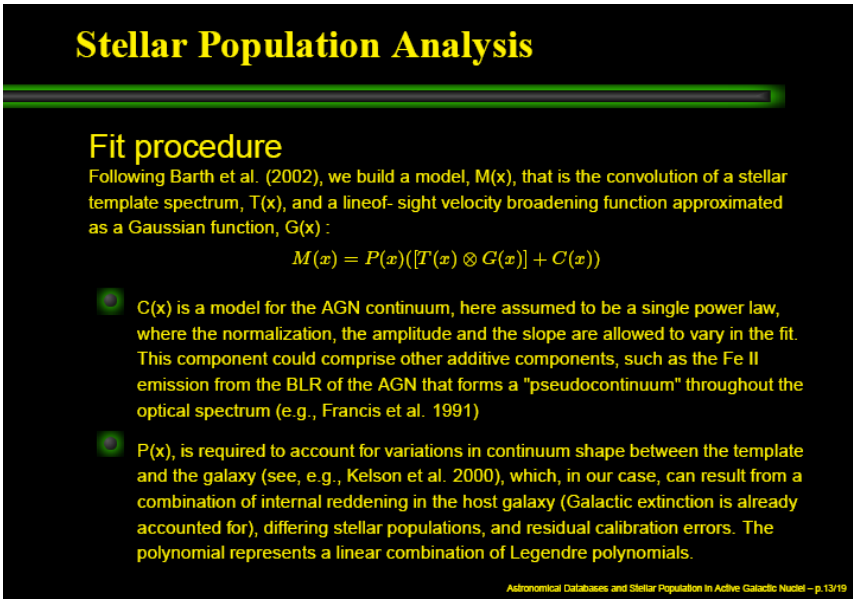
Слика 16: *Слајд са предавања Еди Бона.*

Оно што се може рећи да је однос флукса (Bon et al. 2006) релативистичког акреционог диска и сферног региона око њега приближно 1 за већину анализираних АГЈ.

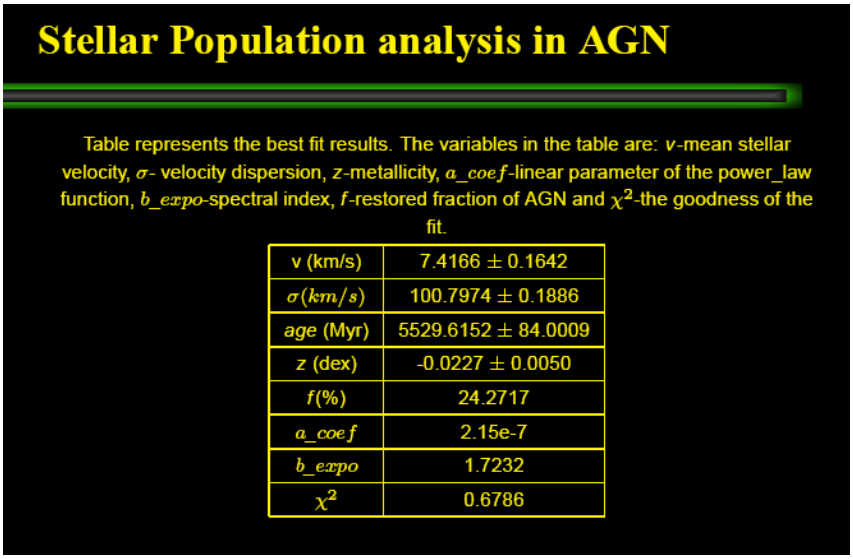
Наташа Гавриловић дала је изванредан увид у астрономске базе података са специфичним нагласком на ХиперЛеду, базу података која садржи више од 4 милиона објеката, међу којима је више од 2 милиона галаксија и око 100000 квазара (http://leda.univ-lyon1.fr/). Такође, приказан је рад на анализи звезданих популација. Међу првим циљевима ове анализе је фитовање звезданих популација и континуума у АГЈ, како би се они на правилан начин могли екстраховати и анализирати АГЈ емисионе линије. Приказан је модел који је конструисан $M(x) = P(x)([T(x) \otimes G(x)] + C(x))$, где је T(x) модел звезданог спектра, G(x) Гаусовска функција у правцу визуре повећања брзина, док је C(x) модел континуума АГЈ. Такође су приказани први резултати овог модела на неким примерима.



Слика 17: *Слајд са предавања Еди Бона.*

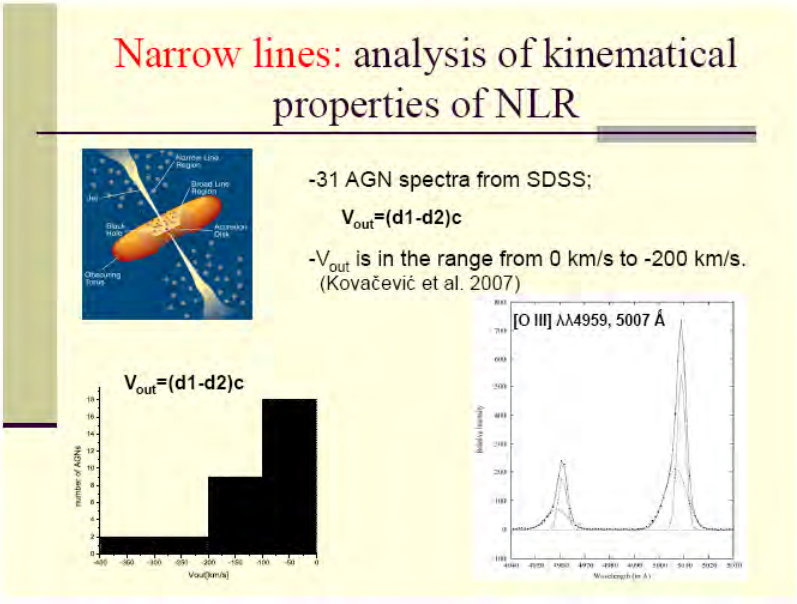


Слика 18: *Слајд са предавања Наташе Гаврлиовић.*



Слика 19: *Слајд са предавања Наташе Гаврлиовић.*

Јелена Ковачевић изложила је анализу уских линија у спектрима АГЈ, почевши од уклањања космолошког помака, ефекта црвеног помака и континуума, до одређивања физичких и кинематичких карактеристика усколинијског региона. Из анализе 31 спектара АГЈ преузетих из СДСС базе добијено је да су брзине од 0 до 200км/с (Kovačević et al. 2007).



Слика 20: *Слајд са предавања Јелене Ковачевић.*

Током сва три радна дана излагани су постери научних радова, а последњег дана школе организивано је такмичење студенстких радова, са пропозицијом да свака презентација траје 5 минута. У жирију су учествовали: др Evaggelia Lyratzi, проф. др Emmanouil Danezis, University of Athens, др Милан Димитријевић, научни саветник Астрономске опсерваторије Београд (председник жирија), др Лука Поповић, научни саветник Астрономске опсерваторије Београд и др Павел Котрч (Astronomical Institute v.v.i. Academy of Sciences, Ondrejov, Czech Republic). Жири је једногласно одлучио да је најбољи студентски рад Ивана Милића и Санде Дејанић који су радили под руководством dr Pavel Kotrča (Astronomical Institute v.v.i. Academy of Sciences, Ondrejov, Czech Republic), на другом месту је био рад студента Jana Elnera, Charles University in Prague, Чешка република, док је на трећем месту био рад студенткиње Eve Arazimove, Charles University in Prague, Чешка република. Др Милан С. Димитријевић, прогласио је победнике такмичења и доделио им симболичне новчане награде и књиге, као и дипломе свим полазницима школе. Приређен је коктел за све учеснике школе. На основу одлуке Научно наставног већа Математичког факултета учесницима је додељено 6 ЕСП бодова што је и јасно назначено на дипломи (видети сл. 21). Од 23 полазника школе 78% је имало рад (њихова имена су наведена у Табели 2). Сва остала имена полазника школе наведена су на ДВД презентацији (Димитријевић, Ковачевић, 2009).

Табела 2: *Полазници Летње школе који су имали рад*

Име полазника школе	Институција
Eva Arazimova	Charles University in Prague
Jan Elner	Charles University in Prague
Matus Kocka	Masaryk University in Brno
Jiři Krtička	Masaryk University in Brno
Jiři Kubat	Astronomycal institute of Academy of Science of Czech Republic
Jana Polednikova	Masaryk University in Brno
Hassan Bourhrous	University in Ifrane
Милан Глигорић	Универзитет у Бања Луци
Далибор Обрадовић	Универзитет у Бања Луци
Немања Ракић	Универзитет у Бања Луци
Ђорђе Смиљић	Универзитет у Бања Луци
Дајана Врањеш	Универзитет у Бања Луци
Марија Борисов	Математички факултет у Београду
Санда Дејанић	Математички факултет у Београду
Иван Милић	Математички факултет у Београду
Олга Недељков	Математички факултет у Београду
Сања Томић	Математички факултет у Београду
Маријана Цветковић	Математички факултет у Београду



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for attending courses in

Stellar atmospheres and winds

RNDr Jiří Kubát _____

Dr Jiří Krtička _____

The peculiar and complex line profiles in the spectra of hot emission stars and quasars

Prof. Dr Emmanouil Danezis _____

Prof. Dr Milan S. Dimitrijević _____

Dr Evaggelia Lyratzi _____

Dr Antonios Antoniou _____

Active Galactic Nuclei

Prof. Dr Luka Č. Popović _____

Doing astronomy with Sloan Digital Sky Survey

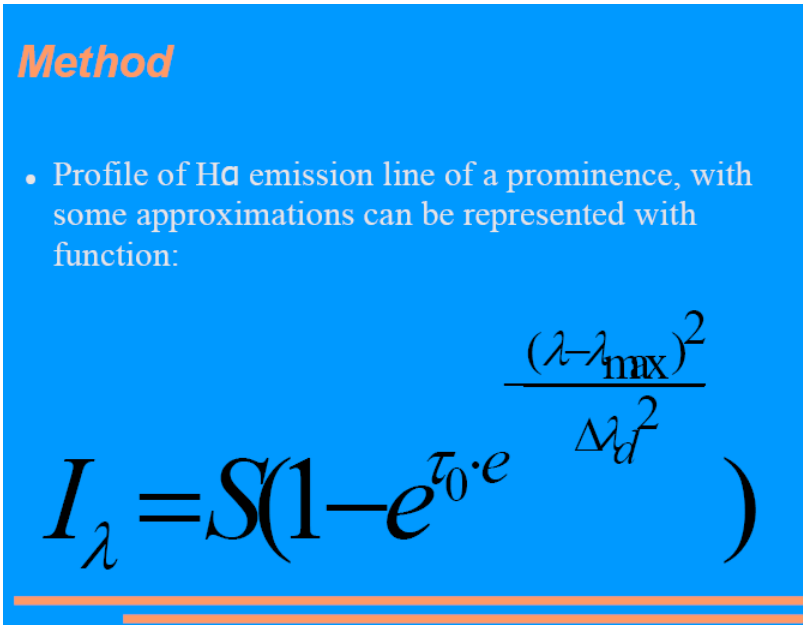
Prof. Dr Željko Ivezić _____

Prof. Dr Milan S. Dimitrijević
Chair of the School

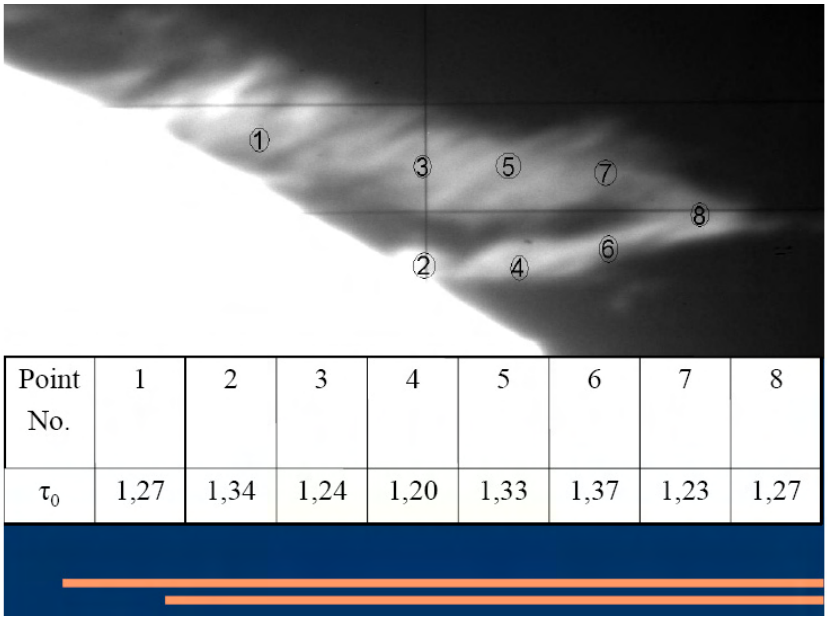
Prof. Dr Miodrag Mateljević
Dean of Faculty of Mathematics

Слика 21: *Сертификат о похађању летње школе са наведеним именима професора, именом директора школе др Милана С. Димитријевића и декана Математичког факултета проф. др Миодрага Матељевића.*

У свом раду Иван Милић и Санда Дејанић дали су процену оптичке дебљине у сунчевим протуберанцама. Наиме, они су фитовали Hα емисиону линију протуберанце функцијом која зависи од неколико параметара и при томе су користили итеративан метод. Анализирали су 52 протуберанце и добили 188 профила линија, а оптичка дебљина је била у интервалу од 0.97 до 1.57.



Слика 22: *Слајд из најбоље студентске презентације аутора Ивана Милића, Санде Дејанић и Павела Котрча: опис функције која је коришћена за фитовање Hα линија код сунчевих протуберанци.*



Point No.	1	2	3	4	5	6	7	8
τ_0	1,27	1,34	1,24	1,20	1,33	1,37	1,23	1,27

Слика 23: *Слајд из најбоље студентске презентације аутора Ивана Милића, Санде Дејанић и Павела Котрча: процењене вредности параметра из фитоване функције у одабраним тачкама.*

Свечана вечера поводом затварања школе приређена је у етно ресторану "Дача", на којој су осим организатора и предавача учествовали и спонзори летње школе господин Hans J. Langer (Ханс Ј. Лангер) и господин Чеда Мраз.



Слика 24: *Детаљ са свечане вечере: поздравни говор др Милана С. Димитријевића директора Летње школе (стоји), слева на десно седе: проф. др Жељко Ивезић, господин Ханс Лангер и господин Чедомир Мраз. Фото: др Миодраг Дачић, виши научни сарадник АОБ.*

4. ЗАКЉУЧАК

На основу предходно изложеног, може се рећи да је Друга Летња школа из астрономије покрила теме које спадају међу најмодерније у савременој астрономији, које су изложене веома детаљно. Такође, сматрамо да у наредним летњим школама теме треба да остану генералне али учесницима је интересантно да практични део буде још више заступљен.

На овом месту истакли бисмо посебан допринос у реализацији целог пројекта који су дали спонзори: RAUCH, Београдска пекарска индустрија, Coca Cola, ECOFINANCE, Тон Плус, Анекс, господин Ханс Ј. Лангер и господин Чедомир Мраз, пројекти чији су руководиоци: др. Милан С. Димитријевић, др Лука Ч. Поповић, проф. др Жарко Мијајловић и проф. др Неда Бокан и Задруга студената Универзитета у Београду.

На крају бисмо истакли допринос др Миодрага Дачића, вишег научног сарадник АОБ, који је фотографски пропратио овај догађај, а слике се налазе на ДВДу који садржи и програм, апстракте предавања, презентације професора и полазника школе и остали материјал везан за овај догађај (Dimitrijević & Kovačević, 2009).

Захвалница

Овај рад је урађен у оквиру пројекта 146001 *Утицај сударних процеса на спектре астрофизичке плазме*, пројекта 146002 *Астрофизичка спектроскопија вангалактичких објеката* 146022 и пројекта *Историја и епистемологија природних наука*, код Министарства за науку и технолошки развој Републике Србије.

Литература

Adelman-McCarthy, J. K., Agüeros, M. A., Allam, S. S., Anderson, K. J.: 2007, "The Fifth Data Release of the Sloan Digital Sky Survey", *Astrophysical Journal Supplement Series*, **172**, 634-644.

Bates, B., Halliwell, D. R.: 1986, "Discrete absorption components in spectra of mass-losing stars - an analytical model for the trajectories of gas parcels and streams", *MNRAS*, **223,** 673-681.

Bon, E., Popović, L. Č., Ilić, D., Mediavilla, E: 2006, "Stratification in the broad line region of AGN: The two-component model", *New Astronomy Reviews*, **50**, 716-719.

Danezis, E., Nikolaidis, D., Lyratzi, E., Stathopoulou, M., Theodossiou, E., Kosionidis, A., Drakopoulos, C., Christou, G., Koutsouris, P.: 2003, "A new model for the structure of the DACs regions in the Oe and Be stellar atmospheres", *Astrophysics and Space Science*, **284**, 1119–1142.

Danezis, E., Popović, L. Č., Lyratzi, E., Dimitrijević, M. S.: 2006, "The peculiar absorption and emission phenomena from stars to quasars", in The Physics of Ionized Gases, 23rd Summer School and International Symposium on the Physics of Ionized Gases, Invited Lerctures, Topical Invited Lectures and Progress Reports, eds. Lj. Hadžievski, B. P. Marinković, N. S. Simonović, *American Institute of Physics Conference Proceedings*, **876**, , 373-384

Dimitrijević, M. S., Kovačević, A. B: 2009, "The Second Summer School in Astronomy: Program, Presentations and Photos", DVD, Eds. M. S. Dimitrijević and Andjelka Kovačević, ISBN 978-86-80019-30-7.

Dimitrijević, M.S., Sahal-Bréchot, S.: 1984, "Stark broadening of neutral helium lines", *Journal of Quantitative Spectroscopy and Radiative Transfer*, **31**, 301-313.

Dimitrijević, M. S., Konjević, N.*:* 1981, "Modified semiempirical formula for the electron-impact width of ionized atom lines: theory and applications", Reprint from: Spectral Line Shapes, Editor: B. Wende © 1981 Walter de Gruyter & Co., Berlin, New York, Printed in Germany, 211-239.

Dimitrijević, M. S., Kršljanin, V.*:* 1986, "Electron-impact shifts of ion lines: modified semiempirical approach", *Astron. Astrophys*., **165**, 269-274.

Ivezić, Ž., Sesar, B., Jurić, M., Bond, N.: 2008, "The Milky Way Tomography with SDSS. II. Stellar Metallicity", *Astrophysical Journal*, **684**, 287-325.

Jurić, M., Ivezić, Ž., Brooks, A., Lupton, R. H.: 2008, "The Milky Way Tomography with SDSS. I. Stellar Number Density Distribution", *Astrophysical Journal*, **673**, 864-914.

Jovanović, P., Popović, L. Č.: 2008, "Observational Effects of Strong Gravity in Vicinity of Supermassive Black Holes", *Fortsch. Phys.*, **56**, 456-461.

Ковачевић, А. Б., Димитријевић, М. С.: 2008, "Прва летња школа из астрономије и геофизике", Зборник радова конференције" Развој астрономије код Срба V", Београд, 18-22. април, *Публикације Астрономског друштва „Руђер Бошковић"*, св. **8**, 847-858.

Kovačević, J., Bachev, R., Popović, L. Č., Zamanov, R., Marziani, P.: 2008, "Asymmetry of the C IV λ 1549 Å and [O III] λλ 4959, 5007 Å Lines in a Sample of RQ and RL AGN", VI Serbian Conference on Spectral Line Shapes in Astrophysics (VI SCSLSA). *AIP Conference Proceedings*, **938**, 104-108.

Popović, L. Č., Mediavilla, E. G., Kubičela, A., Jovanović, P.: 2002, "Balmer lines emission region in NGC 3516: Kinematical and physical properties", *Astron. Astrophys.*, **390**, 473-480.

Sahal-Bréchot, S.: 1986a, "Impact Theory of the Broadening and Shift of Spectral Lines due to Electrons and Ions in a Plasma", *Astron. Astrophys.*, **1,** 91-123.

Sahal-Bréchot, S.: 1986b, "Impact Theory of the Broadening and Shift of Spectral Lines due to Electrons and Ions in a Plasma", *Astron. Astrophys.*, **2,** 322-354.

Tanaka, Y., Nandra, K., Fabian, A. C., Inoue, H., Otani, C., Dotani, T., Hayashida, K., Iwasawa, K., Kii, T., Kunieda, H., Makino, F., Matsuoka, M.: 1995, "Gravitationally redshifted emission implying an accretion disk and massive black hole in the active galaxy MCG-6-30-15", *Nature*, **375**, 659-661.

THE SECOND SUMMER SCHOOL IN ASTRONOMY

Here we presented a complete project of The Second Summer School in Astronomy, which was held in Belgrade 29-01.10.2008.

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Београд, 22-26. април 2010,
уредник М. С. Димитријевић
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VII СРПСКА КОНФЕРЕНЦИЈА О ОБЛИЦИМА СПЕКТРАЛНИХ ЛИНИЈА У АСТРОФИЗИЦИ

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Резиме: У овом раду сумирали смо рад Седме Српске Конференције о Облицима Спектралних Линија у Астрофизици (СКОСЛА). Главна расправа Конференције била је о томе шта можемо рећи како функционишу Активна Галактичка Језгра (АГЈ) на основу анализе облика њихових спектралних линија. Разматрано је и Штарково ширење спектара одређених класа звезда, као и веза између експерименталне спектроскопије и астрофизичке плазме.

1. УВОД

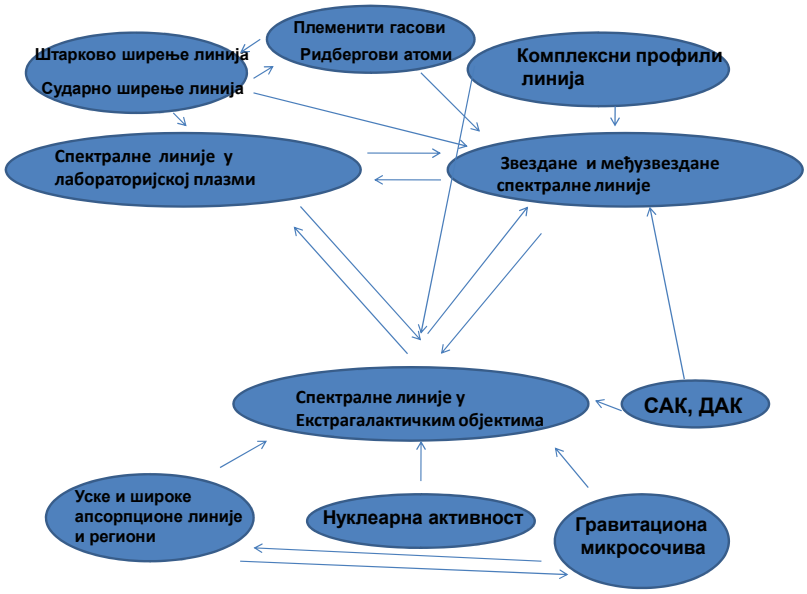
Седма Српска Конференција о облицима спектралних линија у астрофизици одржана је у Зрењанину од 15. до 19. јуна 2009. године.

Организацију Конференције је финансијски подржало Министарство за науку и технолошки развој Републике Србије. Конференција је уврштена у званичну активност обележавања Међународне године астрономије. Као што је на самом отварању Конференције, један од аутора (МСД) истакао (видети Слика 2), спектралне линије (њихова геометријска својства - ширине и облици) су моћна оруђа за изучавање емисионих и апсорпционих карактеристика гасова у астрофизичким објектима: од Сунчевог система до најудаљенијих објеката - квазара. Самим тим, ове линије настају из извора који зраче на широком опсегу таласних дужина, и имају различите физичке углове и кинематичке карактеристике. Односно, у енергетском домену ове линије се налазе од X зрачења (Fe K) па све до радио подручја.

Експериментална и теоријска истраживања лабораторијске плазме се широко примењују у спектроскопским астрофизичким истраживањима, при чему су нарочито за прорачун облика линија атомски подаци неопходни.

Конференција је окупила астрономе (посматрачи и теоретичари) и физичаре како би се направио преглед тренутног нивоа истраживања на овом пољу (локално у Србији, као и глобално).

Главни циљ је био унапређење знања у разматраној области, као и бољег разумевања значаја емисионих и апсорпционих линија за будућа астрофизичка истраживања. Фокус програма као и релације између различитих тема које су разматране на Конференцији приказан је на Слици 1.



Слика 1: *Схематски приказ релација између тема дискутованих на Конференцији.*

СКОЛСА серија конференција (детаљан историјат видети у раду Димитријевић, 2008) је мост између лабораторијске и астрофизичке спектроскопије. Интеракција између ова два поља истраживања треба да се појачава у будућности, на шта указује и састав Научно-организационог комитета НОК (Слика 4).

О значају синергије између ових поља говори и чињеница да је Зборник радова са Конференције штампан у часопису *New Astronomy Reviews* на 176 страна (Слика 3) чији су уредници били Лука Ч. Поповић и Милан С. Димитријевић. Можемо рећи да је по први пут у српској астрономији зборник радова са једне конференције штампан у овако престижном светском часопису.



Слика 2: *Милан С. Димитријевић, копредседник Научног организационог комитета (НОК) и главни покретач СКОЛСА, свечано отвара Конференцију. С десна на лево седе: др Џилијен Пич (члан НОК), др Драгана Илић (коподредседник ЛОК) и др Лука Ч. Поповић (копредседник НОК и председник ЛОК).*



Слика 3: *Др Лука Ч. Поповић и др Милан С. Димитријевић написали су уреднички увод за New Astronomy Reviews у коме је штампан зборник радова са VII СКОЛСА.*

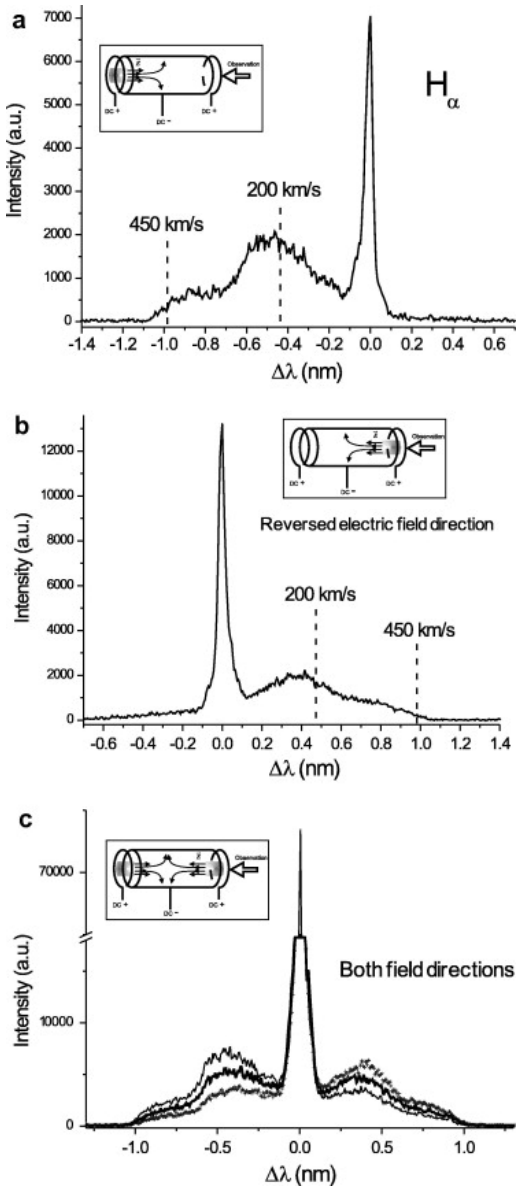


Слика 4: *Научни организациони комитет (НОК) (лева колона) и локални организациони комитет (ЛОК) (десна колона). Копредседници НОК су др Милан С. Димитријевић и др Лука Ч. Поповић. (ДВД издање материјала Конференције).*

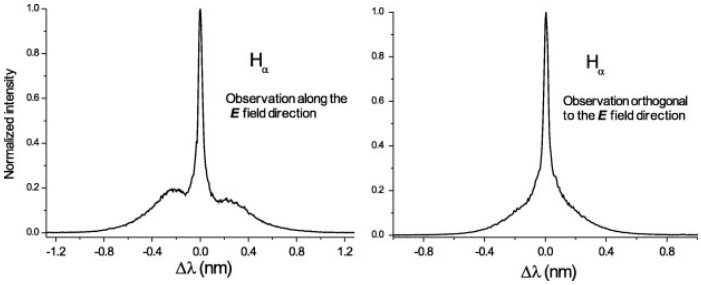
2. СПЕКТРАЛНЕ ЛИНИЈЕ У ЛАБОРАТОРИЈСКОЈ ПЛАЗМИ

Анализа профила линија се веома често користи у астрофизичким истраживањима. Профили линија атома и јона се фитују различитим типовима функција у зависности од физичких узрока који изазивају ширење. Подаци о карактеристикама астрофизичке плазме се добијају из ширине спектралних линија (Sulentic et al., 2000**).** Астрофизичке плазме имају широк опсег параметара: густине, температуре и макроскопске брзине. Јака магнетна и електрична поља такође могу бити присутна (њихов утицај се може уочити у профилима линија и линијским интензитетима). Са друге стране лабораторијска плазма може имати широк опсег параметара у зависности од извора, тако да је могуће постићи да њихове вредности буду блиске параметрима астрофизичке плазме (Griem, 1964). Међутим то није могуће постићи код објеката који имају веома јака магнетна поља и велике брзине као у широколинијским регионима активних галактичких језгара (AGJ). У раду Kuraica et al., (2009) је приказано неколико примера спектара лабораторијске плазме које имају сличне карактеристике са астрофизичким спектрима. Овде је издвојен (видети Сл 5) профил линија водоникових атома које су веома проширене ексцесивно или са Доплеровим помаком због њихових, за лабораторијску плазму великих, брзина (100-500 m/s). Као што се може видети овај спектар је сличан онима код неких врелих звезда и уског линијског региона код АГЈ (Netzer, 2008). Иако су брзине мале у односу на

широко линијски регион Доплеров механизам је у основи исти (Sulentic et al. 2000). Са друге стране овакве брзине атома су карактеристичне за лабораторијску плазму и токамаке.



Слика 5: *Водоникова Балмер алфа линија са великим Доплеровим помаком, забележена у плитком катодном пражњењу: а) Електрично поље је у правцу визуре, б) супротан смер електричног поља и с) електрично поље присутно у оба смера. Напон: 1.45 kV, притисак: 0.4 mbar.*



Слика 6: *Водоникова алфа линија добијена из Гримовог пражњења, забележена у правцу електричног поља (лево) и управно на њега (десно). Напон: 2 kV, притисак:2 mbar.*

У случају Гримовог пражњења водоникови атоми су великих брзина (400 км/s) (Слика 6) због чега настаје велико Доплерово ширење профила линија где су оба крила присутна. Профил забележен у правцу електричног поља је асиметричан са два крила која су благо одвојена од централног профила, док је у другом случају профил симетричан. Слични профили су забележени код АГЈ, а узроковани су радијалним кретањем емитера (Strateva et al., 2003). Неопходна је пажљива интерпретација спектара код оних извора где могу бити присутни ефекти електричног и магнетног поља, Доплеровог ширења и оптичког преноса кроз нехомогени гас. Ове сличности лабораторијских и астрофизичких профила и блискост до одређеног нивоа параметара плазме отварају могућност експерименталне симулације астрофизичке плазме.

На Конференцији је разматрана и важност улоге атома и молекула у Ридберговом стању (Gnedin et al.,2009) у астрофизици и то из најмање два разлога: великих су димензија и слабих веза, због чега се највероватније налазе у хладним звездама и космичким објектима, смеђим, белим, и М црвеним патуљцима. Присуство оваквих Ридбергових атома у атмосферама поменутих типова звезда очитовало се као недостатак флукса у Спицеровим посматрањима. Показано је да у атмосферама хладних звезда хемијонизациони процеси у којима учествују Ридбергови атоми постају веома важни.

Био је дат и преглед (Ben Nessib, 2009) *ab initio* прорачуна Штарковог ширења у квантно механичком приступу, семикласичној поремећајној и семи емпиријској теорији коришћењем SUPERSTRUCTURE и Cowan кода.

Ab initio значи да се у прорачунима полази од карактеристика атома из којих се рачунају енергетски нивои и јачине осцилатора, који се обично узимају из посебних теоријских прорачуна или експеримента. У Табели 1 у другој колони су приказани електронско сударно ширење рачунато Cowan кодом за атомску структуру и модификованим семиемприијским приступом за прорачун Штарковог ширења. Они су упоређени са експерименталним резултатима (Djeniže et al. 1990) за *3p4s-3p4p* прелаз и резултатима Dimitrijević et al. (1996) за прелазе *3p4p-3p5s.*

Табела 1: *Електронско ударно ширење за S III линије на T=40000 K и електронској густини N_e=2.1 10^{23} m^{-3}. Експериментални резултати за 3p4s-3p4p прелаз су узети из Djeniže et al. (1990), а за 3p4p-3p5s прелазе из Dimitrijević et al. (1996).*

Прелаз	W_{CC+MSE} (Å)	W_M(Å)
3p 4s $^3P^o$ – 3p 4p ^3D	0.405	0.432
3p 4p ^3D - 3p 5s $^3P^o$	0.410	0.402
3p 4p ^3S - 3p 5s $^3P^o$	0.396	0.380

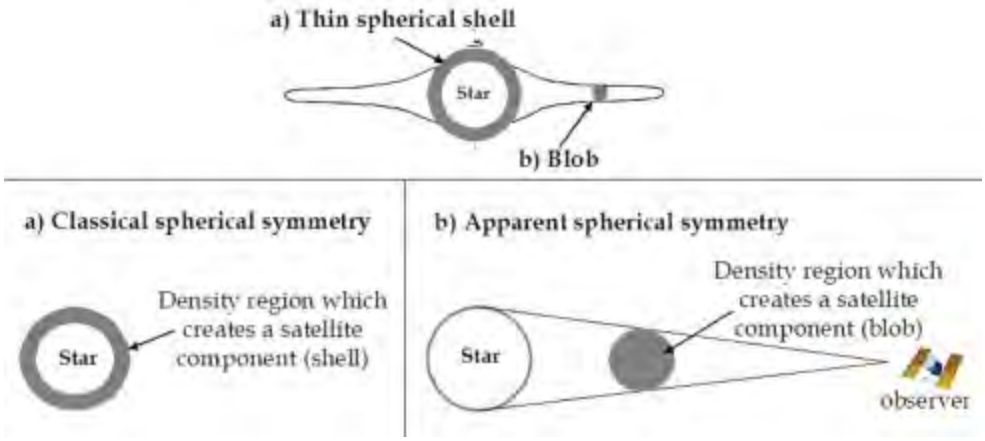
Elabidi et al. (2004) су израчунали ab initio атомске податке потребне за примену модификованог семиемпиријског формализма за електронско, ударно ширење јона линија Ne VII, Ne VIII, Si XI. Ови аутори су израчунали допринос еластичних судара на прагу за ексцитацију енергија и екстраполирали их испод прага као што је дато у раду Dimitrijević и Konjević (1980). Ab initio рачун је интересантан јер не захтева додатне податке, атомски подаци неопходни за параметре Штарковог ширења могу се израчунит коришћењем одговарајућег атомског пакета (SUPERSTRUCTURE, Cowan код). У будућности тестираће се и други кодови за добијање јачина осцилатора и енергија атомских енергетских нивоа потребих за примену семикласичног поремећајног формализма Штарковог ширења (RMATRIX, MCHF, CIV3).

3. ЗВЕЗДАНЕ И МЕЂУЗВЕЗДАНЕ СПЕКТРАЛНЕ ЛИНИЈЕ

У овој секцији Конференције аутори E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, A. Antoniou (2009) дали су преглед истраживања комплексних УВ линија у врелим звездама, затим посматрачке чињенице и проблеме који су везани са посебним и комплексним профилима спектралних линија, и приказали ГР модел и његову примену. У случају врелих звезда појављују се апсорпционе спектралне линије које нису повезане са неком познатом апсорпционом линијом звезде исте спектралне класе, а зову се дискретне апсорпционе компоненте (ДАК). Као што је показано у раду Danezis et al. (1991) то нису непознате апсорпционе линије већ спектралне линије истог јона и исте таласне дужине као и главна спектрална линија, померене за различито Δλ, пошто су настале у регионима различите густине који ротирају и крећу се радијално са различитим брзинама.

Аутори су предложили да пошто су вреле емисионе звезде окружене танким сферним омотачем који прелази у диск у екваторијалној равни, густи региони који креирају посматране ДАК у звезданом спектру могу бити или

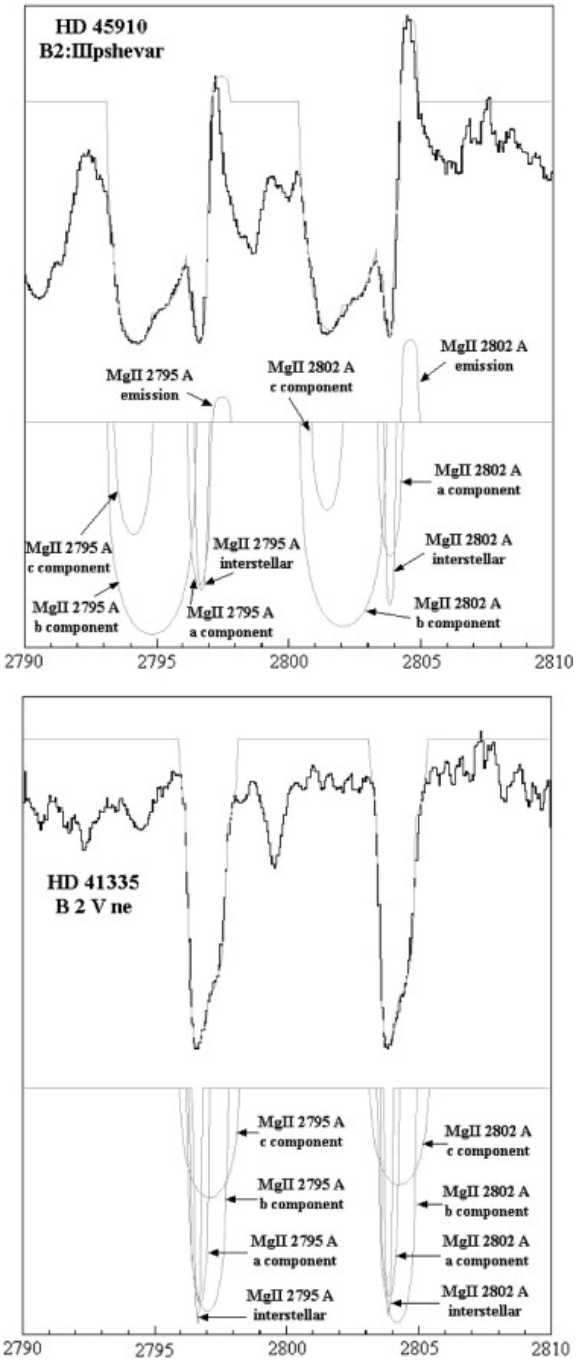
танке љуске око звезде или сферни густи региони који леже у диску који је окружује (Слика 7).



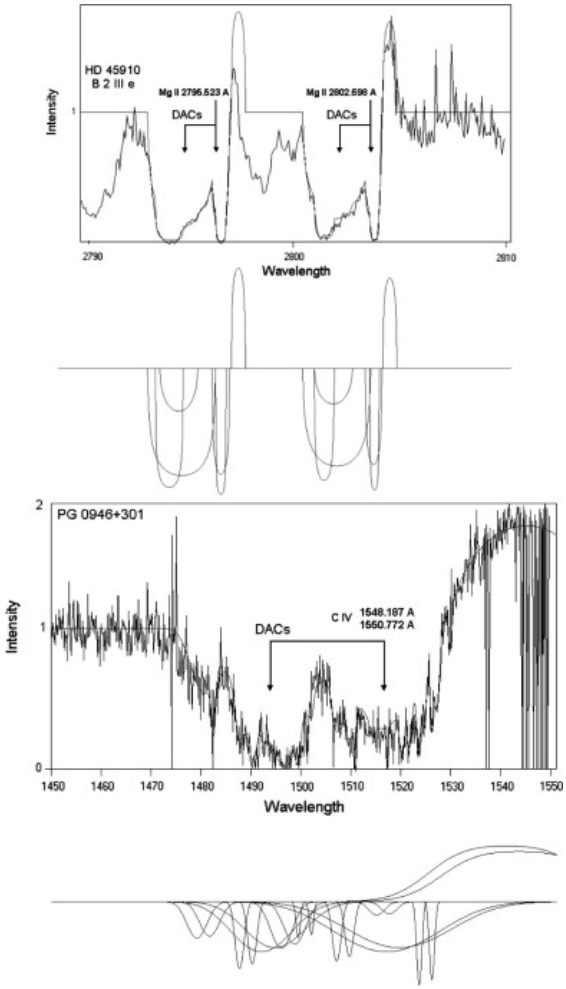
Слика 7: *ДАК настају у а) танкој сферној опни око вреле звзде или б) сферном густом региону у диску око звезде.*

Други проблем код оваквих звезда је присуство веома комплексних профила спектралних линија који се састоје из више компоненти које се преклапају. Зато је поменути научни тим предложио за такву појаву посебно име САК феномен (сателитске апсорпционе компоненте). Наиме ако региони у којима настају ДАК ротирају великим брзинама и крећу се радијално са малим, то производи линије великих ширина и малих помераја. Као резултат оне се мешају међу собом као и са главном спектралном линијом, због чега нису више дискретне па се користи нови назив САК. Према томе ДАК и САК су два аспекта једног истог феномена. На слици 8. се види да Mg II профили линија звезде AXMon (HD45910) који представљају ДАК и звезде HD41335, који представљају САК настају на исти начин. Једина разлика је у томе што су компоненте HD41335 мање померене и због тога помешане међусобно.

Сличан феномен може се детектовати у спектрима неких активних галактичких језгара, као што је на Слици 9 приказано за C IV UV дублет АГЈ (PG 0946+301). Вредности радијалних брзина и однос интензитета линија показују да два посматрана CIV профила представљају ДАК феномен сличан оном детектованом у спектру вреле звезде HD45910.



Слика 8: *ДАК за Mg II профил линија звезде AXMon (HD45910) и САК звезде HD41335. Црном линијом су означени посматрани профили линија а сивом оно што даје модел.*



Слика 9: *ДАК феномен у АГЈ: сличност ДАК код звезде HD45910 (MgII дублет) са АГЈ PG0946+301(CIV дублет).*

Овај научни тим је успешно применио ГР модел на спектралне линије врелих звезда и квазара, чиме је по први пут израчунат велики број параметара, и омогућено изучавање физичких закона у регионима где настају ДАК и САК.

Проф. др Џилијен Пич (Слика 10) је приказала формализам и рачунску технику која се може успешно применити на добијање профила линија од њиховог центра до крила за све температуре и све оне поремећајне густине за које је апроксимација једног пертурбера валидна. У развоју је одређивање доприноса прелаза где емитер-пертурбер систем заузима ограничено стање подржано почетним или крајњим потенцијалима молекуларног стања (Peach and Whittingham, 2009).



Слика 10: *Проф. др Џилијен Пич држи свечани говор на затварању Конференције. Проф. Пич је учесник прве у овој серији Конференција.*



Слика 11: *Др Силви Сахал Брешо са Париске Опсерваторије.*

Др Силви Сахал Брешо (Слика 11) описала (Sahal-Bréchot, 2009) је истраживања на Парискоj Опсерваторији у оквиру сударне теорије ширења линија. Захваљујући новим резултатима, може се имати нови увид у физику објеката чије се проширене линије анализирају. По њеном мишљењу то је позитиван пример интердисциплинарних истраживања, на граници атомске физике и астрофизике. У будућности истраживања ширења линија могу се

проширити и на друге домене астрофизике. Нпр. линијска поларизација у молекуларним линијама међузвезданог медијума почиње да се мери веома прецизно.

Са развојем ванатмосферске астрономије, спектралне линије ретких елемената сада се могу посматрати у звезданим спектрима са добром резолуцијом и атомски подаци за такве атоме и јоне су од све већег значаја. Simić et al. (2009) су дали преглед рада на пољу истраживања утицаја Штарковог ширења, ретких елемената у спектрима звезда и садашњих нових одређивања параметара Штарковог ширења неутралног телура на Београдској Опсерваторији.

4. СПЕКТРАЛНЕ ЛИНИЈЕ У ВАНГАЛАКТИЧКИМ ОБЈЕКТИМА

Ова секција је била највећа на Конференцији са укупно 17 предавања. Најпре ћемо истаћи предавање које је одржао проф. др Мартин Гаскел (Слика 12) који је пионир истраживања променљивости зрачења АГЈ, што може послужити за истраживање оног што се дешава око супермасивних црних рупа. Организовао је многе међународне посматрачке кампање оваквих објеката.

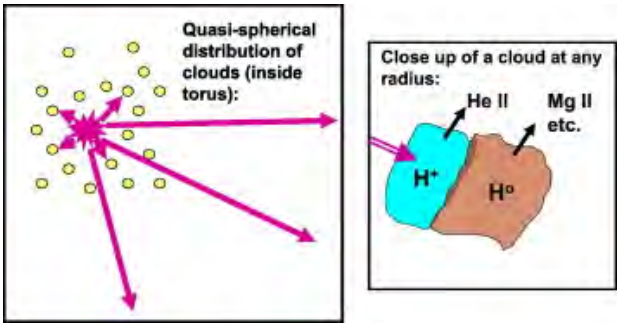


Слика 12: *Проф. др Мартин Гаскел свира оргуље у Лутеранској цркви за време екскурзије у Ковачици. Проф. Гаскел је и композитор хришћанске духовне музике (http://www.as.utexas.edu/~gaskell/).*

Мартин Гаскел (Gaskell, 2009) је дао преглед напретка који је начињен у разумевању природе широколинијског региона АГЈ као и његове улоге.

Реверберационо мапирање је показало да поменути регион има предоминантно Кеплерово кретање са јаком турбуленцијом и значајним

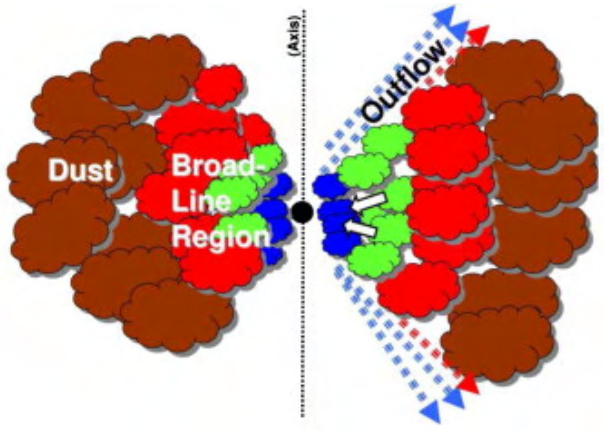
падањем материје ка црној рупи (акреција). Стопа акреције је довољна да обезбеди неопходну енергију која се иззрачи из АГЈ. Пошто су кретања у широколинијском региону гравитационо доминантна, и његова структура је веома слична код већине АГЈ, може се одредити маса црне рупе. Добра корелација између ових маса и маса добијених на основу луминозности звезданог овала галаксије обезбеђују јаку подршку коректности слике коју имамо о широколинијском региону (Слика 13). Иако постоје још многе мистерије око детаља како функционишу АГЈ, општа слика торуса и широколинијског региона су јасне (Слика 14). По мишљењу проф. Гаскела међузвездани материјал који прилази језгру распоређује се у раван танак торус. Материјал губи угаони момент због магнетно ротационе нестабилности и постепено се спирално увија према унутрашњости. Када материјал торуса досегне сублимациони радијус прашине, она испарава и тако настаје широколинијски регион. Турбулентни широколинијски регион наставља да се спирално увија према црној рупи где се евентуално догађа акреција. Степен јонизације се повећава како се гас све више приближава. Оптички провидан материјал, који има тенеденцију да се накупља према средишњој равни производи непрекидно зрачење, док онај који је више оптички танак продукује широколинијски регион. Не учествује сав широколинијски регион у акрецији. Један његов део се уклања са површине торуса великом брзином, разређеним ветром, као што је показано у свим магнетнохидродинамичким симулацијама и посматрањима. Међутим, проф. Гаскел је истакао да ова слика коју имамо мора добро да се провери да би се видело да ли описује све објекте а не само неколико добро посматраних као што је NGC5548.



Слика 13: *Лево је приказан традиционалан модел широколинијског региона. Десно је схематски приказ сваког облака.*

Треба још рада уложити у испитивање да ли диск модел (који је главни ривал приказаном моделу) може да објасни све појаве код ових објеката. Знамо да је тамо гас који отиче као и онај који је у акрецији око црне рупе. Питање је колико од овог доприноси широколинијским профилима. Ilić et al. (2008) показали су да отицање може да се повеже са неким од

широколинијских региона, тако да је одређивање релативног доприноса само на основу фитовања профила линија веома тешко. По мишљењу проф. Гаскела реверберационо мапирање и спектрополариметрија могу да дају најбољи одговор. Kollatschny (2003) је нашао извесне доказе за отицање материје у Mrk110, док су Denney at al. (2009) добили јаснији доказ постојања компоненте отицања материје у реверберационом мапирању NGC 3227. Проф. Гаскел сматра да NGC 3227 не представља главни проблем за фаворизован модел.



Слика 14: *Схематски приказ широколинијски регион и торус АГЈ у равни.*

Оно што би представљало проблем је уколико планирана посматрачка кампања за овај објекат потврди отицање гаса из широколинијског региона. Ово нас може упозорити на чињеницу да се АГЈ могу разликовати по доминација утицања или отицања гаса у овом региону. Иако је проф. Гаскел у свом излагању указивао на сличности међу АГЈ и које све последице могу настати, постоје и разлике у широколинијском региону. Највеће разлике су у емисији оптичких Fe II линија. У моделу широколинијског региона који је дискутовао проф. Гаскел, оптичка емисија Fe II настаје у спољном делу овог региона унутар торуса али то не објашњава зашто су оптичке FeII линије толико изражене код неких објеката у односу на друге. Још једна мистерија коју је истакао проф. Гаскел је јачина емисије усколинијског региона и то је у јакој антикорелацији са Fe II емисијом. Комплетан модел АГЈ морао би објаснити ова два региона и њихову интеракцију.

Ала Шаповалова (Слика 15), једна од најистакнутијих посматрача и организатора посматрачких кампања АГЈ у свету, представила је резултате посматрачког програма (око 10 година) широких линија и континуума три АГЈ: 3C390.3, NGC4151 и NGC5548 (Shapovalova et al, 2009).

Њен тим истарживао је променљивост у Hβ и Hα линијама, као и корелације између линија и континуума.

За објекат NGC5548 је добијено да широке Балмерове линије настају у турбулентном акреционом диску, који је способан и да репроцесира централни континуум.

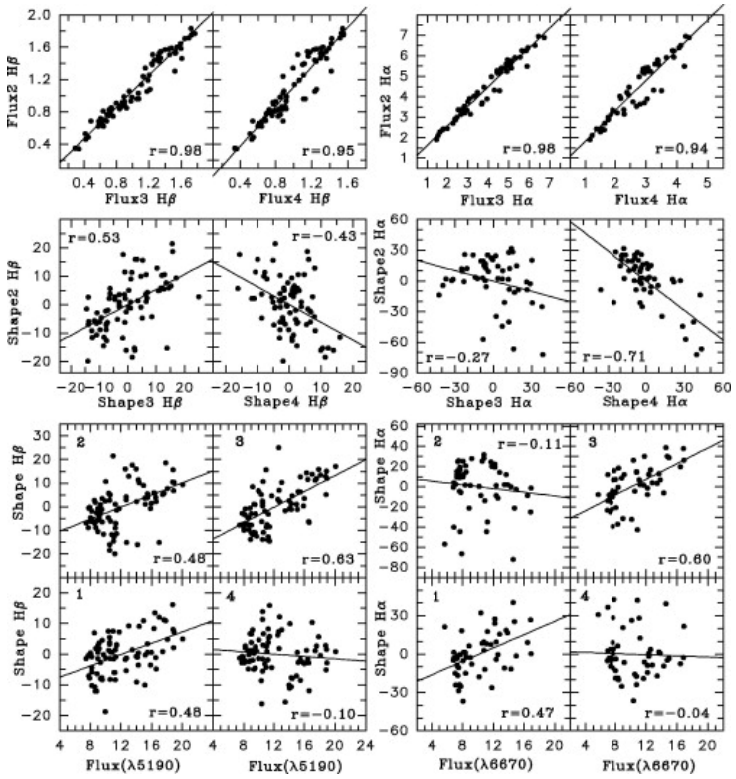


Слика 15*: Ала Шаповалова, један од најистакнутијих у свету организатора посматрачких кампања АГЈ, излаже рад на Конференцији.*

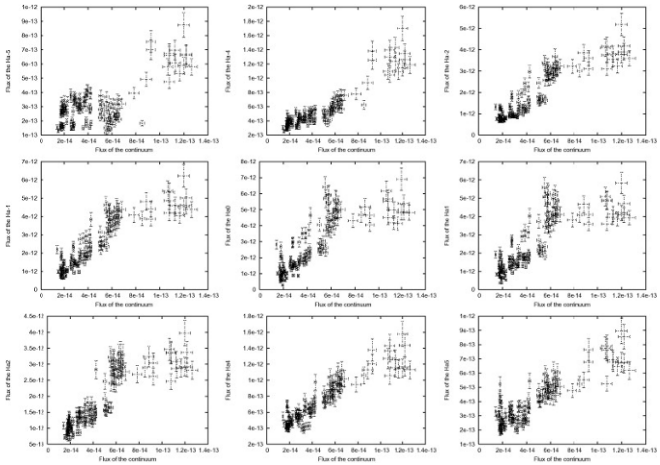
На Слици 16 приказано је како изгледају флукс–флукс, облик–облик линија и континуум флукс–облик линија корелације за различите сегменте линија Hα и Hβ за објекат NGC5548.

Широколинијски регион NGC4151 је много комплекснији. Линије настају у најмање два или три удаљена региона (један је фотојонизован са централним извором АГЈ а други је загреван ударним таласима). На Слици 17 приказана је зависност флуксева различитих сегмената широких линија од континуума флукса.

У случају 3C390.3 широке линије са два врха јасно указују на емисију диска. Променљивост у профилима линија могу се објаснити као поремећај у акреционом диску (детаљније видети у Shapovalova et al, 2010).

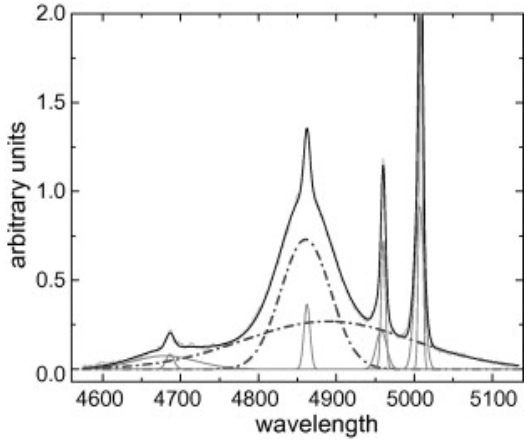


Слика 16: *Флукс–флукс, облик–облик линија и континуум флукс–облик линија корелације за различите сегменте Hα и Hβ за NGC5548. Број сегмената је дат у горњем левом углу док је корелациони коефицијент приказан на десном делу слике.*



Слика 17: *Флуксеви различитих сегмената широких линија као функције континуума флукса NGC4151.*

Џек Сулентик, (Sulentic et al., 2009) представио је 4D Eigenvector 1 (4DE1) простор који служи као сурогат H-R дијаграма за квазаре. То омогућује опис и унифицирање разлика међу свима широколинијским АГЈ. Спектар квазара може се усредњити коришћењем 4DE1 вектора баш као и звездани спектри што се усредњавају са OBAFGKM класификационим низом. Сулентик је пронашао да квазари са FWHM Hβ<4000 km s^{-1} (популација А) и FWHM Hβ>4000 km s^{-1} (популација Б) приказују многе значајне разлике које могу указати на актуелну дихотомију. Мерења широких линија и фитовање оснажују идеју дихотомије јер су фундаментално различите. Наиме, линије популација А имају Лоренцов облик а линије код популација Б добро се фитују са двоструким Гаусијаном. Ове разлике имају утицај на одређивање масе црне рупе као и на закључке о структури извора и кинематике. Слика 18 представља најснажнији доказ до сада за широколинијску и веома широку линијску интерпретацију Hβ линије у популацији Б (то су углавном RL квазари и 25% od RQ). На тој слици је приказан средњи композитни спектар за око 130 квазара, као што се види двоструки Гаусов фит лепо опсиује профил Hβ у SDSS композитном спектру.



Слика 18: *Композитни средњи спектар извора објеката популације Б. Профил нацртан цртицом-тачком указује на два Гаусијана (широколинијски регион и веома широколинијски регион са црвеним помаком) за Hβ.*

Сулентик је у закључку истакао да можемо идентификовати три класе модела који могу објаснити веома широколинијски регион: а) гравитација (којим се могу објаснити карактеристике овог региона да је веома широк и са великим црвеним помаком) б) утицање материје (којим се такође може објаснити високи црвни помак) г) померање фотона процесом расејања (овим се могу објаснити особине да је регион веома широк, његов црвени помак велик, и да постаје проминентнији на већој луминозности. Израчунате масе црних рупа нису довољно велике да би потврдиле настанак веома

широког линијског региона у њиховој близини. То је такође подржано чињеницом да се линије из тог региона могу добро фитовати симетричним Гаусијаном. Сулентик подржава модел б) и г) и сматра да треба наставити истраживања у том смеру.

На Конференцији су Јовановић, Поповић и Симић (2009) представили утицај гравитационих микросочива на широке линије квазара, са посебним освртом на Fe Kα линију, користећи модел акреционог диска покривеног апосрпционим регионом. Они су се у свом истраживању фокусирали на питање колико комбиновани утицај унутрашње апсорпције и гравитационог микросочива може променити Fe Kα профиле, емитоване из нискојонизованог широколинијског региона икс зрачења код квазара (LoB-AL). Аутори су развили модел рентгенског апсорпционог/потамњујућег региона који може да опише посматране (Done et al 2007) P Cygni профиле Fe Kα линија. Модел (Jovanović, Popović 2007) који су аутори користили, подразумева да се апсорпциони регион састоји од великог броја појединачних сферних апсорпционих облака (истог малог радијуса), расејаних у простору тако да пројекције њихових центара на посматрачеву небеску раван (Xi,Yi) има двокомпонентну нормалну дистрибуцију $N(\mu,\Sigma)$, где је $\mu=[\mu_X,\mu_Y]^T$

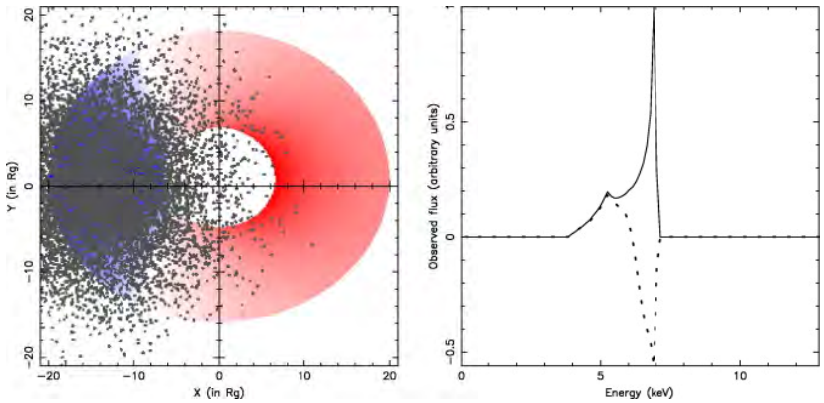
$$\Sigma = \begin{bmatrix} \sigma_X^2 & \rho\sigma_X\sigma_Y \\ \rho\sigma_X\sigma_Y & \sigma_Y^2 \end{bmatrix}$$

Овде су μ_X, μ_Y средње вредности координата Xi, Yi, док су σ_X, σ_Y њихове стандардне девијације и ρ је корелација међу њима. Коришћене су следеће вредности параметара у нумеричким симулацијама: $\rho=0$, $\mu_X=X_A$, $\mu_Y=Y_A$ и $\sigma_X=\sigma_Y=R_A$, где је X_A, Y_A центар а R_A је радијус пројекције целог апсорпционог региона. Апсорпциони коефицијент A(X,Y) за сваки сферни облак у апсорционом региону је дат са (Jovanović, Popović 2007)

$$A(X,Y) = (1 - I_A(X,Y)) \cdot e^{-\left(\frac{g(X,Y)\ E_0 - E_A}{\sigma_E}\right)^2}$$

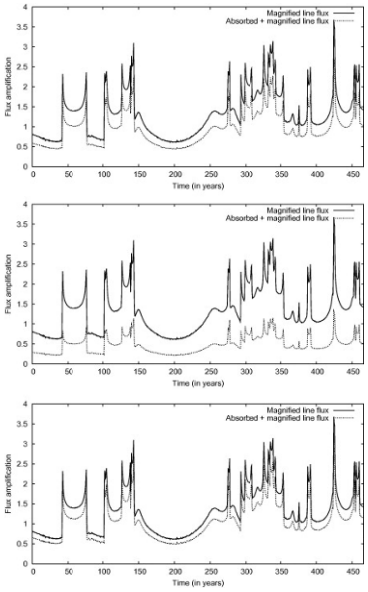
где коефицијент интензитета апцорпције $I_A(X,Y)$ описује дистрибуцију апсорпције у целом региону, E_A је централна енергија апсорпције и σ_E ширина апсорпционог опсега (дисперзија брзина).

На слици 19 (десно) приказана је деформација Fe Kα линије због апсорпционог региона који покрива приближавајућу страну диска (слика 19 лево). Добијени профил P Cygni за Fe Kα има емисиону компоненту на 5 KeV и апсорпциону на 7 KeV (што се слаже са посматрањима Done at al 2007).

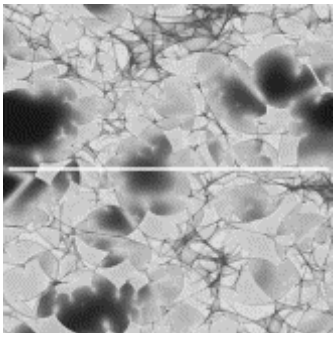


Слика 19: *Моделовани акрециони диск покривен врелом апсорпционом материјом (лево) и одговарајућа апосорпција FeKα, приказана испрекиданом линијом (десно), континуална крива представља FeKα без апсорпције.*

Ширина и дубина апсорпционе компоненте зависи од пројекције овог региона на акрециони диск. Аутори су такође показали да комбиновани утицај апсорпције и гравитационог микросочива може објаснити посматране варијације Fe Kα линије у случају објекта H1413+117.



Слика 20: *Поређење између симулираних кривих неапсорбоване (континуална крива) и апсорбоване Fe Kα (испрекидана линија). Симулације су рађене за акрециони диск који пролази дуж хоризонталне путање у мапи увећања слике А квазара H1413+117 (слика 21).*



Слика 21: *Мапа гравитационог увећања квазара H1413+117 слика A. Бела линија представља анализирану путању центра акреционог диска.*

Јовановић, Поповић и Симић успели су да направе мрежу модела за променљивост Fe Kα апсорпционе линије квазара H1413+117A (Слике 20 и 21) узроковану гравитационим микросочивом, што се може користити за поређење са посматраним варијацијама. Такође се ови резултати могу користити за тестирање карактеристика како апсорпционог региона тако и акреционог диска у случајевима утицаја сочива на квазаре са Fe Kα апсорпционом компонентом.

4. ПОСТЕР СЕКЦИЈА

На Конференцији се такмичило 18 аутора за најбољи постер. Жири у саставу Цилијен Пич, Кристијан Дамијан и Мартин Гаскел, после петоминутних презентација и разгледања постера одлучио је да додели награду најбољем (Слике 22 и 23) *Van der Waals broadening in atmospheric pressure surface wave discharges sustained in rare gases* чији су аутори José Muñoz, Cristina Yubero, Milan S. Dimitrijević и María Dolores Calzada. Истраживања Ван дер Валсовог ширења су тренутно једна од веома важних области у спектроскопији јер се вредности овог параметра могу повезати преко Линдхолм-Фоли теорије са температуром гаса, што је важно за дијагностику плазме и одређивање кинематичких карактеристика тешких честица. Аутори су анализирали профиле неколико атомских линија племенитих гасова (које настају под утицајем микроталаса, 2.45GHz) на атмосферском притиску у циљу одређивања најпогоднијих за мерење температуре гаса. Посебна пажња је дата утицају Штарковог ширења на Лоренцову ширину, из које се добија и Ван дер Валсово ширење.



Слика 22: *José Muñoz излаже најбољи постер на Конференцији.*



Слика 23: *Доц. др Драгана Илић, коподпредседник ЛОК, додељује награду за најбољи постер на свечаној вечери Конференције.*

5. УМЕСТО ЗАКЉУЧКА, ПОГЛЕД УНАПРЕД

На Конференцији су приказани нови резултати, који су унапредили наше актуелно знање о АГЈ. Настанак и еволуција супермасивних црних рупа је главно отворено питање вангалактичке физике. Раст масе црне рупе и повратни утицај АГЈ на галаксију домаћина су два кључна процеса који могу утицати на еволуциони модел галаксија. Оно што нас очекује у блиској будућности су интерферометријска посматрања унутрашњег акреционог протока око Sgr A (ово нам је најближе галактичко језгро) као и

спектроскопска посматрања релативистичког ширења линија гвожђа у АГЈ што ће дати могућност за мапирање простор-времена астрофизичких црних рупа. Ова могућност биће реализована само ако се зрачење из унутрашњег акреционог протока може идентификовати и раздвојити од емисије или од млазева и отицања. За то ће бити коришћена нова техника која филтрира добијене слике и спектре засноване на кинематичким својствима флуидних елемената у унутрашњем акреционом току као и на својствима јаких гравитационих сочива у Керовом простор-времену. Max-Planck-Institut für extraterrestrische Physik има у плану изградњу инструмента GRAVITY са адаптивном оптиком (http://www.mpe.mpg.de/ir/gravity/index.php). Са тачношћу од 10 лучних микросекунди, овај инструмент ће моћи да изучава кретање унутар растојања од неколико пута величине хоризонта догађаја масивне црне рупе и потенцијално тестирати Општу релативност на самој граници. Овај инструмент имаће за циљ и одређивање величине и састава широколинијског региона АГЈ, торуса прашине и кондензационог региона. Због своје велике осетљивости и инфрацрвених сензора, ова научна мисија проширће скуп доступних објеката (у односу на друге VLTI инструменте), обезбеђујући већи варијетет геометрија, што је кључ у дискусији унифицираног модела.



Слика 24: *ДВД издање материјала са Конференције. Слика која покрива ДВД је уједно и званична Конференцијска слика: у првом реду стоје (слева на десно) Мартин Гаскел, Лука Ч. Поповић, Милан С. Димитријевић, Тамара Богдановић, Мајкл Ераклеоус, Драгана Илић и Џорџ Чартас.*

Можемо слободно рећи, да је Конференција посвећена темама које ће бити актуелне и у будућности и од којих се очекује велики пробој. Апстракти, програм и фотографије са Конференције доступни су у електронском виду (Popović, Dimitrijević, Jevremović, Ilić 2009) (Слика 24).

Захвалница

Овај рад је урађен у оквиру пројекта 146001 *Утицај сударних процеса на спектре астрофизичке плазме*, пројекта 146002 *Астрофизичка спектроскопија вангалактичких објеката* и пројекта 146022 *Историја и епистемологија природних наука*, код Министарства за науку и технолошки развој Републике Србије.

Литература

Ben Nesib, N.: 2009 "Ab initio calculations of Stark broadening parameters", *New. Astron. Rev.*, **53**, 255-258.

Danezis, E., Lyratzi, E., Popović, L. Č., Dimitrijević, M. S., Antoniou, A.: 2009, " Interpreting the complex line profiles in the stellar spectra ", *New Astron. Rev*., **53**, 214-221.

Danezis, E, Theodossiou, E., Laskarides, P.: 1991, "The far UV spectrum of the Be star AX Monocerotis", *Astrophysics and Space Science*, **179**, 111–139.

Denney, K. D. et al.: 2009, "A revised broad-line region radius and black hole mass for the narrow-line Seyfert 1 NGC 4051", *ApJ*, **702**, 1353-1366.

Dimitrijević, M. S., Konjević, N.: 1980, "Stark widths of doubly- and triply-ionized atom lines", *Journal of Quantitative Spectroscopy and Radiative Transfer*, **24**, 451-459.

Dimitrijević, M. S., Djeniže, S., Srećković, A., Platiša, M.: 1996, „On the S III and S IV Spectral Line Stark Broadening Parameters", *Physica Scripta*, **53**, 545-548.

Димитријевић, М. С.: 2008, "Шеста српска конференција о облицима спектралних линија у астрофизици", *Зборник радова конференције" Развој астрономије код Срба V*", Београд, 18-22. Април 2008, Публикације Астрономског друштва "Руђер Бошковић", **8**, 829-846.

Dimitrijević, M. S., Popović, L. Č, Jevremović, D., Ilić, D.: 2009, "VII Serbian Confrence On Spectral Line Shapes In Astrophysics: Abstracts, Program and Photos", DVD, Eds. Serbian astronomical society and Astronomical Observatory Belgrade, ISBN978-86-80019-34-5.

Djeniže, S., Srećković, A., Platiša, M., Konjević, R., Labat, J., Purić, J.: 1990, *Phys. Rev. A*, **42 ,** 2379.

Done, C., Sobolewska, M., Gierliński, M., Schurch, N.: 2007, "The iron K feature in narrow line Seyfert 1 galaxies: evidence for a P Cygni profile?", *MNRAS*, **374**, L15-L19.

Elabidi, H., Ben Nessib, N., Sahal-Bréchot, S.: 2004, " Quantum mechanical calculations of the electron-impact broadening of spectral lines for intermediate coupling", *J. Phys. B: At. Mol. Opt. Phys.*, **37**, 63-71.

Gaskell, M.: 2009, "What broad emission lines tell us about how active galactic nuclei work", *New Astron. Rev*., **53,** 140-148.

Gnedin, Y., Mihajlov, A, Ignjatović, Lj, Sakan, N., Srećković, V., Zakharov, M., Bezuglov, N., Klycharev, N.: 2009, "Rydberg atoms in astrophysics", *New. Astron. Rev.* **53**, 259-265.

Griem, H. R .: 1964, "Plasma Spectroscopy", McGraw-Hill.

Ilić, D., Popović L. Č., León-Tavares, J., Lobanov A., Shapovalova A. I., Chavushyan, V.: 2008, "The broad line region in Mrk 668 and NGC 4151: an outflow model" *Memorie della Societa Astronomica Ita*liana, **79**, 1105-1108.

Jovanović, P., Popović, L. Č., Simić, S.: 2009, "Influence of gravitational microlensing on broad absorption lines of QSOs: The case of the Fe Kα line", *New Astron. Rev.*, **53,** 156-161.

Jovanović, P., Popović, L. Č.: 2007, "The Shape of the FeKα Spectral Line in the Case of Partly Obscured Accretion Disk", *AIP Conf. Proc. Series* VI Serbian Conference on Spectral Line Shapes in Astrophysics (VI SCSLSA), **938**, 76-81

Kollatschny, W.: 2003, "Accretion disk wind in the AGN broad-line region: Spectroscopically resolved line profile variations in Mrk 110*", A&A*, **407**, 461-472.

Kuraica, M. M., Obradović, B., Cvetanović, N., Dojčinović, I., Purić, J.: 2009, "Examples of spectroscopy of laboratory plasma with possible connection to astrophysical plasmas", *New Astron. Reviews*, **53**, 266-271.

Netzer, H.: 2008, " Ionized gas in active galactic nuclei", *New. Astron. Rev.*, **52**, 257-273.

Peach, G., Whittingham, I.: 2009, "The theory of line shapes relevant to the spectra of cool stars", *New Astron. Rev*., **53**, 227-230.

Sahal-Bréchot, S.: 2009, "From collisional line broadening to atomic polarization and collisional depolarization; Astrophysical applications ", *New Astron. Rev*., **53,** 231-239.

Shapovalova, A., Popović, L. Č., Bochkarev, N., Burenkov, A., Chavushyan, V. Collin, S., Doroshenko, V., Ilić, D., Kovačević, A.: 2009, "Long-term variability of the Broad Emission Line profiles in AGN", *New Astron. Rev.*, **53,** 191-197.

Shapovalova, A., Popović, L. Č. et al.: 2010, "Spectral optical monitoring of 3C390.3 in 1995-2007: I. Light curves and flux variation of the continuum and broad lines", *A&A*, accepted.

Simić, Z., Dimitrijević, M. S., Kovačević, A.: 2009, "Stark broadening of spectral lines in chemically peculiar stars: Te I lines and recent calculations for trace elements", *New Astron. Rev*, **53,** 246-251.

Strateva et al.: 2003, "Double-peaked Low-Ionization Emission Lines in Active Galactic Nuclei", *AJ*, **126**, 1720-1749.

Sulentic, J. W., Marziani, P., Dultzin-Hacyan, D.: 2000, "Phenomenology of Broad Emission Lines in Active Galactic Nuclei", *Ann. Rev. Astron. Astrophys.*, **38**, 521-571.

Sulentic, J. W., Marziani, P., Zamfir, S.: 2009, "Comparing Hβ line profiles in the 4D Eigenvector 1 context", *New Astron. Rev*., **53,** 198-201.

VII SERBIAN CONFERENCE ON SPECTRAL LINE SHAPES IN ASTROPHYSICS

Here we presented a summary of VII Serbian Conference on Spectral Line Shapes in Astrophysics, which was held in Zrenjanin 15-19.06.2009.

Зборник радова конференције "Развој астрономије код Срба VI"
Београд 22-26. април 2010,
уредник М. С. Димитријевић
Публ. Астр. друш. "Руђер Бошковић" бр. 10, 2011, 289-341

АКТИВНОСТИ САРАДНИКА ПРОЈЕКТА 146001 "УТИЦАЈ СУДАРНИХ ПРОЦЕСА НА СПЕКТРЕ АСТРОФИЗИЧКЕ ПЛАЗМЕ" - 2008-2009

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Резиме: Приказане су активности сарадника на пројекту 146001 «Утицај сударних процеса на спектре астрофизичке плазме», који финансира Министарство за науку и технолошки развој, у периоду од 1. јануара 2008. до 31. децембра 2009. године. Осим библиографије научних резултата, наведени су и други подаци о различитим активностима сарадника на пројекту.

У оквиру пројекта «Утицај сударних процеса на спектре астрофизичке плазме», истраживала се плазма у астрофизици, лабораторији и технологији. Посебна пажња посвећена је истраживању профила спектралних линија проширених сударима са наелектрисаним честима (Штарков ефекат), од значаја за дијагностику и моделирање звездане плазме, плазме у лабораторији и технолошке плазме. Коришћени су, испитивани и развијани семикласични пертурбациони и модификовани семиемпиријски формализми и примењивани за добијање параметара Штарковог ширења, а добијени резултати су послужили за истраживање његовог утицаја у звезданим атмосферама.

Сарадници пројекта објавили су 8 радова у водећим међународним часописима и то у (број радова дат у загради): *Astronomy and Astrophysics* (1), *Astrophysical Journal* (3), *Astrophysical Journal Supplement Series* (1), *Monthly Notices of the Royal Astronomical Society* (2), *Spectrochimica Acta B* (1).

У међународним часописима *New Astronomy* (1), *New Astronomy Review* (5) and *European Journal of Physics D* (1) публиковано је 7 радова а у међународним часописима који нису на SCI листи и књигама међународних издавача објављено је 18 радова.

Остали резултати су: Предавања по позиву на међународним конференцијама штампана у целини у књигама међународних издавача (2) и осталим зборницима (2), националне монографије (1), научни радови у националним часописима и књигама (16), научни радови у зборницима

међународних конференција штампани у целини (17), предавања по позиву на националним конференцијама штампана у целини (2), радови на националним конференцијама штампани у целини (22), предавања на међународним конференцијама штампана у изводу (10), саопштења на међународним конференцијама објављена у изводу (49), предавања на националним конференцијама штампана у изводу (3), прикази књига у међународним часописима (1) и саопштења на националним конференцијама штампана у изводу (3). Зоран Симић је у овом периоду одбранио докторску дисертацију.

Укупно, сарадници пројекта објавили су 139 библиографских јединица од којих су 83 везане за пројекат а 56 нису.

Сарадници пројекта су такође организовали четири конференције и једну летњу школу, дајући и на тај начин допринос развоју научне сарадње. То су:

1. «РАЗВОЈ АСТРОНОМИЈЕ КОД СРБА V», Београд, 18 – 22. април 2008, М. С. Димитријевић, председник Научног комитета, чланови М. Дачић, Локални организациони комитет, чланови М. Дачић, М. С. Димитријевић
2. 6th SERBIAN-BULGARIAN ASTRONOMICAL CONFERENCE, Београд, 7 – 11. мај, 2008, М. С. Димитријевић ко-председник Научног комитета, чланови М. Дачић, Д. Јевремовић; А. Ковачевић председник Локалног организационог комитета, чланови М. Дачић, М. С. Димитријевић, Н. Миловановић, З. Симић.
3. 24TH SUMMER SCHOOL AND INTERNATIONAL SYMPOSIUM ON THE PHYSICS OF IONIZED GASES - [SPIG 2008], August 25-29, 2008, Novi Sad, Serbia, М. С. Димитријевић ко-председник Локалног организационог комитета, чланови Н. Миловановић, М. Дачић, З. Симић, А. Ковачевић.
4. The Second Summer School in Astronomy, September 29 – October 1, 2008, Belgrade, Serbia, М. С. Димитријевић ко-председник Научног комитета, А. Ковачевић председник Локалног организационог комитета, чланови М. Дачић, З. Симић, (Ушла у званични програм обележавања 200 година од оснивања Београдског универзитета).
5. 7th Serbian Conference on Spectral Line Shapes in Astrophysics, June 15-19, 2009, Zrenjanin, Serbia; М. С. Димитријевић ко-председник Научног комитета, члан Д. Јевремовић: Д. Јевремовић председник Локалног организационог комитета, чланови М. Дачић, М. С. Димитријевић, З. Симић, А. Ковачевић

Поред тога, дали су допринос и организацији следећих конференција:

1. « ЂОРЂЕ СТАНОЈЕВИЋ – ЖИВОТ И ДЕЛО - Поводом 150 година од рођења“, Нови Сад, 10-11. октобар 2008, М. С. Димитријевић уредник Зборника и члан научно – организационог комитета.
2. 1st Workshop: Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, М. С. Димитријевић ко-подпредседник Научног комитета, чланови А. Ковачевић, З. Симић.

3. XV NATIONAL CONFERENCE OF ASTRONOMERS OF SERBIA, Анђелка Ковачевић, члан Локалног организационог комитета.
4. International Conference on Spectral Line Shapes, 15-20 June 2008, Valladolid, Spain, Милан С. Димитријевић члан Научног комитета

У периоду 2008-2009. на пројекту је било ангажовано седам истраживача, шест са Астрономске опсерваторије и Анђелка Ковачевић са Математичког факултета. Пројектом је у разматраном периоду руководио М. С. Димитријевић, а списак сарадника је:

1. ***Миодраг Дачић***, (рођ. 1946) са укупно 20 им
2. ***Милан С. Димитријевић***, (рођ. 1947) са укупно 24 им
3. ***Дарко Јевремовић***, (рођ. 1968) са укупно 18 им
4. ***Анђелка Ковачевић***, (рођ. 1972, МФ) са укупно 16 им
5. ***Ненад Миловановић***, (рођ. 1972) са укупно 24 им
6. ***Зоран Симић***, (рођ. 1967) са укупно 24 им
7. ***Драгана Танкосић***, (рођ. 1968) са укупно 8 им



Слика 1: *Милан С. Димитријевић.*



Слика 2: *Миодраг Дачић.*



Слика 3: *Анђелка Ковачевић.*

За две године, седам учесника су остварила 134 истраживачка месеца, тј. 11,2 године. Просечно годиште истраживача било је 1963,9 или око 46 година.

Пројекат је Министарство за науку и технолошки развој Србије прихватило на конкурсу расписаном 2005. године, а финансијска средства која је доделило за рад на пројекту показана су ниже.



Слика 4: *Ненад Миловановић.*

2009.

- 1. Средства за рад истраживача 8 121 038 дин
- 2. Средства за режијске трошкове 2 320 320 дин
- 3. Средства за директне мат. трошкове 596 654 дин

Укупно 11 038 012 дин

2008.

- 1. Средства за рад истраживача 6 009 281 дин
- 2. Средства за режијске трошкове 2 001 003 дин
- 3. Средства за директне мат. трошкове 890 952 дин

Укупно 8 901 236 дин

Укупно 2008 - 2009. 19 939 248 дин
(~210 000 ЕУР – 1 ЕУР = 95 дин)



Слика 5: *Дарко Јевремовић.*



Слика 6: *Драгана Танкосић.*

Средствима за режијске трошкове располагао је директор Астрономске опсерваторије и коришћена су за администрацију и опште трошкове институције. Директни материјални трошкови пројекта су утрошени за службена путовања, међународну сарадњу и куповину репроматеријала и ситне опреме.

У току 2008. и 2009. године, истраживања утицаја сударних процеса на спектре астрофизичке плазме одвијала су се у више праваца. Настављено је истраживање утицаја Штарковог ширења на спектре хемијски необичних звезда А типа и белих патуљака. Истражен је заједнички утицај ефекта Штарковог ширења и хиперфине структуре код линија јонизованог мангана, показано када су ови ефекти значајни и размотрено како се могу узети у обзир (Popović et al. 2008, *New Astronomy*, **13,** 85).

Истражена је зависност Штарковог ширења у звезданим спектрима од температуре и предложена побољшана метода за узимање у обзир ове зависности, код рачунања модела звезданих атмосфера и у дијагностици лабораторијске плазме (Zmerli et al. 2008, *European Journal of Physics D* **48,** 389).

Истражен је утицај Штарковог ширења код веома топлих (ефективна температура 40000 до 100000 K) и густих белих патуљака DO типа и применом програма за прорачун атомске структуре ab initio су одређени параметри Штарковог ширења за спектралне линије Si VI (Hamdi et al. 2008, *Monthly Notices of the Royal Astronomical Society*, **387,** 871).

Спектар звезде GJ 117 посматран је на 2,7 метарском телескопу на Мек Доналдс опсерваторији. Његовом анализом помоћу моделирања звездане атмосфере PHOENIX кодом нађено је да је $^{6}Li/^{7}Li=0.05+/-0.02$. Такође је анализиран механизам настанка литијума у овој звезди (Christian et al. 2008, *Astrophysical Journal*, **686**, 542).

Рађено је на развоју Дартмутске базе података за истраживање звездане еволуције и у ту сврху је истраживана и прорачунавана еволуциона историја појединих типова звезда (Dotter et al. 2008, Astrophysical Journal Supplement Series, **178**, 89).

Пошто су истражени ефекти промене хемијског састава звезданих популација на елемент по елемент основи на еволуционом низу, и изохронама до гране црвених џинова, уључени су синтетички звездани спектри са оним изохроним моделима који омогућавају предвиђање интегрисане боје, Лик индекса и спектара. Старије популације показују утицај односа елемената у њиховим спектрима са већом амплитудом него млађе (Lee et al. 2009, *Astrophysical Journal*, 694, 902).

Разрађен је и публикован низ модела спектара и анализиран пренос зрачења за широке апсорпционе линије гвожђа ниског степена јонизације код активних галактичких језгара. Добијени резултати иду у прилог идеји да FeLoBALs могу бити еволуциони стадијум у развоју квазара (Casebeer et al. 2008, *Astrophysical Journal*, **676**, 857).

Истраживана је променљивост оптичког спектра код галаксија (Shapovalova et al. 2008, *Astronomy and Astrophysics*, **486** (1), 99-111).

Истражен је укупан и релативан допринос релевантних апсорпционих процеса непрозрачности атмосфера ДБ белих патуљака у УВ и ВУВ областима (Ignjatović et al. 2009, *Monthly Notices of the Royal Astronomical Society*, **396,** 2201).

Разрађена је метода за мерење температуре гаса у аргон – хелијум микроталасној плазми на атмосферском притиску, помоћу Ван дер Валсовог ширења спектралних линија у оптичком делу спектра и одређене најпогодније линије за ову сврху (Muñoz et al. 2009, *Spectrochimica Acta B* **64,** 167).

Осим тога, рађено је на анализи Штарковог ширења спектралних линија за Српску виртуелну опсерваторију (Jevremović et al. 2009, *New Astronomy*

Review, **53**, 222), кинематици широколинијске области код квазара (Lyratzi et al. 2009, *New Astronomy Review*, **53**, 179), интерпретацији комплексних профила спектралних линија у звезданим спектрима (Danezis et al. 2009, *New Astronomy Review*, **53**, 214), Штарковом ширењу спектралних линија хемијски нерегуларних звезда (Simić et al. 2009, *New Astronomy Review*, **53**, 246) и анализи промењљивости профила емисионих линија код активних галактичких језгара (Shapovalova et al. 2009, *New Astronomy Review*, **53**, 246).

Ово су само најважнији резултати а остало се може видети из библиографије објављених радова у прилогу.

Свакако највећи успех и признање резултатима пројекта је што смо заједно са партнерима из Француске, Енглеске, Аустрије, Шведске, Италије, Русије и Венецуеле добили ФП7 пројекат „Виртуелни Центар за Атомске и Молекуларне податке“.

Поред тога, остварена је успешна сарадња са Париском опсерваторијом, и Универзитетима, опсерваторијама и институтима у Атини, Кордоби, Паризу, Лиону, Санкт Петербургу, Москви, Нижњем Архизу, Лондону, Белфасту, Дартмуту, Гронингену, Вашингтону, Оклахоми, Алабами, Вичити, Висконсину, Џорџији, Калифорнији, Хановеру, Гетингену, Сао Паолу, Монреалу, Мексику и Тунису, као и са Институтом за астрономију у Софији (пројекат САНУ-БАН) и Катедром за примењену физику Техничког универзитета у Софији што се види из списка објављених радова у прилогу.



Слика 7: *Зоран Симић.*

Такође, М. С. Димитријевић је био руководилац докторске дисертације Зорану Симићу коју је он одбранио 15. јула 2008.

У оквиру пројекта, рађено је и на развоју и потхрањивању базе података STARK-B заједно са Силви Сахал – Брешо и Николом Мороом са Париске опсерваторије.

БИБЛИОГРАФИЈА НАУЧНИХ РАДОВА САРАДНИКА ПРОЈЕКТА 146001 У ПЕРИОДУ 2008-2009

НАУЧНИ РАДОВИ У ВРХУНСКИМ МЕЂУНАРОДНИМ ЧАСОПИСИМА

1. A. I. Shapovalova, L. Č. Popović, S. Collin, A. N. Burenkov, V. H. Chavushyan, N. G. Bochkarev, E. Benítez, D. Dultzin, A. Kovačević, N. Borisov, L. Carrasco, J. Leon-Tavares, A. Mercado, J. R. Valdes, V. V. Vlasyuk, V. E. Zhdanova: 2008, LONG-TERM VARIABILITY OF THE OPTICAL SPECTRA OF NGC 4151. I. LIGHT CURVES AND FLUX CORRELATIONS, Astronomy and Astrophysics, **486** (1), 99-111.
2. D. J. Christian, M. Mathioudakis, D. Jevremović: 2008, ^{6}Li IN THE ATMOSPHERE OF GJ 117 REVISITED, Astrophysical Journal, **686** (1), 542-547.
3. A. Dotter, B. Chaboyer, D. Jevremović, V. Kostov, E. Baron, J. W. Ferguson,: 2008, THE DARTMOUTH STELLAR EVOLUTION DATABASE, Astrophysical Journal Supplement Series, **178** (1), 89-101.
4. D. Casebeer, E. Baron, K. Leighly, D. Jevremović, D. Branch: 2008, A SELF-CONSISTENT NLTE-SPECTRA SYNTHESIS MODEL OF FeLoBAL QSOs, Astrophysical Journal, **676** (2), 857-867.
5. R. Hamdi, N. Ben Nessib, N. Milovanović, L. Č. Popović, M. S. Dimitrijević, S. Sahal-Bréchot, 2008, ATOMIC DATA AND ELECTRON-IMPACT BROADENING EFFECT IN DO WHITE DWARF ATMOSPHERES: Si VI, Monthly Notices of the Royal Astronomical Society, **387,** 871-882.
6. J. Muñoz, M. S. Dimitrijević, C. Yubero, M. D. Calzada: USING THE VAN DER WAALS BROADENING OF SPECTRAL ATOMIC LINES TO MEASURE THE GAS TEMPERATURE OF AN ARGON-HELIUM MICROWAVE PLASMA AT ATMOSPHERIC PRESSURE, Spectrochimica Acta B **64** (2009), 167-172.
7. Lj. M. Ignjatović, A. A. Mihajlov, N. M. Sakan, M. S. Dimitrijhević, A. Metropoulos: 2009, THE TOTAL AND RELATIVE CONTRIBUTION OF THE RELEVANT ABSORPTION PROCESSES TO THE OPACITZ OF DB WHITE DWARF ATMOSPHERES IN THE UV AND VUV REGIONS, Monthly Notices of the Royal Astronomical Society, **396,** 2201-2210.

8. H. C. Lee, G. Worthey, A. Dotter, B. Chaboyer, D. Jevremović, E. Baron, M. M. Briley, J. W. Ferguson, P. Coelho, S. C. Trager: 2009, STELLAR POPULATION MODELS AND INDIVIDUAL ELEMENT ABUNDANCES. II. STELLAR SPECTRA AND INTEGRATED LIGHT MODELS, Astrophysical Journal, **694**, 902-923.

НАУЧНИ РАДОВИ У МЕЂУНАРОДНИМ ЧАСОПИСИМА

1. L. Č. Popović, M. S. Dimitrijević, Z. Simić, M. Dačić, A. Kovačević, S. Sahal-Bréchot: 2008, STARK BROADENING AND HFS OF Mn II, New Astronomy, **13,** 85-92.
2. B. Zmerli, N. Ben Nessib, M. S. Dimitrijević, 2008, TEMPERATURE DEPENDENCE OF ATOMIC SPECTRAL LINE WIDTHS IN A PLASMA, European Journal of Physics D **48,** 389-395.
3. D. Jevremović, M.S. Dimitrijević, L. Č. Popović, M. Dačić, V. Protić Benišek, E. Bon, N. Gavrilović, J. Kovačević, V. Benišek, A. Kovačević, D. Ilić, S. Sahal-Bréchot, K. Tsvetkova, Z. Simić, M. Malović: 2009, THE PROJECT OF SERBIAN VIRTUAL OBSERVATORY AND DATA FOR STELLAR ATMOSPHERE MODELING, New Astronomy Review, **53,** 222–226.
4. E. Lyratzi, L. Č. Popović, E. Danezis, M. S. Dimitrijević, A. Antoniou: 2009, KINEMATICS OF THE BROAD ABSORPTION LINE REGION IN QSOS: ROTATION AND RANDOM MOTION, New Astronomy Review, **53,** 179–185.
5. E. Danezis, E. Lyratzi, L. Č. PopovićM. S. Dimitrijević, A. Antoniou: 2009, INTERPRETING THE COMPLEX LINE PROFILES IN THE STELLAR SPECTRA, New Astronomy Review, **53,** 214–221.
6. Z. Simić, M.S. Dimitrijević, A. Kovačević: 2009, STARK BROADENING OF SPECTRAL LINES IN CHEMICALLY PECULIAR STARS: TE I LINES AND RECENT CALCULATIONS FOR TRACE ELEMENTS, New Astronomy Review, **53,** 246 –251.
7. A. I. Shapovalova, L. Č. Popović, N. G. Bochkarev, A. N. Burenkov, V. H. Chavushyan, S. Collin, V. T. Doroshenko, D. Ilić, A. Kovačević: 2009, LONG-TERM VARIABILITY OF THE BROAD EMISSION LINE PROFILES IN AGN, New Astronomy Review, **53,** 181 – 197..

ПЛЕНАРНА ПРЕДАВАЊА НА МЕЂУНАРОДНИМ КОНФЕРЕНЦИЈАМА ШТАМПАНА У ОКВИРУ КЊИГА И ЧАСОПИСА МЕЂУНАРОДНИХ ИЗДАВАЧА

1. A. Antoniou, E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević: 2008, KINEMATICAL PARAMETERS IN THE CORONAL AND POST-CORONAL REGIONS OF THE Oe STARS, 24th Summer School and International Symposium on the Physics of Ionized Gases, Journal of Physics: Conference Series **133**, 012028 (1-8).

2. M. S. Dimitrijević, M. Stavinschi: 2008, ROMANIAN-SERBIAN COLLABORATION IN ASTRONOMY“, in “Exploring the Solar System and the Universe”, Eds. V. Mioc, C. Dumitrache, N. Popescu, American Institute of Physics Conference Proceedings **1043**, 32-38.

ПЛЕНАРНА ПРЕДАВАЊА НА МЕЂУНАРОДНИМ КОНФЕРЕНЦИЈАМА ШТАМПАНА У ЦЕЛИНИ

1. Lj. M. Ignjatović, A. A. Mihajlov, M. S. Dimitrijević, V. Srećković: 2009, THE (n-n') –MIXING PROCESS IN STELLAR ATMOSPHERES, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 25-33.
2. A. N. Klycharev, M. Yu. Zakharov, A. A. Matveev, A. A. Mihajlov, Lj. M. Ignjatović, M. S. Dimitrijević: 2009, CHEMI-IONIZATION – EXPERIMENT, THEORIES, GEOCOSMICAL PERSPECTIVES, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 51-65.

ПЛЕНАРНА ПРЕДАВАЊА НА МЕЂУНАРОДНИМ КОНФЕРЕНЦИЈАМА ОДРЖАНА У РАЗМАТРАНОМ ПЕРИОДУ, ШТАМПАНА У ИЗВОДУ

1. Z. Simić, M. S. Dimitrijević, A. Kovačević: 2009, STARK BROADENING OF SPECTRAL LINES IN CHEMICALLY PECULIAR STARS, VII Serbian Conference on Spectral Line Shapes in Astrophysics (VII SCSLSA), Zrenjanin 15-19 June 2009, Book of abstracts, eds. L. Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Serbian Astronomical Society and Astronomical Observatory, Belgrade 2009, 40.
2. E. Lyratzi, E. Danezis, L. Č. Popović, M. S. Dimitrijević, A. Antoniou: 2009, WAYS OF CREATION OF SACs AND DACs IN THE PLASMA AROUND QUASARS, VII Serbian Conference on Spectral Line Shapes in Astrophysics (VII SCSLSA), Zrenjanin 15-19 June 2009, Book of abstracts, eds. L. Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Serbian Astronomical Society and Astronomical Observatory, Belgrade 2009, 37.
3. D. Jevremović, M. S. Dimitrijević, L. Č. Popović, M. Dačić, V. Protić-Benišek, E. Bon, V. Benišek, A. Kovačević, S. Sahal-Bréchot: 2009, THE PROJECT OF SERBIAN VIRTUAL OBSERVATORY AND DATA FOR STELLAR SPECTRA MODELLISATION, VII Serbian Conference on Spectral Line Shapes in Astrophysics (VII SCSLSA), Zrenjanin 15-19 June 2009, Book of abstracts, eds. L. Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Serbian Astronomical Society and Astronomical Observatory, Belgrade 2009, 34-35.
4. Lj. M. Ignjatović, A. A. Mihajlov, N. Sakan, V. A. Srećković, M. S. Dimitrijević, D. Jevremović: 2009, THE CHEMI-IONIZATION PROCESSES IN THE

SOLAR PHOTOSPHERE, VII Serbian Conference on Spectral Line Shapes in Astrophysics (VII SCSLSA), Zrenjanin 15-19 June 2009, Book of abstracts, eds. L. Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Serbian Astronomical Society and Astronomical Observatory, Belgrade 2009, 18.

5. E. Danezis, E. Lyratzi, A. Antoniou, L. Č. Popović, M. S. Dimitrijević, 2009, INTERPRETING THE COMPLEX LINE PROFILES IN THE STELLAR SPECTRA, VII Serbian Conference on Spectral Line Shapes in Astrophysics (VII SCSLSA), Zrenjanin 15-19 June 2009, Book of abstracts, eds. L. Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Serbian Astronomical Society and Astronomical Observatory, Belgrade 2009, 13.
6. E. Danezis, E. Lyratzi, A. Antoniou, L. Č. Popović, M. S. Dimitrijević, E. Theodossiou, 2009, STUDYING THE COMPLEX SPECTRAL LINE PROFILES IN THE SPECTRA OF HOT EMISSION STARS AND QUASARS, 1st Workshop: Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, Abstracts of Invited Lectures and Poster Papers, University of Athens, Faculty of Physics, Department of Astrophysics, Astronomy and Mechanics, без броја стране.
7. M. Christova, M. S. Dimitrijević, 2009, STARK BROADENING OF SPECTRAL LINES OF INERT GASES, 1st Workshop: Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, Abstracts of Invited Lectures and Poster Papers, University of Athens, Faculty of Physics, Department of Astrophysics, Astronomy and Mechanics, без броја стране.
8. M. S. Dimitrijević, 2009, STARK BROADENING INFLUENCE ON ASTRONOMICAL SPECTRA, 1st Workshop: Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, Abstracts of Invited Lectures and Poster Papers, University of Athens, Faculty of Physics, Department of Astrophysics, Astronomy and Mechanics, без броја стране.
9. K. Tsvetkova, M. Tsvetkov, M. S. Dimitrijević, V. Protić-Benišek, 2009, WIDE-FIELD PLATE ARCHIVES IN ROZHEN AND BELGRADE OBSER-VATORIES, 1st Workshop: Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, Abstracts of Invited Lectures and Poster Papers, University of Athens, Faculty of Physics, Department of Astrophysics, Astronomy and Mechanics, без броја стране.
10. M. S. Dimitrijević, 2009, INFLUENCE OF COLLISIONS WITH CHARGED PARTICLES ON ASTRONOMICAL SPECTRA, 7th General Conference of the Balkan Physical Union, Alexandroupolis, 9-13 September, 2009, Book of Abstracts, Balkan Physical Union and Hellenic Physical Society, 11-12.

МЕЂУНАРОДНИ ЧАСОПИСИ КОЈИ НИСУ НА SCI ЛИСТИ И КЊИГЕ МЕЂУНАРОДНИХ ИЗДАВАЧА

1. M. S. Dimitrijević, M. Christova, Z. Simić, S. Sahal-Bréchot: 2008, ELECTRON-IMPACT BROADENING OF Ar I 737.212 nm SPECTRAL LINE FOR STELLAR ATMOSPHERES RESEARCH, in "Exploring the Solar System and the Universe", Eds. V. Mioc, C. Dumitrache, N. Popescu, American Institute of Physics Conference Proceedings **1043**, 408-409.
2. M. S. Dimitrijević, A. Kovačević, Z. Simić, M. Dačić : 2008, STARK BROADENING OF O V 1371 A LINE IN STELLAR ATMOSPHERES, in "Exploring the Solar System and the Universe", Eds. V. Mioc, C. Dumitrache, N. Popescu, American Institute of Physics Conference Proceedings **1043**, 410-411.
3. E. Lyratzi, E. Danezis, L. Č. Popović, M. S. Dimitrijević, A. Antoniou: 2008, DACs AND SACs IN THE UV SPECTRUM OF THE QUASAR PG 0946+301, in Spectral Line Shapes 15, 19th International Conference on Spectral Line Shapes, AIP Conference Proceedings **1058**, 323-325.
4. E. Lyratzi, E. Danezis, L. Č. Popović, M. S. Dimitrijević, A. Antoniou: 2008, KINEMATICS OF BROAD ABSORPTION LINE REGIONS OF PG 1254+047, in Spectral Line Shapes 15, 19th International Conference on Spectral Line Shapes, AIP Conference Proceedings **1058**, 320-322.
5. A. Antoniou, E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, E. Theodosiou, G. Katsavrias: 2008, A STUDY OF THE STRUCTURE OF DIFFERENT IONIZATION POTENTIAL REGIONS IN THE ATMOSPHERE OF AX MON (HD 45910), in Spectral Line Shapes 15, 19th International Conference on Spectral Line Shapes, AIP Conference Proceedings **1058**, 317-319.
6. A. Antoniou, E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, E. Theodosiou, D. Stathopoulos: 2008, AX Mon (HD 45910) KINEMATICAL PARAMETERS IN THE Fe II SPECTRAL LINES AS A FUNCTION OF THE EXCITATION POTENTIAL, in Spectral Line Shapes 15, 19th International Conference on Spectral Line Shapes, AIP Conference Proceedings **1058**, 314-316.
7. E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, A. Antoniou: 2008, SIMILARITY BETWEEN DACs/SACs PHENOMENA IN HOT EMISSION STARS AND QUASARS ABSORPTION LINES, in Spectral Line Shapes 15, 19th International Conference on Spectral Line Shapes, AIP Conference Proceedings **1058**, 305-307.
8. J. Muñoz, M. S. Dimitrijević, C. Yubero, M. D. Calzada: 2008, GAS TEMPERATURE DETERMINATION IN ARGON-HELIUM PLASMA AT ATMOSPHERIC PRESSURE USING VAN DER WAALS BROADENING, in Spectral Line Shapes 15, 19th International Conference on Spectral Line Shapes, AIP Conference Proceedings **1058**, 149-151.

9. M. Christova, L. Christov, M. S. Dimitrijević, N. Andreev: 2008, CALCULATION OF THE SHIFTS OF ARGON SPECTRAL LINES, in Spectral Line Shapes 15, 19th International Conference on Spectral Line Shapes, AIP Conference Proceedings **1058**, 6-8.
10. M. Christova, L. Christov, E. Castaños-Martinez, M. S. Dimitrijević, M. Moisan: 2008, USING LINE BROADENING TO DETERMINE THE ELECTRON DENSITY IN AN ARGON SURFACE-WAVE DISCHARGE AT ATMOSPHERIC PRESSURE, in "Spectral Line Shapes", Vol. 15, 19th International Conference, Eds.M. A. Gigosos, M. A. Gonzalez, American Institute of Physics Conference Proceedings **1058**, 3-5.
11. M. S. Dimitrijević, E. Th. Theodossiou, P. Z. Mantarakis: 2008, MILUTIN MILANKOVIĆ AND THE REFORM OF THE JULIAN CALENDAR IN 1923, Journal of Astronomical History and Heritage **11** (2008), 50-54.
12. E. Th. Theodossiou, V. N. Manimanis, E. Danezis, M. S. Dimitrijević: 2009, THE COSMOLOGY OF THE GNOSTICS AND THE ORTHODOX CHURCH, Transdisciplinarity in Science and Religion **5**, 47-52.
13. E. Th. Theodossiou, V. N. Manimanis, M. S. Dimitrijević, E. Danezis : 2008, RIGAS VELESTINLIS AND ASTRONOMY IN HIS „ANTHOLOGY OF PHYSICS", in "Exploring the Solar System and the Universe", Eds. V. Mioc, C. Dumitrache, N. Popescu, American Institute of Physics Conference Proceedings **1043**, 74-75.
14. Z. Simić, M. S. Dimitrijević, L. Č. Popović, M. Dačić, A. Kovačević, S. Sahal-Bréchot: ON STARK BROADENING OF Mn II LINES IN Ap-STAR CONDITIONS, Contributions to the Astronomical Observatory Skalnate Pleso **38**, (2008), 451-452.
15. M. S. Dimitrijević, Z. Simić, A. Kovačević, M. Dačić, S. Sahal-Bréchot: ON STARK BROADENING OF Te I SPECTRAL LINES FOR CP STAR PLASMA ANALYSIS, Contributions to the Astronomical Observatory Skalnate Pleso **38**, (2008), 403-404.
16. M. S. Dimitrijević, T. Ryabchikova, Z. Simić, L. Č. Popović, M. Dačić: ELECTRON-IMPACT BROADENING OF IONIZED CHROMIUM LINES FOR Ap STAR ATMOSPHERES ANALYSIS, Contributions to the Astronomical Observatory Skalnate Pleso **38**, (2008), 401-402.
17. G. Peach, M. S. Dimitrijević, P. C. Stancil: 2009, DIVISION XII, COMMISSION 14, WORKING GROUP COLLISION PROCESSES, ed. K. A. van der Hucht, Transactions IAU **27A**, Reports on Astronomy 2006-2009, 385-399.
18. M. S. Dimitrijević, E. Th. Theodossiou: 2009, THE ORTHODOX CHURCH AND ASTRONOMY IN COMMON FIGHT AGAINST ASTROLOGICAL SUPERSTITION, Transdisciplinarity in Science and Religion **5**, 87-93.

МОНОГРАФИЈЕ НАЦИОНАЛНОГ ЗНАЧАЈА

1. Анђелка Ковачевић, О ОДРЕЂИВАЊУ МАСА АСТЕРОИДА, Библиотека Dissertacio 245, Задужбина Андрејевић, Београд, 2008.

НАУЧНИ РАДОВИ У НАЦИОНАЛНИМ ЧАСОПИСИМА И КЊИГАМА

1. E. Theodossiou, E. Danezis, M. S. Dimitrijević, V. N. Manimanis: ΑΣΤΡΟΝΟΜΙΑ – ΜΥΘΟΛΟΓΙΑ ΚΑΙ ΤΕΧΝΗ, Αεροπος 77, Ιανουαριου - Φεβρουαριοσ 2008, 3 – 10.
2. E. Theodossiou, M. S. Dimitrijević, E. Danezis: Η ΣΗΜΑΝΤΙΚΗ ΣΗΜΑΣΙΑ ΤΟΥ ΥΔΑΤΟΣ ΑΠΟ ΤΙΣ ΑΡΧΑΙΕΣ ΕΛΛΗΝΙΚΕΣ ΚΟΣΜΟΓΟΝΙΕΣ ΕΩΣ ΤΗ ΣΥΓΧΡΟΝΗ ΑΣΤΡΟΦΥΣΙΚΗ, Αεροπος 79, Μαιοσ - Ιουνιοσ 2008, 4 – 9.
3. E. Theodossiou, E. Danezis, M. S. Dimitrijević: ΑΝΑΞΙΜΑΝΔΡΟΣ (610-540 π.Χ.), ΓΕΝΝΗΣΗ, ΘΑΝΑΤΟΣ, ΑΠΕΙΡΟ, Πεμπτουσια, 26, Απριλιοσ - Ιουλιοσ 2008, 86-93.
4. E. Theodossiou, A. Dacanalis, M. S. Dimitrijević, P. Mantarakis: HELIOCENTRIC SYSTEM FROM THE ORPHIC HYMNS AND THE PYTHAGOREANS TO EMPEROR JULIAN, Bulgarian Astronomical Journal , 11, 2008, 1-15.
5. Ефстратиос Теодосију, Петрос Мандаракис, Милан С. Димитријевић, Василиос Н. Маниманис, Еманоел Данезис: 2008, ОД АНАКСИМАНДРОВОГ «БЕСКОНАЧНО» (APEIRON) У СТАРОЈ ГРЧКОЈ ДО ТЕОРИЈЕ О БЕСКОНАЧНОСТИ УНИВЕРЗУМА У МОДЕРНОЈ КОЗМОЛОГИЈИ, Зборник Матице српске за класичне студије, бр. 10, Нови Сад 2008, 281-297.
6. Милан С. Димитријевић: 2008, ЂОРЂЕ СТАНОЈЕВИЋ – ПОВОДОМ 150. ГОДИШЊИЦЕ РОЂЕЊА, Анали Огранка САНУ у Новом Саду, бр. 4, Нови Сад 2008, 77-84.
7. М. С. Димитријевић: РАД МИЛУТИНА МИЛАНКОВИЋА У АСТРОНОМИЈИ, у Милутин Миланковић као инспирација, Т. Ј. Халаши, И. П. Ћосић, Р. Ј. Халаши, Едиција Техничке науке – монографије 32, Универзитет у Новом Саду, Факултет техничких наука, ФТН Издаваштво, Нови Сад, 2008, 49-73.
8. Евстратије Теодосију, Ари Даканалис, Милан С. Димитријевић, Петрос Мантаракис: 2008, ПОРЕКЛО ХЕЛИОЦЕНТРИЧКОГ СИСТЕМА, Phlogiston, 16, 2008, 83-105.
9. E. Theodossiou, A. Dacanalis, E. Danezis, M. S. Dimitrijević, P. Mantarakis: ORIGINS OF THE HELIOCENTRIC SYSTEM, Phlogiston, 16, 2008, 107-125.
10. Милан С. Димитријевић: 2009, КОСМИЧКИ МОТИВИ У СРПСКОЈ СРЕДЊОВЕКОВНОЈ НУМИЗМАТИЦИ II, Динар, бр. 30, Београд 2009, 10-11.
11. Милан С. Димитријевић: 2009, ЂОРЂЕ СТАНОЈЕВИЋ – ЧОВЕК КОЈИ ЈЕ СРПСКОМ НАРОДУ ПОДАРИО СВЕТЛОСТ, Луча, год. 18, бр. 1, Суботица 2009, 27-36.
12. Милан С. Димитријевић: 2009, МИЛУТИН МИЛАНКОВИЋ И ТАЈНА ЛЕДЕНИХ ДОБА, Весник Удружења универзитетских професора и научника Србије, год. 19, бр. 20, јануар (на унутрачњој страни – април), 2009, 1-2.

13. E. Th. Theodossiou, S. Azzopardi, M. S. Dimitrijević, V. Manimanis: 2009, THE ASTRONOMICAL CLOCK OF PRAGUE AND THE ASTRONOMICAL LEGACY OF ANTIQUITY (ПРАШКИ АСТРОНОМСКИ САТ И АСТРОНОМСКО НАСЛЕЂЕ АНТИКЕ), Антички свет, европска и српска наука, Зборник радова, Друштво за античке студије Србије, Службени гласник, Београд, 374-391.
14. E. Theodossiou, M. S. Dimitrijević, E. Danezis: ΟΙ ΔΙΑΦΟΡΕΤΙΚΕΣ ΕΝΝΟΙΕΣ ΤΟΥ ΟΡΟΥ ΟΥΡΑΝΟΣ ΚΑΙ Η ΣΗΜΑΣΙΑ ΤΟΥ ΑΙΘΕΡΑ ΣΤΑ ΕΡΓΑ ΤΟΥ ΑΡΙΣΤΟΤΕΛΗ ΚΑΙ ΑΛΛΩΝ ΦΙΛΟΣΟΦΩΝ (РАЗЛИЧИТА ЗНАЧЕЊА ПОЈМА „УРАНОС“ И ЗНАЧАЈ ЕТРА У ДЕЛИМА АРИСТОТЕЛА), Αεροπος 85, Μαιοσ - Ιουνιοσ 2009, 4-7.
15. D. Jevremović, M. S. Dimitrijević, L. Č. Popović, M. Dačić, V. Protić Benišek, E. Bon, V. Benišek, D. Ilić, A. Kovačević, M. Malović: 2009, SERBIAN VIRTUAL OBSERVATORY, Pregled NCD, 15, 52-58.
16. М. С. Димитријевић: МИЛУТИН МИЛАНКОВИЋ И ЊЕГОВО АСТРОНОМСКО ДЕЛО – ТАЈНА ЛЕДЕНИХ ДОБА, у Сећање на Милутина Миланковића, Удружење универзитетских професора и научника Србије, Београд, 2009, 21-39, и сепарат са нумерацијом 1-19.
17. E. Theodossiou, V. Manimanis, E. Danezis, M. S. Dimitrijević,: ΠΡΟΣΩΚΡΑΤΙΚΟΙ ΕΛΛΗΝΕΣ ΦΙΛΟΣΟΦΟΙ ΚΑΙ ΠΕΡΙΒΑΛΛΟΝ (ГРЧКИ ПРЕСОКРАТОВСКИ ФИЛОСОФИ И ЧОВЕКОВА СРЕДИНА), Αεροπος 87, Σεπτεμβριοσ - Οκτοβριοσ 2009, 4-9.
18. D. Jevremović, M. S. Dimitrijević, L. Č. Popović, M. Dačić, V. Protić Benišek, E. Bon, V. Benišek, D. Ilić, A. Kovačević, M. Malović: 2009, SERBIAN VIRTUAL OBSERVATORY, Pregled NCD, 15, 52-58.

НАУЧНИ РАДОВИ У ЗБОРНИЦИМА МЕЂУНАРОДНИХ КОНФЕРЕНЦИЈА ШТАМПАНИ У ЦЕЛИНИ

1. J. Muñoz, M. S. Dimitrijević, C. Yubero, M. D. Calzada: 2008, USE OF THE VAN DER WAALS BROADENING OF ATOMIC ARGON LINES TO MEASURE THE GAS TEMPERATURE IN AN ATMOSPHERIC PRESSURE Ar-He SURFACE WAVE DISCHARGE, 24th Summer School and International Symposium on the Physics of Ionized Gases, SPIG 2008, Contributed papers & abstracts of invited lectures, topical invited lectures and progress reports, eds. G. Malović, L. Č. Popović, M. S. Dimitrijević, Publications of the Astronomical Observatory of Belgrade **84**, 281-284.
2. A. Antoniou, E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, E. Theodossiou, D. Stathopoulos: 2008, A STUDY OF AX Mon (HD 45910) KINEMATICAL PARAMERERS OF THE Fe II DENSITY REGIONS, 24th Summer School and International Symposium on the Physics of Ionized Gases, SPIG 2008, Contributed papers & abstracts of invited lectures, topical invited lectures and progress reports, eds. G. Malović, L. Č. Popović, M. S. Dimitrijević, Publications of the Astronomical Observatory of Belgrade **84**, 455-458.

3. E. Danezis, E. Lyratzi, L. Č. Popović, A. Antoniou, M. S. Dimitrijević: 2008, THE VERY BROAD LINES IN THE UV SPECTRA OF HOT EMISSION STARS - A POSSIBLE EXPLANATION, 24th Summer School and International Symposium on the Physics of Ionized Gases, SPIG 2008, Contributed papers & abstracts of invited lectures, topical invited lectures and progress reports, eds. G. Malović, L. Č. Popović, M. S. Dimitrijević, Publications of the Astronomical Observatory of Belgrade **84**, 463-466.
4. A. Kovačević, A. I. Shapovalova, L. Č. Popović, A. N. Burenkov, V. Chavushyan:2008, THE BLR STRUCTURE OF NGC4151 - POSSIBLE OUTFLOW MODEL, Publications of the Astronomical Observatory of Belgrade, **84**, 471-474.
5. J. Kovačević, L. Č. Popović, M. S. Dimitrijević: 2008, RELATIONS AMONG EMISSION LINES AND CONTINUUM LUMINOSITY IN ACTIVE GALACTIC NUCLEI, 24th Summer School and International Symposium on the Physics of Ionized Gases, SPIG 2008, Contributed papers & abstracts of invited lectures, topical invited lectures and progress reports, eds. G. Malović, L. Č. Popović, M. S. Dimitrijević, Publications of the Astronomical Observatory of Belgrade **84**, 475-478.
6. E. Lyratzi, E. Danezis, L. Č. Popović, M. S. Dimitrijević, A. Antoniou: 2008, DACs AND SACs PHENOMENA IN THE C IV EMITTING REGIONS OF QSOs, 24th Summer School and International Symposium on the Physics of Ionized Gases, SPIG 2008, Contributed papers & abstracts of invited lectures, topical invited lectures and progress reports, eds. G. Malović, L. Č. Popović, M. S. Dimitrijević, Publications of the Astronomical Observatory of Belgrade **84**, 483-486.
7. Z. Simić, M. S. Dimitrijević, A. Kovačević, M.. Dačić: 2008, STARK BROADENING OF Sn III LINES IN A TYPE STELLAR ATMOSPHERES, 24th Summer School and International Symposium on the Physics of Ionized Gases, SPIG 2008, Contributed papers & abstracts of invited lectures, topical invited lectures and progress reports, eds. G. Malović, L. Č. Popović, M. S. Dimitrijević, Publications of the Astronomical Observatory of Belgrade **84**, 487-490.
8. R. Hamdi, N. Ben Nessib, N. Milovanović, L. Č. Popović, M. S. Dimitrijević, S. Sahal-Bréchot: 2008, ATOMIC DATA AND STARK BROADENING PARAMETERS FOR DO WHITE DWARF ATMOSPHERES RESEARCH: Si VI, Proceedings of the VII symposium of Belarus and Serbia on Physics and diagnostics of laboratory and astrophysical plasmas (PDP-VII'2008), September 22-26, 2008, Minsk, Belarus, eds. V. I. Arkhipenko, V. S. Burakov, A, F. Chernyavskii, National Academy of Sciences of Belarus and B. L. Stepanov Institute of Physics, Minsk, 2008, 56-59.
9. E. Th. Theodossiou, M. S. Dimitrijević, V. N. Manimanis, Th. Grammenos: 2008, „HYDOR" FROM ANCIENT GREEK COSMOGONIES TO MODERN ASTROPHYSICS, Европске идеје, античка цивилизација и српска култура, Друштво за античке студије, Службени гласник, Београд, 423-435.

10. E. Th. Theodossiou, V. N. Manimanis, Shea Goyette, M. S. Dimitrijević: 2008, MOSCHOPHOROS, KRIOPHOROS, ICHTHYS: CONSTELLATION, MYTHOLOGY AND TIME, Европске идеје, античка цивилизација и српска култура, Друштво за античке студије, Службени гласник, Београд, 436-450.
11. M. S. Dimitrijević, M. Christova, Z. Simić, S. Sahal-Bréchot: 2009, ON THE REGULARITIES OF STARK BROADENING PARAMETERS OF Ar I LINES WITHIN A SPECTRAL SERIES, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 183-188.
12. J. Kovačević, L. Č. Popović, M. S. Dimitrijević: 2009, THE ROLE OF OPTICAL Fe II ^{4}F, ^{6}S AND ^{4}G GROUP OF LINES IN AGN SPECTRA, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 199-203.
13. M. S. Dimitrijević, Z. Simić, A. Kovačević, M. Dačić, S. Sahal-Bréchot: 2009, STARK BROADENING OF NEUTRAL TELLURIUM SPECTRAL LINES IN WHITE DWARF ATMOSPHERES, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 311-314.
14. Z. Simić, M. S. Dimitrijević, A. Kovačević, M. Dačić: 2009, ON THE STARK BROADENING OF Cr II 3d5 – 3d4 4p SPECTRAL LINES IN HOT STAR SPECTRA, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 421-424.
15. A. Antoniou, E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, E. Theodosiou, D. Stathopoulos: 2009, A STUDY OF THE ATMOSPHERIC STRUCTURE OF AX Mon (HD 45910), Communications in Asteroseismology **159**, 119-120.
16. M. S. Dimitrijević: 2009, ACTIVITIES OF PARTICIPANTS OF THE PROJECT 146001 »INFLUENCE OF COLLISIONAL PROCESSES ON THE ASTROPHYSICAL PLASMA SPECTRA« - 2006-2007, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 157-182.
17. K. Tsvetkova, M. Tsvetkov, V. Protić-Benišek, M. S. Dimitrijević: 2009, BULGARIAN-SERBIAN COLLABORATION IN THE ASTRONOMICAL WIDE-FIELD PLATE ARCHIVING, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 255-260.

ПРЕДАВАЊА ПО ПОЗИВУ НА НАЦИОНАЛНИМ КОНФЕРЕНЦИЈАМА ШТАМПАНА У ЦЕЛИНИ

1. М. Димитријевић: 2009, Судари емитера и апсорбера са наелектрисаним честицама и звездана плазма, У: Како разумијети Универзум: допринос астрономских и физичких истраживања, Уредници: Б. Предојевић и Л. Ч. Поповић, Природно-математички факултет, Бања Лука, 51-89.
2. Д. Јевремовић: 2009, Моделирање звезданих атмосфера, У: Како разумијети Универзум: допринос астрономских и физичких истраживања, Уредници: Б. Предојевић и Л. Ч. Поповић, Природно-математички факултет, Бања Лука, 91-108.

НАУЧНИ РАДОВИ У ЗБОРНИЦИМА НАЦИОНАЛНИХ КОНФЕРЕНЦИЈА ШТАМПАНИ У ЦЕЛИНИ

1. Милан С. Димитријевић: 2008, ЂОРЂЕ СТАНОЈЕВИЋ – ЖИВОТ И ДЕЛО, Зборник радова научног скупа « ЂОРЂЕ СТАНОЈЕВИЋ – ЖИВОТ И ДЕЛО - Поводом 150 година од рођења“, Нови Сад, 10-11. октобар 2008, уредници М. С. Димитријевић, Б. Миросављевић, В. Марић, Нови Сад, 2008, 9-41.
2. Милан С. Димитријевић: 2008, ЂОРЂЕ СТАНОЈЕВИЋ У РАДОВИМА ЖИЛА ЖАНСЕНА, Зборник радова научног скупа « ЂОРЂЕ СТАНОЈЕВИЋ – ЖИВОТ И ДЕЛО - Поводом 150 година од рођења“, уредници М. С. Димитријевић, Б. Миросављевић, В. Марић, Нови Сад, 10-11. октобар 2008, Нови Сад, 2008, 59-76.
3. Милан С. Димитријевић: 2008, ЂОРЂЕ СТАНОЈЕВИЋ И „ЂАЧКИ НАПРЕДАК“, Зборник радова научног скупа « ЂОРЂЕ СТАНОЈЕВИЋ – ЖИВОТ И ДЕЛО - Поводом 150 година од рођења“, Нови Сад, 10-11. октобар 2008, уредници М. С. Димитријевић, Б. Миросављевић, В. Марић, Нови Сад, 2008, 125-138.
4. Милан С. Димитријевић: 2008, ЂОРЂЕ СТАНОЈЕВИЋ И РЕФОРМА ЈУЛИЈАНСКОГ КАЛЕНДАРА, Зборник радова научног скупа « ЂОРЂЕ СТАНОЈЕВИЋ – ЖИВОТ И ДЕЛО - Поводом 150 година од рођења“, Нови Сад, 10-11. октобар 2008, уредници М. С. Димитријевић, Б. Миросављевић, В. Марић, Нови Сад, 2008, 199-207.
5. Милан С. Димитријевић: 2009, АКТИВНОСТИ САРАДНИКА ПРОЈЕКТА 146001 „УТИЦАЈ СУДАРНИХ ПРОЦЕСА НА СПЕКТРЕ АСТРОФИЗИЧКЕ ПЛАЗМЕ“ – 2006-2007, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 105-150.
6. Катја Цветкова, Милчо Цветков, Војислава Протић-Бенишек, Милан С. Димитријевић: 2009, СРПСКО - БУГАРСКА САРАДЊА У АРХИВИРАЊУ ФОТО-ПЛОЧА ШИРОКОГ ПОЉА, Зборник радова конференције «Развој

астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 813-818.

7. M. S. Dimitrijević, L. Č. Popović, D. Jevremović, M. Dačić, P. Jovanović, A. Kovačević, S. Simić, Z. Simić, D. Ilić, E. Bon, N. Gavrilović, J. Kovačević, N. Milovanović, D. Tankosić, M. Stalevski: 2009, ACTIVITIES OF THE GROUP FOR ASTROPHYSICAL SPECTROSCOPY 2005-2008, Proceedings of the XV National Conference of Astronomers of Serbia, eds. O. Atanacković, Z. Cvetković, D. Ilić, Publications of the Astronomical Observatory of Belgrade, No. 86, 271-278.
8. A. Kovačević, A. I. Shapovalova, L. Č. Popović, A. N. Burenkov, V. Chavushyan: 2009, 1D AND 2D REVERBERATION MAPPING APPLIED ON H_beta LINE OF NGC 4151, Proceedings of the XV National Conference of Astronomers of Serbia, eds. O. Atanacković, Z. Cvetković, D. Ilić, Publications of the Astronomical Observatory of Belgrade, No. 86, 279-282.
9. Милан С. Димитријевић, Миодраг Дачић, Милан Радованац: 2009, О ЈЕДНОМ КОМПЛЕТУ ФОТОГРАФИЈА ЗАПОСЛЕНИХ НА АСТРОНОМСКОЈ ОПСЕРВАТОРИЈИ У БЕОГРАДУ ИЗ ШЕЗДЕСЕТИХ ГОДИНА ДВАДЕСЕТОГ ВЕКА, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 59-68.
10. Евстратије Теодосију, Василије Н. Маниманис, Милан С. Димитријевић, Еманоел Данезис: 2009, РИГА ОД ФЕРЕ И АСТРОНОМИЈА У ЊЕГОВОЈ „АНТОЛОГИЈИ ФИЗИКЕ“ (ПОВОДОМ 250. ГОДИШЊИЦЕ РОЂЕЊА), Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 339-354.
11. Евстратије Теодосију, Петрос Мантаракис, Милан С. Димитријевић, Василије Н. Маниманис, Еманоел Данезис: 2009, ПОЈАМ БЕСКОНАЧНОСТИ И ИДЕЈА О МНОШТВУ СВЕТОВА ОД АНТИЧКИХ ГРЧКИХ ДО МОДЕРНИХ КОСМОЛОГИЈА, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 423-436.
12. Евстратије Теодосију, Василије Н. Маниманис, Сеа Гојет, Милан С. Димитријевић: 2009, МОСХОФОРОС, КРИОФОРОС, ИХТХИС. САЗВЕЖЂА, МИТОЛОГИЈА И УМЕТНОСТ, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 437-450.
13. Евстратије Теодосију, Милан С. Димитријевић, Василије Н. Маниманис, Теодулос Граменос: 2009, „ΥΔΩΡ – ХИДОР» ОД СТАРИХ ГРЧКИХ

КОСМОГОНИЈА ДО МОДЕРНЕ АСТРОФИЗИКЕ, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 451-462.

14. Евстратије Теодосију, Ари Даканалис, Милан С. Димитријевић, Петрос Мантаракис: 2009, ХЕЛИОЦЕНТРИЧКИ СИСТЕМ ОД ОРФИЧКИХ ХИМНИ И ПИТАГОРЕЈАЦА ДО ЦАРА ЈУЛИЈАНА АПОСТАТЕ, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 463-480.
15. Милан С. Димитријевић: 2009, САВРЕМЕНА БУГАРСКА ПОЕЗИЈА, КЛУБ ПЕСНИКА „С ГЕОМ НА РЕДУТУ“ И ЧАРОВИТОСТ ЛИРСКО-КОСМИЧКЕ ИНСПИРАЦИЈЕ, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 759-792.
16. Милан С. Димитријевић, Милчо Цветков: 2009, СРПСКО – БУГАРСКА САРАДЊА У АСТРОНОМИЈИ: ПОСЛЕДЊИХ ДЕСЕТ ГОДИНА РАЗВОЈА, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 795-812.
17. Катја Цветкова, Милчо Цветков, Војислава Протић-Бенишек, Милан С. Димитријевић: 2009, СРПСКО - БУГАРСКА САРАДЊА У АРХИВИРАЊУ ФОТО-ПЛОЧА ШИРОКОГ ПОЉА, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 813-818.
18. Милан С. Димитријевић, Магдалена Ставински: 2009, СРПСКО – РУМУНСКА САРАДЊА У АСТРОНОМИЈИ, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 819-828.
19. Милан С. Димитријевић: 2009, ШЕСТА СРПСКА КОНФЕРЕНЦИЈА О ОБЛИЦИМА СПЕКТРАЛНИХ ЛИНИЈА У АСТРОФИЗИЦИ, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 829-846.
20. Анђелка Ковачевић, Милан С. Димитријевић: 2009, ПРВА ЛЕТЊА ШКОЛА ИЗ АСТРОНОМИЈЕ И ГЕОФИЗИКЕ, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 847-858.
21. M. S. Dimitrijević: 2009, DJORDJE STANOJEVIĆ IN WORKS OF JULES JANSSEN, Proceedings of the XV National Conference of Astronomers of Ser-

bia, eds. O. Atanacković, Z. Cvetković, D. Ilić, Publications of the Astronomical Observatory of Belgrade, No. 86, 205-210.

22. M. S. Dimitrijević, L. Č. Popović, D. Jevremović, M. Dačić, P. Jovanović, A. Kovačević, S. Simić, Z. Simić, D. Ilić, E. Bon, N. Gavrilović, J. Kovačević, N. Milovanović, D. Tankosić, M. Stalevski: 2009, ACTIVITIES OF THE GROUP FOR ASTROPHYSICAL SPECTROSCOPY 2005-2008, Proceedings of the XV National Conference of Astronomers of Serbia, eds. O. Atanacković, Z. Cvetković, D. Ilić, Publications of the Astronomical Observatory of Belgrade, No. 86, 271-278.

ПРИКАЗИ КЊИГА У МЕЂУНАРОДНИМ ЧАСОПИСИМА

1. M. S. Dimitrijević: 2009, BOOK REVIEW: Alexei Nesteruk, The Universe as Communion. Towards the Neo-Patristic Synthesis of Theology and Science, European Journal of Science and Theology, **5** (1), 69-73.

ПРИЛОЗИ У ЗБОРНИЦИМА МЕЂУНАРОДНИХ КОНФЕРЕНЦИЈА ШТАМПАНИ У ИЗВОДУ

1. M. Christova, L. Christov, E. Castanos-Martinez, M. S. Dimitrijević, M. Moissan: 2008, USING LINE BROADENING TO DETERMINE THE ELECTRON DENSITY IN AN ARGON SURFACE-WAVE DISCHARGE AT ATMOSPHERIC PRESSURE, 19th International Conference on Spectral Line Shapes, 15-20 June 2008, Valladolid, Spain, Universidad de Valladolid, 49-50.
2. M. Christova, L. Christov, M. S. Dimitrijević, N. Andreev: 2008, CALCULATION OF THE SHIFTS OF ARGON SPECTRAL LINES, 19th International Conference on Spectral Line Shapes, 15-20 June 2008, Valladolid, Spain, Universidad de Valladolid, 51-52.
3. J. Munoz, M. S. Dimitrijević, C. Yubero, M. D. Calzada: 2008, GAS TEMPERATURE DETERMINATION IN ARGON-HELIUM PLASMA AT ATMOSPHERIC PRESSURE USING VAN DER WAALS BROADENING, 19th International Conference on Spectral Line Shapes, 15-20 June 2008, Valladolid, Spain, Universidad de Valladolid, 109-110.
4. A. Antoniou, E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, E. Theodossiou, D. Stathopoulos: 2008, AX Mon (HD 45910) KINEMATICAL PARAMETERS IN THE Fe II SPECTRAL LINES AS A FUNCTION OF THE EXCITATION POTENTIAL, 19th International Conference on Spectral Line Shapes, 15-20 June 2008, Valladolid, Spain, Universidad de Valladolid, 163-164.
5. A. Antoniou, E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, E. Theodossiou, G. Katsavrias: 2008, A STUDY OF THE STRUCTURE OF DIFFERENT IONIZATION POTENTIAL REGIONS IN THE ATMOSPHERE OF AX Mon (HD 45910), 19th International Conference on Spectral Line Shapes, 15-20 June 2008, Valladolid, Spain, Universidad de Valladolid, 165-166.

6. E. Lyratzi, E. Danezis, L. Č. Popović, M. S. Dimitrijević, A. Antoniou,: 2008, KINEMATICS OF BROAD ABSORPTION LINE REGIONS OF PG 1254+047, 19th International Conference on Spectral Line Shapes, 15-20 June 2008, Valladolid, Spain, Universidad de Valladolid, 167-168.
7. E. Lyratzi, E. Danezis, L. Č. Popović, M. S. Dimitrijević, A. Antoniou,: 2008, DACs AND SACs IN THE UV SPECTRUM OF THE QUASAR PG 0946+301, 19th International Conference on Spectral Line Shapes, 15-20 June 2008, Valladolid, Spain, Universidad de Valladolid, 169-170.
8. E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, A. Antoniou,: 2008, SIMILARITY BETWEEN DACs/SACs PHENOMENA IN HOT EMISSION STARS AND QUASARS ABSORPTION LINES, 19th International Conference on Spectral Line Shapes, 15-20 June 2008, Valladolid, Spain, Universidad de Valladolid, 206-207.
9. Lj. M. Ignjatović, M. S. Dimitrijević, A. A. Mihajlov, V. Srećković: THE PROCESSES OF (n-n')-MIXING IN ATOM-RYDBERG ATOM COLLISIONS IN STELLAR ATMOSPHERES, VI Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, Program and Abstracts, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Astronomical Observatory, Belgrade 2008, 17.
10. D. Jevremović, P. Hauschildt, E. Baron, F. Allard, A. A. Mihajlov, Lj. M. Ignjatović, M. S. Dimitrijević: ON THE MODELLING OF ASTROPHYSICAL SPECTRA USING PHOENIX, VI Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, Program and Abstracts, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Astronomical Observatory, Belgrade 2008, 19
11. A. N. Klyucharev, M. Yu. Zakharov, A. A. Matveev, A. A. Mihajlov, Lj. Ignjatović, M. S. Dimitrijević: CHEMI-IONIZATION – EXPERIMENTS, THEORIES, GEOCOSMICAL PERSPECTIVES, VI Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, Program and Abstracts, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Astronomical Observatory, Belgrade 2008, 21.
12. A. Antoniou, E. Danezis, E. Lyratzi, D. Nikolaidis, L. Č. Popović, M. S. Dimitrijević.: 2008, KINEMATICAL PARAMETERS IN THE CORONAL AND POST-CORONAL REGIONS OF THE Oe STARS, 24th Summer School and International Symposium on the Physics of Ionized Gases, SPIG 2008, Contributed papers & abstracts of invited lectures, topical invited lectures and progress reports, eds. G. Malović, L. Č. Popović, M. S. Dimitrijević, Publications of the Astronomical Observatory of Belgrade **84**, 443.
13. M. S. Dimitrijević: INVESTIGATIONS ON BELGRADE OBSERVATORY OF THE INFLUENCE OF COLLISIONAL PROCESSES ON ASTROPHYSICAL PLASMA SPECTRA IN 2006-2008, VI Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, Program and Abstracts, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Astronomical Observatory, Belgrade 2008, 32.

14. M. S. Dimitrijević, M. Christova, Z. Simić: ON THE REGULARITIES OF STARK BROADENING PARAMETERS WITHIN SPECTRAL SERIES: Ar I LINES, VI Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, Program and Abstracts, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Astronomical Observatory, Belgrade 2008, 34.
15. J. Kovačević, L. Č. Popović, M. S. Dimitrijević: THE ROLE OF OPTICAL Fe II ^{4}F, ^{6}S and ^{4}G GROUP OF LINES IN AGN SPECTRA, VI Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, Program and Abstracts, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Astronomical Observatory, Belgrade 2008, 38.
16. K. Tsvetkova, M. Tsvetkov, V. Protić-Benišek, M. S. Dimitrijević: BULGARIAN-SERBIAN COLLABORATION IN THE ASTRONOMICAL WIDE-FIELD PLATE ARCHIVING, VI Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, Program and Abstracts, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Astronomical Observatory, Belgrade 2008, 44.
17. M. S. Dimitrijević, Z. Simić, A. Kovačević, M. Dačić, S. Sahal-Bréchot: STARK BROADENING OF NEUTRAL TELLURIUM SPECTRAL LINES IN WHITE DWARF ATMOSPHERES, VI Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, Program and Abstracts, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Astronomical Observatory, Belgrade 2008, 55.
18. Z. Simić, M. S. Dimitrijević, A. Kovačević, M. Dačić: ON THE STARK BROADENING OF Cr II $3d^5 - 3d^4p$ SPECTRAL LINES IN HOT STAR SPECTRA, VI Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, Program and Abstracts, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Astronomical Observatory, Belgrade 2008, 71.
19. M. S. Dimitrijević, M. Stavinschi: 2008, ROMANIAN-SERBIAN COLLABORATION IN ASTRONOMY, Exploring the Solar System and the Universe, Bucharest 8-12 April 2008, Abstract book, Astronomical Institute of the Romanian Academy, 8.
20. M. S. Dimitrijević, A. Kovačević, Z. Simić, M. Dačić: 2008, STARK BROADENING OF O V 1371 Å LINE IN STELLAR ATMOSPHERES, Exploring the Solar System and the Universe, Bucharest 8-12 April 2008, Abstract book, Astronomical Institute of the Romanian Academy, 41-42.
21. M. S. Dimitrijević, M. Christova, Z. Simić, S. Sahal-Bréchot: 2008, ELECTRON-IMPACT BROADENING OF Ar I 737.212 nm SPECTRAL LINE FOR STELLAR ATMOSPHERES RESEARCH, Exploring the Solar System and the Universe, Bucharest 8-12 April 2008, Abstract book, Astronomical Institute of the Romanian Academy, 42.
22. M. S. Dimitrijević, L. Č. Popović, D. Jevremović, M. Dačić, P. Jovanović, A. Kovačević, S. Simić, D. Ilić, Z. Simić, E. Bon, N. Gavrilović, J. Kovačević, N. Milovanović, D. Tankosić: 2008, ACTIVITIES OF THE GROUP FOR

ASTRONOMICAL SPECTROSCOPY 2005-2008, XV National Conference of Astronomers of Serbia, 2-5 October 2008, Belgrade, Serbia, Book of abstracts, eds. O. Atanacković, Z. Cvetković, D. Ilić, Faculty of Mathematics and Astronomical Observatory, Belgrade 2008, 63.

23. M. M. Abbas, D. Tankosić, J. F. Spann, A. Leclair, M. J. Dube, J. A. Gaskin: 2008, EXPERIMENTAL STUDIES OF ELECTROSTATIC CHARGING OF INDIVIDUAL LUNAR DUST GRAINS BY PHOTOELECTRIC EMISSIONS AND BY ELECTRON IMPACT, NLSI Lunar Science Conference, held July 20-23, 2008 at NASA Ames Research Center, Moffett Field, California, LPI Contribution No. 1415, abstract no. 2033.
24. D. Tankosić, M. M. Abbas: 2008, MEASUREMENTS ON CHARGING OF APOLLO 11 AND 17 LUNAR DUST GRAINS BY LOW ENERGY ELECTRONS, 39th Lunar and Planetary Science Conference, (Lunar and Planetary Science XXXIX), held March 10-14, 2008 in League City, Texas. LPI Contribution No. 1391, p.1202.
25. M. M. Abbas, D. Tankosić, J. F. Spann, A. Leclair, M. J. Dube, J. A. Gaskin: 2008, LUNAR DUST CHARGING BY SECONDARY ELECTRON EMISSION AND ITS COMPLEX ROLE IN THE LUNAR ENVIRONMENT, 39th Lunar and Planetary Science Conference, (Lunar and Planetary Science XXXIX), held March 10-14, 2008 in League City, Texas. LPI Contribution No. 1391, p.1153.
26. E. Th. Theodossiou, Aris Dacanalis, M. S. Dimitrijević, P. Mantarakis: 2008, THE HELIOCENTRIC VIEW ON THE WORLD FROM THE FIRST TRACES IN ORPHIC HYMNS AND THE PYTHAGOREANS TO THE EMPEROR JULIAN II APOSTATE ХЕЛИОЦЕНТРИЧНИ ПОГЛЕД НА СВЕТ ОД ПРВИХ ЗАЧЕТАКА У ОРФИЧКИМ ХИМНАМА И КОД ПИТАГОРЕЈАЦА ДО ЦАРА ЈУЛИЈАНА II АПОСТАТЕ), Антички свет, европска и српска наука, Међународни научни скуп, књига резимеа, Друштво за античке студије, Сремска Митровица, Београд, 26-28. септембар 2008, 22-23.
27. E. Th. Theodossiou, S. Azzopardi, M. S. Dimitrijević, V. Manimanis: 2008, THE ASTRONOMICAL CLOCK OF PRAGUE AND THE ASTRONOMICAL LEGACY OF ANTIQUITY (ПРАШКИ АСТРОНОМСКИ САТ И АСТРОНОМСКО НАСЛЕЂЕ АНТИКЕ), Антички свет, европска и српска наука, Међународни научни скуп, књига резимеа, Друштво за античке студије, Сремска Митровица, Београд, 26-28. септембар 2008, 23-24.
28. M. S. Dimitrijević: 2008, ORTHODOX CHURCH AND ASTRONOMY IN COMMON FIGHT AGAINST ASTROLOGICAL SUPERSTITION, The Dialogue between Science and Religion in the Orthodox World, 25-27 September, 2008, Bucharest, Romania, Romanian Academy, Faculty of Orthodox Theology, Bucharest, 2008, 16-17.
29. S. R. Federman, G. M. Wahlgren, S. Johansson, M. Dimitrijevic, A. Jorissen, L. I. Mashonkina, F. Salama, J. Tennyson, E. F. van Dishoeck : 2009, COMMISSION 14, ATOMIC AND MOLECULAR DATA, ed. K. A. van der Hucht, Transactions IAU **27A**, Reports on Astronomy 2006-2009, 374.

30. D. Jevremović, M. S. Dimitrijević, L. Č. Popović, M. Dačić, V. Protić-Benišek, E. Bon, V. Benišek, A. Kovačević, S. Sahal-Bréchot: 2009, THE PROJECT OF SERBIAN VIRTUAL OBSERVATORY AND THE CONNECTION WITH VAMDC, European week of Astronomy and Space Science, Joint European and National Astronomical Meeting, 20-23 April 2009, University of Hertfordshire, Hatfield, UK, 305.
31. M. Dimitrijević, A. Kovačević, Z. Simić, S. Sahal-Bréchot: 2009, ON THE STARK BROADENING OF Ar XV X RAYS, European week of Astronomy and Space Science, Joint European and National Astronomical Meeting, 20-23 April 2009, University of Hertfordshire, Hatfield, UK, 291.
32. A. Antoniou, E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, G. Stamatogiannaki: 2009, STUDDING THE ORIGIN OF SACs AND DACs IN THE SPECTRA OF HOT EMISSION STARS, VII Serbian Conference on Spectral Line Shapes in Astrophysics (VII SCSLSA), Zrenjanin 15-19 June 2009, Book of abstracts, eds. L. Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Serbian Astronomical Society and Astronomical Observatory, Belgrade 2009, 45.
33. M. S. Dimitrijević, A. Kovačević, Z. Simić, S. Sahal-Bréchot: 2009, STARK BROADENING OF Ar XV SPECTRAL LINES WITHIN X/WAVELENGTH RANGE, VII Serbian Conference on Spectral Line Shapes in Astrophysics (VII SCSLSA), Zrenjanin 15-19 June 2009, Book of abstracts, eds. L. Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Serbian Astronomical Society and Astronomical Observatory, Belgrade 2009, 50.
34. R. Hamdi, N. Ben Nessib, M. S. Dimitrijević, S. Sahal-Bréchot: 2009, AB INITIO STARK BROADENING CALCULATIONS FOR Ca V SPECTRAL LINES, VII Serbian Conference on Spectral Line Shapes in Astrophysics (VII SCSLSA), Zrenjanin 15-19 June 2009, Book of abstracts, eds. L. Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Serbian Astronomical Society and Astronomical Observatory, Belgrade 2009, 51.
35. J. Muñoz, C. Yubero, M. S. Dimitrijević, M. D. Calzada: 2009, VAN DER WAALS BROADENING IN ATMOSPHERIC PRESSURE SURFACE WAVE DISCHARGES SUSTAINED IN RARE GASES, VII Serbian Conference on Spectral Line Shapes in Astrophysics (VII SCSLSA), Zrenjanin 15-19 June 2009, Book of abstracts, eds. L. Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Serbian Astronomical Society and Astronomical Observatory, Belgrade 2009, 56.
36. B. Zmerli, N. Ben Nessib, M. S. Dimitrijević: 2009, STARK BROADENING CALCULATIONS OF NEUTRAL COPPER SPECTRAL LINES, VII Serbian Conference on Spectral Line Shapes in Astrophysics (VII SCSLSA), Zrenjanin 15-19 June 2009, Book of abstracts, eds. L. Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Serbian Astronomical Society and Astronomical Observatory, Belgrade 2009, 60.
37. A. Antoniou, E. Danezis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, D. Stathopoulos, A. Haddad, 2009, STUDYING THE ORIGIN OF SACs AND DACs IN THE SPECTRA OF HOT EMISSION STARS, 1st Workshop:

Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, Abstracts of Invited Lectures and Poster Papers, University of Athens, Faculty of Physics, Department of Astrophysics, Astronomy and Mechanics, без броја стране.

38. R. Hamdi, N. Ben Nessib, M. S. Dimitrijević, S. Sahal-Bréchot, 2009, AB INITIO CALCULATIONS OF Ca V STARK BROADENING PARAMETERS, 1st Workshop: Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, Abstracts of Invited Lectures and Poster Papers, University of Athens, Faculty of Physics, Department of Astrophysics, Astronomy and Mechanics, без броја стране.
39. J. Kovačević, L. Č. Popović, M. S. Dimitrijević, 2009, THE PROPERTIES OF Fe II EMISSION REGION IN AGN, 1st Workshop: Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, Abstracts of Invited Lectures and Poster Papers, University of Athens, Faculty of Physics, Department of Astrophysics, Astronomy and Mechanics, без броја стране.
40. E. Lyratzi, E. Danezis, A. Antoniou, L. Č. Popović, M. S. Dimitrijević, D. Stathopoulos, A. Haddad, 2009, WAYS OF CREATION OF SACs AND DACs IN THE PLASMA AROUND QUASARS, 1st Workshop: Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, Abstracts of Invited Lectures and Poster Papers, University of Athens, Faculty of Physics, Department of Astrophysics, Astronomy and Mechanics, без броја стране.
41. J. Munoz, C. Yubero, M. S. Dimitrijević, M. D. Calzada, 2009, ON THE GAS TEMPERATURE DETERMINATION IN ATMOSPHERIC PRESSURE SURFACE WAVE DISCHARGES SUSTAINED IN RARE GASES USING VAN DER WAALS BROADENING, 1st Workshop: Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, Abstracts of Invited Lectures and Poster Papers, University of Athens, Faculty of Physics, Department of Astrophysics, Astronomy and Mechanics, без броја стране.
42. Z. Simić, M. S. Dimitrijević, A. Kovačević, 2009, ON THE STARK BROADENING IN HOT STAR, 1st Workshop: Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, Abstracts of Invited Lectures and Poster Papers, University of Athens, Faculty of Physics, Department of Astrophysics, Astronomy and Mechanics, без броја стране.
43. B. Zmerli, N. Ben Nessib, M. S. Dimitrijević, S. Sahal-Bréchot, 2009, ON THE STARK BROADENING OF Cu I SPECTRAL LINES, 1st Workshop: Astrophysical winds and disks. Similar phenomena in stars and quasars, Platamonas, Greece, September 3-8, 2009, Abstracts of Invited Lectures and Poster Papers, University of Athens, Faculty of Physics, Department of Astrophysics, Astronomy and Mechanics, без броја стране.
44. Lj. M. Ignjatović, A. A. Mihajlov, A. Metropoulos, N. M. Sakan, M. S. Dimitrijević, 2009, THE CONTRIBUTION TO THE ABSORPTION PROCESS

TO THE OPACITY OF DB WHITE DWARF ATMOSFERES IN UV AND VUV REGIONS, 7th General Conference of the Balkan Physical Union, Alexandroupolis, 9-13 September, 2009, Book of Abstracts, Balkan Physical Union and Hellenic Physical Society, 32.

45. E. Theodossiou, V. N. Mamimanis, M. S. Dimitrijević, E. Danezis: 2008, RIGAS VELESTINLIS AND ASTRONOMY IN HIS ANTHOLOGY OF PHYSICS (FOR 250 YEARS FROM HIS BIRTHDAY), Exploring the Solar System and the Universe, Bucharest 8-12 April 2008, Abstract book, Astronomical Institute of the Romanian Academy, 13.
46. M. S. Dimitrijević: 2009, CHURCH AND SCIENCE IN COMMON FIGHT AGAINST SUPERSTITION, Big Questions about the Universe, Sibiu, Romania, 5-8 February 2009, Abstracts, 1.
47. D. Jevremović, M. S. Dimitrijević, L. Č. Popović, M. Dačić, V. Protić-Benišek, E. Bon, V. Benišek, A. Kovačević, S. Sahal-Bréchot: 2009, THE PROJECT OF SERBIAN VIRTUAL OBSERVATORY AND THE CONNECTION WITH VAMDC, European week of Astronomy and Space Science, Joint European and National Astronomical Meeting, 20-23 April 2009, University of Hertfordshire, Hatfield, UK, 305.
48. A. Kovačević, M. S. Dimitrijević,: 2009, SOCIETY OF ASTRONOMERS OF SERBIA, ASTRONOMICAL SOCIETY „RUDJER BOŠKOVIĆ“ AND IYA 2009, European week of Astronomy and Space Science, Joint European and National Astronomical Meeting, 20-23 April 2009, University of Hertfordshire, Hatfield, UK, 96.
49. E. Danezis, E. Th. Theodossiou, M. S. Dimitrijević, A. Dacanalis: 2009, COSMOLOGIES OF ALCMAN, LEUCIPPUS AND DEMOCRITUS AND SOME SIMILARITIES WITH MODERN SCIENTIFIC CONCEPTS (КОЗМОЛОГИЈЕ АЛКМАНА, ЛЕУКИПА И ДЕМОКРИТА И НЕКЕ СЛИЧНОСТИ СА МОДЕРНИМ НАУЧНИМ КОНЦЕПТИМА), Античка култура, европско и српско наслеђе, Међународни научни скуп, књига резимеа, Друштво за античке студије Србије, Матица српска, Београд, Сремска Митровица, Нови Сад, 25-28. септембар 2009, 12.

ПРЕДАВАЊА ПО ПОЗИВУ НА НАЦИОНАЛНИМ КОНФЕРЕНЦИ-ЈАМА ШТАМПАНА У ИЗВОДУ

1. M. S. Dimitrijević, M. Stavinschi: 2008, ROMANIAN-SERBIAN COLLABORATION IN ASTRONOMY, Exploring the Solar System and the Universe, Bucharest 8-12 April 2008, Abstract book, Astronomical Institute of the Romanian Academy, 8.
2. Milan Dimitrijević: 2009, ASTRONOMY AND THE GREAT QUESTIONS ABOUT UNIVERSE, The 5th National Reunion of ADSTR Romania, Cluj-Napoca, 21-23 May 2009, Program, Departamentul de imagine al Facultatii de Teologie Ortodoxa Cluj-Napoca, 7.

3. Милан Димитријевић: 2009, СУДАРИ ЕМИТЕРА И АПСОРБЕРА СА НАЕЛЕКТРИСАНИМ ЧЕСТИЦАМА И ЗВЕЗДАНА ПЛАЗМА, Како разумијети Универзум: допринос астрономских и физичких истраживања, Бања Лука 29. мај 2009, Природно-математички факултет Бања Лука, 11.

НАУЧНИ РАДОВИ У ЗБОРНИЦИМА НАЦИОНАЛНИХ КОНФЕРЕНЦИЈА ШТАМПАНИ У ИЗВОДУ

1. M. S. Dimitrijević: 2008, DJORDJE STANOJEVIĆ IN WORKS OF JULES JANSSEN, XV National Conference of Astronomers of Serbia, 2-5 October 2008, Belgrade, Serbia, Book of abstracts, eds. O. Atanacković, Z. Cvetković, D. Ilić, Faculty of Mathematics and Astronomical Observatory, Belgrade 2008, 51.
2. M. S. Dimitrijević, L. Č. Popović, D. Jevremović, M. Dačić, P. Jovanović, A. Kovačević, S. Simić, D. Ilić, Z. Simić, E. Bon, N. Gavrilović, J. Kovačević, N. Milovanović, D. Tankosić: 2008, ACTIVITIES OF THE GROUP FOR ASTRONOMICAL SPECTROSCOPY 2005-2008, XV National Conference of Astronomers of Serbia, 2-5 October 2008, Belgrade, Serbia, Book of abstracts, eds. O. Atanacković, Z. Cvetković, D. Ilić, Faculty of Mathematics and Astronomical Observatory, Belgrade 2008, 63.
3. Z. Simić: 2009, Influence of Collisions with Charged Particles on Heavy Metal Spectral Line Profiles in Spectra of A Stars and White Dwarfs, Publications of the Astronomical Observatory of Belgrade, **86**, 399.

УРЕЂИВАЊЕ ЗБОРНИКА СКУПОВА И СПЕЦИЈАЛНИХ БРОЈЕВА МЕЂУНАРОДНИХ ЧАСОПИСА

1. Уредили М. С. Димитријевић (Уредник), Б. Миросављевић, В. Марић: 2010, Зборник радова научног скупа « ЂОРЂЕ СТАНОЈЕВИЋ – ЖИВОТ И ДЕЛО - Поводом 150 година од рођења“, Нови Сад, 10-11. октобар 2008, Нови Сад, 2008, стр. 1-251.
2. Eds. G. Malović, L. Č. Popović, M. S. Dimitrijević: 2008, 24TH SUMMER SCHOOL AND INTERNATIONAL SYMPOSIUM ON THE PHYSICS OF IONIZED GASES, Journal of Physics: Conference Series **133**.
3. Eds.: G. Malović, L. Č. Popović, M. S. Dimitrijević: 2008, 24TH SUMMER SCHOOL AND INTERNATIONAL SYMPOSIUM ON THE PHYSICS OF IONIZED GASES, SPIG 2008, CONTRIBUTED PAPERS & ABSTRACTS OF INVITED LECTURES, TOPICAL INVITED LECTURES AND PROGRESS REPORTS, Publications of the Astronomical Observatory of Belgrade **84**, pp. 1-525.
4. Eds.: M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev: 2009, PROCEEDINGS OF THE VI SERBIAN-BULGARIAN ASTRONOMICAL CONFERENCE (Belgrade, 7-11 May 2008), pp. 1-491 (ISBN 978-86-906631-6-3)
5. Eds.L. Č. Popović, M. S. Dimitrijević: 2009, VII SERBIAN CONFERENCE ON SPECTRAL LINE SHAPES IN ASTROPHYSICS, New Astronomy Review, **53**

6. Уредник Милан С. Димитријевић: 2009, ЗБОРНИК РАДОВА КОНФЕРЕНЦИЈЕ «РАЗВОЈ АСТРОНОМИЈЕ КОД СРБА V», Београд, 18 – 22. април 2008, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, стр. 1-935.

ОСТАЛЕ АКТИВНОСТИ И БЕЛЕШКЕ О АКТИВНОСТИМА САРАДНИКА ПРОЈЕКТА

УЏБЕНИЦИ

1. Милан С. Димитријевић, Александар Томић: АСТРОНОМИЈА за IV разред гимназије, 7 издање, Завод за уџбенике, Београд, 2008.

ПРИЛОЗИ И ЧЛАНЦИ

1. Милан С. Димитријевић: ДО КРАЈА УНИВЕРЗУМА, *Планета*, јануар - фебруар 2008, бр. 27, 12.
2. Милан С. Димитријевић: ШЕСТА СРПСКА КОНФЕРЕНЦИЈА О ОБЛИЦИМА СПЕКТРАЛНИХ ЛИНИЈА У АСТРОФИЗИЦИ, *Васиона*, 2007, бр. 2, 96.
3. Анђелка Ковачевић: 2008, ПРОСТОР И ВРЕМЕ, Кроз простор-време, октобар 2008,, http://www.kpv.rs
4. Анђелка Ковачевић: 2008, ДА ЛИ ПОСТОЈИ МУЗИКА ПРОСТОР-ВРЕМЕНА, Кроз простор-време, мај 2009, http://www.kpv.rs
5. Милан С. Димитријевић: УНИВЕРЗУМ И РАЗОТКРИВАЊЕ ТАЈНИ ЊЕГОВИХ РАЗМЕРА И СУДБИНЕ, у Џон и Мери Грибин, «Колико далеко је горе?», ИЦНТ, Београд 2008, 5.
6. Милан С. Димитријевић: ЗЕМЉА СЕ ТЕТУРА, ЗАТО ЈЕ ХЛАДНО, *Политика*, додатак «Култура, уметност, наука», 7 фебруар 2009, 8
7. Милан С. Димитријевић: АСТРОНОМ КОЈИ ЈЕ ЕЛЕКТРИФИЦИРАО СРБИЈУ, *Планета*, март - април 2009, бр. 33, 26.
8. Милан С. Димитриевич: ПРОФЕСИОНАЛНАЯ И ЛЮБИТЕЛЬСКАЯ АСТРОНОМИЯ В СЕРБИИ, *Небо и человек*, 2008, бр. 139, 21-25.
9. Милан С. Димитријевић: ЕЛЕКТРИФИКОВАО ЛЕСКОВАЦ ЂОРЂЕ СТАНОЈЕВИЋ, Успења III, бр. 9, 2009, 11-12.
10. Непотписано, комбиновани текст Дејана Чикаре и Милана С. Димитријевића: ИДЕМО ДАЉЕ, у „Ротари клуб Београд – Стари Град; Оснивање и прве године рада, РК Београд Стари – Град, Београд, 2009.
11. Милан С. Димитријевић: МИТСКО-ПОЕТСКА КОСМОГОНИЈА МАЈЕ МИТОВЕ, Луча, XVIII, бр. 2-3, 2009, 45-48.
12. Милан С. Димитријевић: САВРЕМЕНА БУГАРСКА ПОЕЗИЈА, Успења III, бр. 9, 2009, 26-27.

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Профессиональная и любительская астрономия в Сербии



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Основное астрономическое учреждение в Сербии – Белградская астрономическая обсерватория, одно из самых старых научных учреждений и единственный самостоятельный астрономический институт в бывшей Югославии. Его прошлое является важной частью истории науки и культуры в Сербии.

Декрет об основании Астрономической и Метеорологической обсерватории был подписан 20 марта (7 апреля) 1887 г. министром просвещения и церковных дел Королевства Сербии Миланом Куюнджичем по инициативе Милана Недельковича (Белград, 27 сентября 1857 г. – Белград, 27 декабря 1950 г.), профессора Великой Школы (Белградский университет).

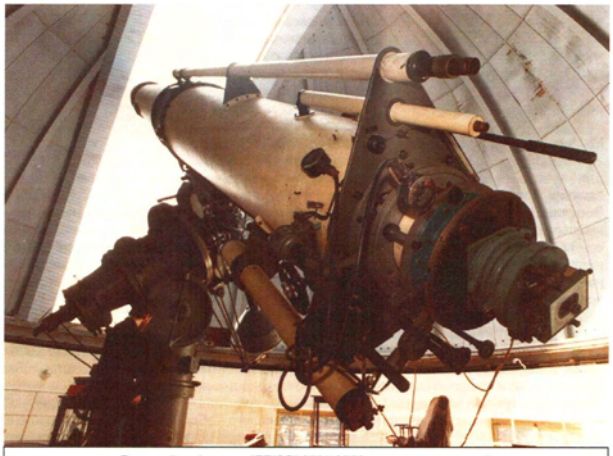
М. Неделькович был назначен первым директором новой Обсерватории и был во главе ее с 26 марта (7 апреля) 1887 г. по 30 января 1924 г. с небольшим перерывом между 5 июля 1899 и 31 октября 1900, когда его отправили на пенсию по политическим причинам – в связи с покушением на бывшего короля Милана. В течение этого периода Недельковича замещал Джордже Станойевич (г. Неготин, 7 апреля 1858 г. – Париж, 24 декабря 1921 г.). Станойевич был первым сербским астрофизиком, позже ректором Белградского университета, большим популяризатором астрономии и науки вообще, инициатором проведения электрификации Белграда, Ужицы, Чачки, Лесковца... Он был строителем первой гидроэлектростанции в Сербии, пионером промышленности охладительных приборов, инициатором формирования комитета и международной организации по проблемам охлаждения и охладительной техники в Париже в 1903. Он являлся также пионером цветной фотографии в Сербии.

Кроме вклада в астрономию и метеорологию, обсерватория, которую возглавлял М. Неделькович, являлась колыбелью сейсмических и геомагнитных исследований в Сербии. Неделькович приобрёл инструменты для геомагнитных измерений от Теге Миклоша Конколи, основателя Будапештской астрономической обсерватории, что позволило ему начать исследования земного магнетизма. Благодаря Конколи, приобретенный в 1903 сейсмограф был установлен в 1904 году в специальном павильоне. Наблюдения с помощью этих приборов выполнялись регулярно, а строительство базы будущего Сейсмологического института в Сербии было закончено в 1906 г. Эта деятельность была продолжена помощником Недельковича Йеленком Михайловичем (г. Врбица, 11 января 1869 г. – Белград, 10 октября 1958 г.), который работал на Обсерватории с 1896 г.

Во время австро-венгерской оккупации Сербии в Первую мировую войну обсерваторию возглавлял Виктор Конрад из Вены. В период поспешного отступления из Сербии австрийцы вывезли или разрушили все инструменты обсерватории. Однако, благодаря чрезвычайному энтузиазму, Неделькович после войны получил в Германии на основании военных репараций множество инструментов и другого оборудования для новой обсерватории.

Инструменты, приобретённые Недельковичем, были единственной наблюдательной базой обсерватории, хотя некоторые из них были демонтированы немцами во Второй мировой войне, два телескопа переданы Люблянскому и Загребскому университетам, а некоторые из меньших остались неустановленными.

В настоящее время в павильонах обсерватории уста-



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Слика 8.

ПРИКАЗИ, ОСВРТИ И ПРИГОДНИ НАПИСИ

1. Милан С. Димитријевић: ШЕСТА СРПСКА КОНФЕРЕНЦИЈА О ОБЛИЦИМА СПЕКТРАЛНИХ ЛИНИЈА У АСТРОФИЗИЦИ, *Васиона*, 2007, бр. 2, 96.
2. Editors (M. K. Tsvetkov, L. G. Filipov, M. S. Dimitrijević, L. Č. Popović): PREFACE, Proceedings of the 5th Bulgarian'Serbian Conference on Astronomy and Space Science, eds. M. K. Tsvetkov, L. G. Filipov, M. S. Dimitrijević, L. Č. Popović, Heron Press, Sofia, with CD supplemented to Bulgarian Journal of Physics, 34 (2), 2007, VII.
3. Милан С. Димитријевић: КАКО ЗАУЗДАТИ ВРЕМЕ – КАЛЕНДАРИ НАШИ НАСУШНИ, у Дејан Максимовић: 3000 година рачунања времена у Ирану, Природњачко друштво «Геа», Вршац, 2008, 3.
4. Gordana Malović, Luka Č. Popović, Milan S. Dimitrijević: 2008, PREFACE, 24th Summer School and International Symposium on the Physics of Ionized Gases, Journal of Physics: Conference Series **133**, 011001 (1).
5. Милан С. Димитријевић, Жарко Мијајловић: ИЗВОД ИЗ РЕЦЕНЗИЈЕ, Анђелка Ковачевић, О одређивању маса астероида, Библиотека Dissertacio 245, Задужбина Андрејевић, Београд, 2008.
6. Editors (M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev) PREFACE, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 2009, 7.
7. L. Č. Popović, M. S. Dimitrijević, PREFACE, New Astronomy Review, Vol. 53, 2009, 107.

ПРЕВОДИ

1. Др Катја Цветкова: АСТРОНОМИЈА У БУГАРСКОЈ, 2009 – У СУСРЕТ МЕЂУНАРОДНОЈ ГОДИНИ АСТРОНОМИЈЕ, *ГЕА*, 2008, бр. 8, 2.

АУДИО ВИЗУЕЛНА ПРОДУКЦИЈА – КОМПАКТ ДИСКОВИ

1. I HUNGARIAN-YUGOSLAV ASTRONOMICAL CONFERENCE, Baja, Hungary, 26-27. April, 1995 [Електронски извор], edited by Istvan Vince, Milan S. Dimitrijevic and Lajos Balazs ; CD prepared by Milan S. Dimitrijevic and Tatjana Milovanov. - Belgrade: Astronomical Observatory, 2008 (Belgrade: Astronomical Observatory). - 1 електронски оптички диск (CD-ROM).
2. X NATIONAL CONFERENCE OF YUGOSLAV ASTRONOMERS, Belgrade, 22-24. September, 1993 [Електронски извор], X национална конференција југословенских астронома, Београд, 22-24. септембар, 1993, organized by Astronomical Observatory Belgrade, edited by Milan S.

Dimitrijevic and Dragutin Djurovic, CD prepared by Milan S. Dimitrijevic and Tatjana Milovanov. - Belgrade: Astronomical Observatory, 2008 (Belgrade: Astronomical Observatory). – 1 електронски оптички диск (CD-ROM).

3. I YUGOSLAV CONFERENCE ON SPECTRAL LINE SHAPES, September 11-14, 1995, Krivaja [Електронски извор], organized by Astronomical Observatory Belgrade, edited by Milan S. Dimitrijevic and Luka C. Popovic, CD prepared by Milan S. Dimitrijevic and Tatjana Milovanov. - Belgrade : Astronomical Observatory, 2008 (Belgrade : Astronomical Observatory). - 1 електронски оптички диск (CD-ROM).
4. LINE SHAPES INVESTIGATIONS IN YUGOSLAVIA AND SERBIA [Електронски извор]: (BIBLIOGRAPHY AND CITATION INDEX), Истраживање облика спектралних линија у Југославији и Србији : (библиографија и индекс цитата), Milan S. Dimitrijević. - CD prepared by Milan S. Dimitrijevic and Tatjana Milovanov. - Belgrade: (Belgrade: Astronomical Observatory), Belgrade 2009 - 1. електронски оптички диск (CD-ROM) (Електронски извор је електронска верзија истоимених књига 1-5 публикованих у едицији "Публикације Астрономске опсерваторије у Београду").
5. PROCEEDINGS AND PHOTOS [Електронски извор], II Yugoslav Conference on Spectral Line Shapes, September 29 - October 2, 1997, Bela Crkva, Yugoslavia, organized by Faculty of Physics, University of Belgrade, edited by Luka Č. Popović and Milivoje Ćuk, CD prepared by Milan S. Dimitrijević and Tatjana Milovanov. - Belgrade: Astronomical Observatory, 2008 (Belgrade : Astronomical Observatory). - 1 електронски оптички диск (CD-ROM).
6. ABSTRACTS, PRESENTATIONS AND PHOTOS [Електронски извор] The First Summer School in Astronomy and Geophysics, August 6-11, 2007, Belgrade, Serbia ; eds. Milan S. Dimitrijević, Nadežda Pejović, Anđelka Kovačević, organized by Faculty of Mathematics, Belgrade. CD prepared by Milan S. Dimitrijević and Tatjana Milovanov - Belgrade: Astronomical Observatory, 2008 (Beograd: Astronomska opservatorija). - 1. електронски оптички диск (DVD).
7. РАЗВОЈ АСТРОНОМИЈЕ КОД СРБА, I, Београд 7-9. април 1997. [Електронски извор]: поводом прославе 110 година Астрономске опсерваторије, Development of Astronomy among Serbs, I: on the occasion of 110th jubilee celebration of the Belgrade Astronomical Observatory, организатор Астрономска опсерваторија, Београд, Уредници Милан С. Димитријевић, Јелена Милоградов-Турин и Лука Ч. Поповић, диск припремили Милан С. Димитријевић и Татјана Милованов. – Београд: Астрономска опсерваторија, 2008 (Београд: Астрономска опсерваторија). - 1 електронски оптички диск (CD-ROM) :
8. ABSTRACTS, PROGRAM AND PHOTOS [Електронски извор], 7th Serbian Co6nference on Spectral Line Shapes in Astrophysics, June 15-19, 2009, Zrenjanin, Serbia ; edited by Luka Č. Popović, M. S. Dimitrijević, D. Jevremović, D. Ilić, Organized by Serbian Astronomical Society and Astronomical Obser-

vatory, Belgrade. DVD prepared by Milan S. Dimitrijević, Miodrag Dačić and Tatjana Milovanov - Belgrade : Serbian Astronomical Society : Astronomical Observatory, 2009 (Beograd: Astronomical Observatory). - 1. електронски оптички диск (DVD).

9. PROCEEDINGS, PHOTOS AND VIDEOS [Електронски извор], The 5th Bulgarian-Serbian Conference on Astronomy and Space Science, May 9-12, 2006, Sofia, Bulgaria, edited by M. K. Tsvetkov, L. Filipov, M. S. Dimitrijević, L. Č. Popović, organized by the Space Research Institute of the Bulgarian Academy of Sciences. DVD prepared by Milan S. Dimitrijević and Tatjana Milovanov - Belgrade: Serbian Astronomical Society: Astronomical Observatory, 2009 (Belgrade : Astronomical Observatory). - 1. електронски оптички диск (DVD).
10. PROCEEDINGS, PHOTOS AND VIDEOS [Електронски извор], VI Serbian-Bulgarian Astronomical Conference, May 7-11, 2008, Belgrade, organized by Astronomical Observatory, Mathematical Faculty and Astronomical Society "Rudjer Bošković", Belgrade, edited by Milan S. Dimitrijević, Milcho Tsvetkov, Luka Č. Popović and Valeri Golev. DVD prepared by Milan S. Dimitrijević and Tatjana Milovanov - Belgrade: Astronomical Observatory, 2009 (Belgrade: Astronomical Observatory). - 1. електронски оптички диск (CD-ROM) (Публикације Астрономског друштва „Руђер Бошковић“, св. 9).
11. PROGRAM, PRESENTATIONS AND PHOTOS [Електронски извор] The Second Summer School in Astronomy, September 29 – October 1, 2008, Belgrade, Serbia, eds. Milan S. Dimitrijević, Anđelka Kovačević, organized by Faculty of Mathematics, Belgrade, Astronomical Observatory, Belgrade, and University of Novi Sad, Faculty of Sciences. DVD prepared by Milan S. Dimitrijević and Tatjana Milovanov - Belgrade: Astronomical Observatory, 2009 (Београд: Астрономска опсерваторија). - 1. електронски оптички диск (DVD).
12. 24TH SUMMER SCHOOL AND INTERNATIONAL SYMPOSIUM ON THE PHYSICS OF IONIZED GASES - [SPIG 2008], August 25-29, 2008, Novi Sad, Serbia, organized by Astronomical Observatory Belgrade, edited by Gordana Malović, Luka Č. Popović and Milan S. Dimitrijević. DVD prepared by Milan S. Dimitrijević and Tatjana Milovanov - Belgrade: Astronomical Observatory, 2008 (Belgrade: Astronomical Observatory). - 1 електронски оптички диск (DVD).
13. РАЗВОЈ АСТРОНОМИЈЕ КОД СРБА, V, 18-22. април 2008. Београд [Електронски извор], Development of Astronomy among Serbs V, 18 - 22 April, 2008, Belgrade, уредник Милан С. Димитријевић, организатор Астрономско друштво “Руђер Бошковић”, диск припремили Милан С. Димитријевић и Татјана Милованов. - Београд: Астрономско друштво “Руђер Бошковић”, Друштво астронома Србије, 2009, (Београд : Астрономско друштво “Руђер Бошковић”). - 1 електронски оптички диск (DVD).

РАЗНО

1. Никола Цветковић: 2009, ПЕСНИЧКА СЛИКА КОСМОСА У ПОЕЗИЈИ МИЛАНА С. ДИМИТРИЈЕВИЋА, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 635.
2. Ђорђе Петковић: 2009, С БЕОГРАДСКЕ ЗВЕЗДАРНИЦЕ, Посвећено Милану С. Димитријевићу, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 723.
3. Војислав Марић, Владан Ђорђевић, Александар Маринчић: ПРЕДЛОГ ЗА ИЗБОР МИЛАНА С. ДИМИТРИЈЕВИЋА ЗА ДОПИСНОГ ЧЛАНА САНУ, Скупштина за избор нових чланова, САНУ, Одељење за математику, физику и геонауке, Београд 2009.

ПОМИЊАЊА УЧЕСНИКА НА ПРОЈЕКТУ У ПЕРИОДИЦИ И КЊИГАМА

1. N. Pejović, Ž. Mihajlović: THE PROJECT ASV, Proceedings of the 5th Bulgarian-Serbian Conference on Astronomy and Space Science, eds. M. K. Tsvetkov, L. G. Filipov, M. S. Dimitrijević, L. Č. Popović, Heron Press, Sofia, with CD supplemented to Bulgarian Journal of Physics, 34 (2), 2007, 95 (M. C. Димитријевић).
2. PROCEEDINGS OF THE 5TH BULGARIAN-SERBIAN CONFERENCE ON ASTRONOMY AND SPACE SCIENCE, eds. M. K. Tsvetkov, L. G. Filipov, M. S. Dimitrijević, L. Č. Popović, Heron Press, Sofia, with CD supplemented to Bulgarian Journal of Physics, 34 (2), 2007, II, Photos (M. C. Димитријевић, M. Дачић), 421, List of participants (M. C. Димитријевић, M. Дачић, H. Миловановић), 423, Scientific Organizing Committee (M. C. Димитријевић).
3. Ифигенија Драганић: АНТИКА И САВРЕМЕНИ СВЕТ; СРЕМСКИ КАРЛОВЦИ – СРЕМСКА МИТРОВИЦА 3. И 4. НОВЕМБАР 2006, *Зборник Матице српске за класичне студије*, Нови Сад 2007, бр. 9, 264 (M. C. Димитријевић).
4. Г. П. Ф.: ВЕЧЕРАС У БИБЛИОТЕЦИ: ТАЈНЕ ЗВЕЗДАНОГ НЕБА, *Кикиндске новине*, 7. фебруар 2008, 7(M. C. Димитријевић) .
5. Г. П. Ф.: ПРЕДАВАЊЕ ИЗ АСТРОНОМИЈЕ: ЗАШТО ЗВЕЗДЕ ЋУТЕ, *Кикиндске новине*, 14. фебруар 2008, 7 (M. C. Димитријевић).
6. О. Т.: АСТРОНОМИЈА У БИБЛИОТЕЦИ: САМИ У СВЕМИРУ?, *Кикиндске*, 15. фебруар 2008, 10 (M. C. Димитријевић).
7. МАТИЦА СРПСКА: ИЗВЕШТАЈ О ЧЕТВОРОГОДИШЊЕМ РАДУ МАТИЦЕ СРПСКЕ 2004-2007, *Рад Матице српске*, Нови Сад 2007, бр. 44, CLXXXI, 7 (M. C. Димитријевић).

8. БИБЛИОТЕКА МАТИЦА СРПСКА: ИЗВЕШТАЈ О ЧЕТВОРОГОДИШЊЕМ РАДУ БИБЛИОТЕКЕ МАТИЦЕ СРПСКЕ 2004-2007, *Рад Матице српске*, Нови Сад 2007, бр. 44, CLXXXI, 364 (М. С. Димитријевић).
9. ДАРОДАВЦИ, *Рад Матице српске*, Нови Сад 2007, бр. 44, CLXXXI, 385 (М. С. Димитријевић).
10. НАБАВКА И РАЗМЕНА ПУБЛИКАЦИЈА, *Рад Матице српске*, Нови Сад 2007, бр. 44, CLXXXI, 405 (М. С. Димитријевић).
11. Николај Тимченко: ПЕСМОПИС, АНТОЛОГИЈА МИРОСЛАВА МИЛОВАНОВИЋА, У „Књижевна баштина Лесковца“, Лесковачки културни центар, Задужбина Николај Тимченко, Лесковац, 2007, 207 (М. С. Димитријевић).
12. Фотографија на стр. 6, (пети с десна), Science and Religion Dialogue in Romania, The Association, for the Dialogue Between Science and Theology in Romania, Bucharest, 2007 (М. С. Димитријевић).
13. Предраг Јашовић: ДЕКОНСТРУИСАНИ СОНЕТИ СА РЕПОМ И АКРОСТИХОМ У ОГЛЕДАЛУ И СИГНАЛИЗАМ, у Предраг Јашовић: Књижевне притоке 2, Бистрица, Нови Сад, 2008, 61 (М. С. Димитријевић).
14. NAUČNI SAVET, *650 monografija Zadužbine »Andrejević« od 1994. do 2007*, Zadužbina »Andrejević«, Beograd, 2008, 15 (М. С. Димитријевић) .
15. BIBLIOTEKA „DISSERTATIO“, *650 monografija Zadužbine »Andrejević« od 1994. do 2007*, Zadužbina »Andrejević«, Beograd, 2008, 17 (М. С. Димитријевић).
16. PREDRAG JOVANOVIĆ: UTICAJ GRAVITACIONIH SOČIVA NA SPEKTRE KVAZARA, *650 monografija Zadužbine »Andrejević« od 1994. do 2007*, Zadužbina »Andrejević«, Beograd, 2008, 86 (М. С. Димитријевић).
17. DRAGANA PETROVIĆ: MODEL PRAŠNJAVE PLAZME I PRIMENA PLAZMA TEHNOLOGIJE, *650 monografija Zadužbine »Andrejević« od 1994. do 2007*, Zadužbina »Andrejević«, Beograd, 2008, 127 (М. С. Димитријевић).
18. BIBLIOTEKA „INSPIRATIO“, *650 monografija Zadužbine »Andrejević« od 1994. do 2007*, Zadužbina »Andrejević«, Beograd, 2008, 245 (М. С. Димитријевић).
19. MILAN S. DIMITRIJEVIĆ: SRPSKI ASTRONOMI U INDEKSU NAUČNIH CITATA U XX VEKU, *650 monografija Zadužbine »Andrejević« od 1994. do 2007*, Zadužbina »Andrejević«, Beograd, 2008, 246 (М. С. Димитријевић).
20. ГОДИШЊАК БМС ЗА 2007. ГОДИНУ, *Вести*, Гласило Библиотеке Матице српске, април 2008, бр. 65, 5 (М. С. Димитријевић).
21. Т. Трикић: СОНДА НАСА УСПЕШНО СЛЕТЕЛА НА ЦРВЕНУ ПЛАНЕТУ: „ФЕНИКС“ ТРАЖИ ЖИВОТ НА МАРСУ, *Блиц*, 27. мај 2008, 6 (М. С. Димитријевић).
22. ИЗВЕШТАЈ О РАДУ БИБЛИОТЕКЕ МАТИЦЕ СРПСКЕ ЗА 2007. ГОДИНУ, Годишњак Библиотеке Матице српске за 2007. годину, Нови Сад 2008, 7 (М. С. Димитријевић).

23. НАБАВКА И РАЗМЕНА ПУБЛИКАЦИЈА, Годишњак Библиотеке Матице српске за 2007. годину, Нови Сад 2008, 12 (М. С. Димитријевић).
24. ДАРОДАВЦИ, Годишњак Библиотеке Матице српске за 2007. годину, Нови Сад 2008, 35 (М. С. Димитријевић).
25. Јелена Ковачек-Светличић: БИБЛИОТЕКА МИЛАНА С: ДИМИТРИЈЕВИЋА У БИБЛИОТЕЦИ МАТИЦЕ СРПСКЕ, Годишњак Библиотеке Матице српске за 2007. годину, Нови Сад 2008, 109 (М. С. Димитријевић).
26. ЗАХВАЉУЈЕМО, Радина Вучетић: Престоница независне Србије (1878-1918), Креативни центар, Београд, 2008, стр.32 (М. С. Димитријевић).
27. Peach, G., Mullamphy, D. F. T., Whittingham, I. B.: UNIFICATION OF THE IMPACT AND ONE-PERTURBER THEORIES OF LINE SHAPES, in Spectral Line Shapes 15, 19th International Conference on Spectral Line Shapes, AIP Conference Proceedings **1058** (2008) 234 (М. С. Димитријевић).
28. INTERNATIONAL SCIENTIFIC COMMITTEE, in Spectral Line Shapes 15, 19th International Conference on Spectral Line Shapes, AIP Conference Proceedings **1058** (2008) XV (М. С. Димитријевић) .
29. CONFERENCE PHOTO, in Spectral Line Shapes 15, 19th International Conference on Spectral Line Shapes, AIP Conference Proceedings **1058** (2008) XIX (М. С. Димитријевић).
30. LIST OF PARTICIPANTS, in Spectral Line Shapes 15, 19th International Conference on Spectral Line Shapes, AIP Conference Proceedings **1058** (2008) 385 (М. С. Димитријевић).
31. MEMBERS OF ACADEMY OF NONLINEAR SCIENCES, u Doprinos nelinearnim naukama Vol. 2, ed. Katica Stevanović Hedrih, Akademija nelinearnih nauka, 2008, 2 (М. С. Димитријевић).
32. „3000 ГОДИНА РАЧУНАЊА ВРЕМЕНА У ИРАНУ“, ПРОМОЦИЈА КЊИГЕ, ВЕЛИКА САЛА СКУПШТИНЕ ОПШТИНЕ ВРШАЦ, 3. ОКТОБАР 2008, ГЕА, бр. 8, 2008, 30 (М. С. Димитријевић).
33. Н. М.: СРПСКИ АСТРОНОМИ НА ПУТУ ДО ЗВЕЗДА, Политика, 10. фебруар 2008, 48 (М. С. Димитријевић).
34. Vasile Mioc, Christiana Dumitrache, Nedelia Antonia Popescu: THE INTERNATIONAL CONFERENCE “EXPLORING THE SOLAR SYSTEM AND THE UNIVERSE”, BUCHAREST, ROMANIA, 8-12 APRIL 2008, Romanian Astronomical Journal, 18, 93, 2008 (Анђелка Ковачевић, Зоран Симић, Миодраг Дачић, М. С. Димитријевић)
35. С. Нин. (Слободан Нинковић): ДИМИТРИЈЕВИЋ, МИЛАН С., Енциклопедија Српског народа, Завод за уџбенике, Београд, 2008, 288 (М. С. Димитријевић).
36. Саша Симић: 2008, *Променљивост светлосне криве гама бљескова: Модификација модела ударних таласа,* Докторска дисертација, Природно-математички факултет, Крагујевац (М. С. Димитријевић)
37. Јелена Ковачевић: 2008, *Емисиони Fe II, [O III] и C IV региони у активним галактичким језгрима,* Магистарски рад, Математички факултет Универзитета у Београду, Београд, 2008 (М. С. Димитријевић).

38. Зоран Симић: 2008, *Утицај судара са наелектрисаним честицама на профиле спектралних линија тешких метала у спектрима звезда класе A и белих патуљака*, Докторска дисертација, Математички факултет Универзитета у Београду, Београд, 2008 (М. С. Димитријевић).
39. Andjelka Kovačević: 2009, SOME ASPECTS OF ASTEROID MASS DETERMINATION, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 67 (М. С. Димитријевић).
40. Надежда Пејовић: 2009, ЖИВОТ И ДЕЛО ПРОФЕСОРА ДР ЈОВАНА СИМОВЉЕВИЋА (1929-2007), Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 377 (М. С. Димитријевић).
41. Надежда Пејовић, Жарко Мијајловић: 2009, АСТРОНОМИЈА У УЏБЕНИКУ *ОСНОВИ МАТЕМАТИЧНЕ И ФИЗИЧКЕ ГЕОГРАФИЈЕ* ПАВЛА ВУЈЕВИЋА, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 391 (М. С. Димитријевић).
42. Александар Томић: 2009, КОЛАТЕРАЛНА ШТЕТА ОДБАЦИВАЊА МЕТАФИЗИКЕ – ЗАКОН ГРАВИТАЦИЈЕ И КВАНТОВАЊЕ, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 521 (М. С. Димитријевић).
43. N. Pejović, A. Valjarević, Ž. Mijajlović, D. Ćirić: 2009, DEVELOPMENT OF ASTRONOMY IN TOPLICA REGION, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 373 (М. С. Димитријевић).
44. PROCEEDINGS OF THE 6TH SERBIAN-BULGARIAN ASTRONOMICAL CONFERENCE, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 2009, 458-480, PHOTOS (Анђелка Ковачевић, Дарко Јевремовић, Миодраг Дачић, Зоран Симић, М. С. Димитријевић), 487, LIST OF PARTICIPANTS (Анђелка Ковачевић, Дарко Јевремовић, Миодраг Дачић, Зоран Симић, М. С. Димитријевић).
45. Т. Ј. Халаши, И. П. Ћосић, Р. Ј. Халаши: ПРЕДГОВОР, FOREWORD, у Милутин Миланковић као инспирација, Т. Ј. Халаши, И. П. Ћосић, Р. Ј. Халаши, Едиција Техничке науке – монографије 32, Универзитет у Новом Саду, Факултет техничких наука, ФТН Издаваштво, Нови Сад, 2008, 5 (М. С. Димитријевић).

46. Милан Јеличић: НЕОБЈАВЉЕНЕ ХРОНИЧАРСКЕ ВЕСТИ ПО ПРЕЛАСКУ *ВАСИОНЕ* НА ВЕЛИКИ ФОРМАТ 2005. ГОДИНЕ, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 869 (М. С. Димитријевић, Н. Миловановић, М. Дачић).
47. Никола Цветковић: ПОЕТСКА ЗВЕЗДАРНИЦА ЂОРЂА ЂЕТКОВИЋА (Фрагменти), Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 721 (М. С. Димитријевић).
48. Лука Ч. Поповић, Јелена Ковачевић, Драгана Илић: 2009, СПЕКТРОСКОПСКА ИСТРАЖИВАЊА ВАНГАЛАКТИЧКИХ ОБЈЕКАТА НА АСТРОНОМСКОЈ ОПСЕРВАТОРИЈИ (2006 – 2007), Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 151 (М. С. Димитријевић, М. Дачић.З. Симић).
49. Никола Цветковић: 2009, КОСМИЧКО-ПОЕТСКЕ И СИМБОЛИЧКЕ ВИЗИЈЕ У ИКОНОГРАФИЈИ СРПСКЕ СРЕДЊОВЕКОВНЕ НУМИЗМАТИКЕ У ДЕЛУ СЕРГИЈА ДИМИТРИЈЕВИЋА (фрагмент), Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 481 (М. С. Димитријевић).
50. Надежда Пејовић, Александар Ваљаревић, Александар Симоновић, Жарко Мијајловић: 2009, ИСТОРИЈА АСТРОНОМИЈЕ У ПРОКУПЉУ, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 291 (М. С. Димитријевић).
51. ФОТОГРАФИЈЕ, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 903 (М. С. Димитријевић, А. Ковачевић, М. Дачић).
52. СТУДИО ЗА ЕЛЕКТРОНСКЕ МЕДИЈЕ „ВЛАДА ПЕТРИЋ“, Програм Музеја југословенске кинотеке, септембар 2009, додатак у средини (М. С. Димитријевић).
53. И.М.: 2009, АСТРОНОМИ У КИНОТЕЦИ, Данас, 21. септембар 2009, 12 (М. С. Димитријевић).
54. С. Кораћ: 2009, КАНДИДАТИ ЗА САНУ, Политика, 7. октобар 2009, 17 (М. С. Димитријевић).
55. С. Кораћ: 2009, НОВИ СТАРИ КАНДИДАТИ, Политика, 9. октобар 2009, 13(М. С. Димитријевић) .

56. 800 КЊИГА ЗАДУЖБИНЕ АНДРЕЈЕВИЋ: 2009, 800 књига и 15 година Задужбине Андрејевић, Задужбина Андрејевић, Београд (М. С. Димитријевић, Анђелка Ковачевић, Ненад Миловановић, Зоран Симић).
57. PROCEEDINGS OF THE XV NATIONAL CONFERENCE OF ASTRONOMERS OF SERBIA, 2009, eds. O. Atanacković, Z. Cvetković, D. Ilić, Publications of the Astronomical Observatory of Belgrade, No. 86, 3, PARTICIPANTS OF THE 15TH NATIONAL CONFERENCE OF ASTRONOMERS OF SERBIA (Photo) (М. С. Димитријевић), 427, LIST OF PARTICIPANTS (М. С. Димитријевић, Анђелка Ковачевић, Дарко Јевремовић).
58. Jelena Milogradov Turin: THE FIRST 100 GRADUATES IN ASTRONOMY FROM THE UNIVERSITY OF BELGRADE, Proceedings of the XV National Conference of Astronomers of Serbia, eds. O. Atanacković, Z. Cvetković, D. Ilić, Publications of the Astronomical Observatory of Belgrade, No. 86, 361 (М. С. Димитријевић, Миодраг Дачић).
59. Ивана Мићевић: ЗАКУЛИСНЕ РАДЊЕ ОКО ИЗБОРА КАНДИДАТА ЗА ЧЛАНСТВО У САНУ УВЕК СУ ИНТРИГИРАЛЕ СРПСКУ ЈАВНОСТ; ДОГОВОР БИРА АКАДЕМИКА, Вечерње новости, 18. октобар 2009, 11 (М. С. Димитријевић).
60. Бранко Миличић: БЕОГРАЂАНИН МИЛАН ЈОВАНОВИЋ „ЗАБОРАВИО“ У МИНХЕНУ СВОЈ СТАРИ ПОЗИВ И ЛАТИО СЕ ПЕРА; АДВОКАТ ЗАВРШИО МЕЂУ ПИСЦИМА, Вести, Франкфурт, 25. 10. 2009, 16 (М. С. Димитријевић).
61. Дејан Чикара: РОТАРИ КЛУБ БЕОГРАД – СТАРИ ГРАД; ОСНИВАЊЕ И ПРВЕ ГОДИНЕ РАДА, РК Београд Стари – Град, Београд, 2009 (М. С. Димитријевић).
62. ФОТОГРАФИЈА НА НАСЛОВНОЈ СТРАНИ, Билтен РК Београд Стари – Град, 526, 23. децембар 2009, 1 (М. С. Димитријевић).
63. M. S. Dimitrijević: 2009, ACTIVITIES OF PARTICIPANTS OF THE PROJECT 146001 »INFLUENCE OF COLLISIONAL PROCESSES ON THE ASTROPHYSICAL PLASMA SPECTRA« - 2006-2007, Proceedings of the 6th Serbian-Bulgarian Astronomical Conference, Belgrade 7-11 May 2008, eds. M. S. Dimitrijević, M. Tsvetkov, L. Č. Popović, V. Golev, Publ. Astron. Soc. »Rudjer Bošković«, No. 9, 157(Миодраг Дачић, Драгана Танкосић, Дарко Јевремовић, Анђелка Ковачевић, Ненад Миловановић, Зоран Симић). .
64. Милан С. Димитријевић: 2009, АКТИВНОСТИ САРАДНИКА ПРОЈЕКТА 146001 „УТИЦАЈ СУДАРНИХ ПРОЦЕСА НА СПЕКТРЕ АСТРОФИЗИЧКЕ ПЛАЗМЕ“ – 2006-2007, Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 105 (Миодраг Дачић, Драгана Танкосић, Дарко Јевремовић, Анђелка Ковачевић, Ненад Миловановић, Зоран Симић).
65. Милан С. Димитријевић: 2009, ШЕСТА СРПСКА КОНФЕРЕНЦИЈА О ОБЛИЦИМА СПЕКТРАЛНИХ ЛИНИЈА У АСТРОФИЗИЦИ, Зборник

радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, Публикације Астрономског друштва «Руђер Бошковић» Св. 8, Београд 2009, 829 (Миодраг Дачић, Драгана Танкосић, Дарко Јевремовић, Ненад Миловановић, Зоран Симић).

ЈАВНА ПРЕДАВАЊА

1. „ГДЕ СУ ОНИ!“ - ТАЈНА ВЕЛИКОГ ЋУТАЊА ВАНЗЕМАЉСКИХ ЦИВИЛИЗАЦИЈА,, Градска библиотека «Јован Поповић», Кикинда, 7. фебруар 2008 (М. С. Димитријевић). .
2. ТАЈНА ВЕЛИКОГ ЋУТАЊА ВАНЗЕМАЉСКИХ ЦИВИЛИЗАЦИЈА,, Гимназија, Прокупље, 20. фебруар 2008 (М. С. Димитријевић).
3. ПРОМОЦИЈА ИЗДАЊА ЗАДУЖБИНЕ «АНДРЕЈЕВИЋ», Победници двадесет четвртог конкурса, Задужбина Илије Милосављевића Коларца, Видојко Јовић, Милан Димитријевић, Светомир П. Стожинић, Славица Ђукић-Дејановић, Јован Г. Душанић, Душан Старчевић, Коста Андрејевић, Београд, 29. мај 2008.
4. 1D AND 2D REVERBERATION MAPPING, Астрономси институт Чешке академије наука (Анђелка Ковачевић за време студијског боравка од 16. јуна до 14. јула 2008, у Одсеку за галаксије и планетарне системе Астрономског института Чешке академије наука).
5. 19 ICSLS У ВАЉАДОЛИДУ И EXPO 2008 У САРАГОСИ, Група за Астрофизичку спектроскопију – састанци четвртком, 24. јула 2008 (М. С. Димитријевић).
6. КОЛИКО ДАЛЕКО ЈЕ ГОРЕ?, Група за Астрофизичку спектроскопију – састанци четвртком, 11. септембра 2008 (М. С. Димитријевић).
7. ПРОМОЦИЈА КЊИГЕ Дејана Максимовића: «3000 година рачунања времена у Ирану», Свечана сала Општине Вршац, 3. октобра 2008 (М. С. Димитријевић).
8. DATABASE FOR STARK BROADENING OF ISOLATED LINES OF ATOMS AND IONS IN THE IMPACT APPROXIMATION (Милан С. Димитријевић и Sylvie Sahal-Bréchot), LERMA, Observatoire de Paris-Meudon, 16. октобар 2008.
9. DJORDJE STANOJEVIĆ, UN ÉLÈVE ET COLLABORATEUR SERBE DE JULES JANSSEN, LERMA, Observatoire de Paris-Meudon, 16. октобар 2008 (М. С. Димитријевић).
10. БАЗА ПОДАТАКА ШТАРК-Б и ПУТ У ПАРИЗ И КОРДОБУ СА ПОСЕТОМ ПРАДОУ И РЕМБРАНТОВОЈ ИЗЛОЖБИ, Група за Астрофизичку спектроскопију – састанци четвртком, 6. новембра 2008 (М. С. Димитријевић).
11. ХЕЛИОЦЕНТРИЧКИ СИСТЕМ ОД ОРФИЧКИХ ХИМНИ И ПИТАГОРЕЈАЦА ДО ЦАРА ЈУЛИЈАНА АПОСТАТЕ, Група за Астрофизичку спектроскопију – састанци четвртком, 20. новембра 2008 (М. С. Димитријевић). (М. С. Димитријевић)

12. ТАЈНА ВЕЛИКОГ ЋУТАЊА ВАНЗЕМАЉСКИХ ЦИВИЛИЗАЦИЈА, Виша Техничка школа, Зрењанин, 11. децембар 2008 (М. С. Димитријевић).
13. ЂОРЂЕ СТАНОЈЕВИЋ – ДРУГИ РУКОВОДИЛАЦ АСТРОНОМСКЕ ОПСЕРВАТОРИЈЕ, Група за Астрофизичку спектроскопију – састанци четвртком, 25. децембар 2008 (М. С. Димитријевић).
14. ТАЈНА ВЕЛИКОГ ЋУТАЊА КОСМИЧКИХ ЦИВИЛИЗАЦИЈА,, Институт „Михајло Пупин“, 17. фебруар 2009 (М. С. Димитријевић).
15. КОНФЕРЕНЦИЈА “ВЕЛИКА ПИТАЊА О УНИВЕРЗУМУ” СИБИУ 5-8 ФЕБРУАР 2009, ПРОГЛАШЕЊЕ ГОДИНЕ АСТРОНОМИЈЕ У РУМУНИЈИ И ШТА СМО ВИДЕЛИ НА ПУТУ, Група за Астрофизичку спектроскопију – састанци четвртком, 19. фебруар 2009 (М. С. Димитријевић).
16. ТАЈНА ВЕЛИКОГ ЋУТАЊА ВАНЗЕМАЉСКИХ ЦИВИЛИЗАЦИЈА Гимназија, Ћуприја“, 27. фебруар 2009 (М. С. Димитријевић) .
17. L'OBSERVATOIRE ASTRONOMIQUE DE BELGRADE ET ASTRONOMIE EN SERBIE, Observatoire de Paris-Meudon, 9. април 2009 (М. С. Димитријевић).
18. JENAM-2009, «ЕВРОПСКА НЕДЕЉА АСТРОНОМИЈЕ И КОСМИЧКИХ ИСТРАЖИВАЊА», Група за Астрофизичку спектроскопију – састанци четвртком, 7. мај 2009 (М. С. Димитријевић).
19. ТАЈНА ВЕЛИКОГ ЋУТАЊА КОСМИЧКИХ ЦИВИЛИЗАЦИЈА, Огранак САНУ у Новом Саду, Платонеум, 13. мај 2009 (М. С. Димитријевић).
20. ТАЈНА ВЕЛИКОГ ЋУТАЊА КОСМИЧКИХ ЦИВИЛИЗАЦИЈА,, Библиотека „Јован Поповић“, Кикинда, 4. јуни 2009(М. С. Димитријевић).
21. JENAM 2009 – Европска недеља астрономије и космичких истраживања, Катедра за астрономију Математичког факултета, Београд, 9. јуни 2009.
22. ПАРИСКА ОПСЕРВАТОРИЈА, Група за Астрофизичку спектроскопију – састанци четвртком, 6. август 2009 (М. С. Димитријевић).
23. ГИБРАЛТАР – ЗЕМЉА КОЈА СЕ МОЖЕ ОБИЋИ ПЕШКЕ, Група за Астрофизичку спектроскопију – састанци четвртком, 20. август 2009 (М. С. Димитријевић).
24. СЕДМА КОНФЕРЕНЦИЈА БАЛКАНСКЕ УНИЈЕ ФИЗИЧАРА, АЛЕКСАНДРУПОЛИС 9-13.09.2009, Група за Астрофизичку спектроскопију – састанци четвртком, 17. септембар 2009 (М. С. Димитријевић).
25. КОСМОС НА ДОХВАТ РУКЕ – ФРАНЦУСКО СРПСКА САРАДЊА У АСТРОНОМИЈИ, Француски културни центар, 17. септембар 2009 (М. С. Димитријевић).
26. МИЛУТИН МИЛАНКОВИЋ И АСТРОНОМИЈА, Учионица Народне опсерваторије, 22. септембар 2009 (М. С. Димитријевић).
27. КОНФЕРЕНЦИЈА “АНТИЧКА КУЛТУРА, ЕВРОПСКО И СРПСКО НАСЛЕЂЕ“ И ПУТ У БУГАРСКУ, Група за Астрофизичку спектроскопију – састанци четвртком, 8. октобар 2009 (М. С. Димитријевић).



9. ВРШАЧКИ АСТРОНОМСКИ СУСРЕТ
Сала Дома омладине Вршац

ПРОГРАМ

ПЕТАК, 9. октобар
17:00 - СВЕЧАНО ОТВАРАЊЕ
17:15 - АСТРОНОМИЈА 21 ВЕКА
предавач: др Милан Димитријевић
18:15 - МЕЂУЗВЕЗДАНИ ГАС У ГАЛАКСИЈИ
предавач: Александар Оташевић
19:15 - ПОТРАГА ЗА ЕКСТРЕМОФИЛНИМ ОРГАНИЗМИМА У СУНЧЕВОМ СИСТЕМУ
предавач: Срђан Ђукић
20:15 - ТИТАН - ЧУДЕСНИ САТУРНОВ САТЕЛИТ
предавач: Драган Лазаревић

СУБОТА, 10. октобар
16:00 - СМОТРА ТЕЛЕСКОПА И ДУРБИНА
17:00 - ГАМА БЉЕСКОВИ
предавач: Дарко Доневски
18:00 - 130 ГОДИНА РАЗВОЈА ФОТОГРАФИЈЕ
предавач: Саша Зоркић
19:00 - ИСТРАЖИВАЊЕ СУНЧЕВОГ СИСТЕМА КОСМИЧКИМ СОНДАМА
предавач: Срђан Пењивраг
20:00 - ОРТОВ ОБЛАК КОМЕТА
предавач: Даница Лукач

покровитељи:
Фонд за отворено друштво
Дом омладине Вршац
Вршачка гимназија

Могуће су мање измене у програму предавања

Слика 9.

28. АСТРОНОМИЈА ДВАДЕСЕТ И ПРВОГ ВЕКА, Природњачко друштво «ГЕА», Вршац, 9. октобар 2009 (М. С. Димитријевић).
29. МИЛУТИН МИЛАНКОВИЋ И ТАЈНА ЛЕДЕНИХ ДОБА, Матица српска у Зрењанину и Друштво за популаризацију науке, Архив града Зрењанина, Зрењанин, 3. новембар 2009 (М. С. Димитријевић).
30. КОНФЕРЕНЦИЈА ВАМДЦ ПРОЈЕКТА У ПАРИЗУ И ПАРИСКА ОПСЕРВАТОРИЈА, Група за Астрофизичку спектроскопију – састанци четвртком, 6. новембар 2009 (М. С. Димитријевић).
31. ПРОМОЦИЈА КЊИГЕ «БЛАГОДАРНИК» Милана С. Косовића, (Душан Стојковић, Јелена Милоградов Турин, Милан С. Димитријевић), Удружење књижевника Србије 16. децембар 2009.
32. САРАДЊА СА УНИВЕРЗИТЕТОМ У КОРДОБИ, Група за Астрофизичку спектроскопију – састанци четвртком, 24. децембар 2009 (М. С. Димитријевић).
33. ЗВЕЗДЕ ГОСПОЂИЦЕ ЛИВИТ, Коларчев народни универзитет, у оквиру циклуса «Жене у астрономији» (Анђелка Ковачевић).

НАСТУПИ НА ТВ И РАДИЈУ И ФИЛМСКЕ ПРОЈЕКЦИЈЕ

1. АСТЕРОИДИ, ТВ Панчево, 2008 (Анђелка Ковачевић).
2. ВЕСТИ (О проглашењу године астрономије), ТВ Б92, 14. јануара 2009, у 10^{ч} (Миодраг Дачић, Милан С. Димитријевић)
3. ДНЕВНИК (Поводом предавања „Тајна великог ћутања ванземаљских цивилизација“, ТВ у Кикинди, 5. јуни 2009 (Милан С. Димитријевић).
4. ТАЈНА ВЕЛИКОГ ЋУТАЊА ВАНЗЕМАЉСКИХ ЦИВИЛИЗАЦИЈ «Дијалог култура», аутор и уредник Дренка Добросављевић, тон мајстор Марица Јунг, Радио-телевизија Војводине, 30. Август 2009, 23^{ч}-24^{ч} (Милан С. Димитријевић).
5. ХОРИЗОНТИ (О години астрономије, разговор са Кораљком Курценвергер), БХ Радио 1, 21. Септембар 2009, 12:10 (Милан С. Димитријевић).
6. ЦИКЛУС НАУЧНО ФАНТАСТИЧНИХ ФИЛМОВА У МУЗЕЈУ КИНОТЕКЕ поводом Међународне године астрономије, јесен 2009, организовала Анђелка Ковачевић
7. ЦИКЛУС НАУЧНО-ПОПУЛАРНИХ ЕМИСИЈА М. С. ДИМИТРИЈЕВИЋА у Студију за електронске медије „Влада Петрић“, Музеја кинотеке, поводом међународне године астрономије, 21-25. септембар 2009, организовала Анђелка Ковачевић.

септембар 2009 програм

СТУДИО ЗА ЕЛЕКТРОНСКЕ МЕДИЈЕ
«Влада Петрић»

Септембар 2009.

21 - 25. септембар, увек са почетком у 18:00

1. дан
Свечано отварање

ЧОВЕК И ВРЕМЕ
Режија Драгољуб Бата Војводић
Сценариста и водитељ Др Милан С. Димитријевић
1x 56м
РТС ТВНС 2003

2. дан

СУНЧЕВ СИСТЕМ
Редитељ Тања Феро
Сценариста и водитељ Др Милан С. Димитријевић
1x 48м
ТВБ 1987

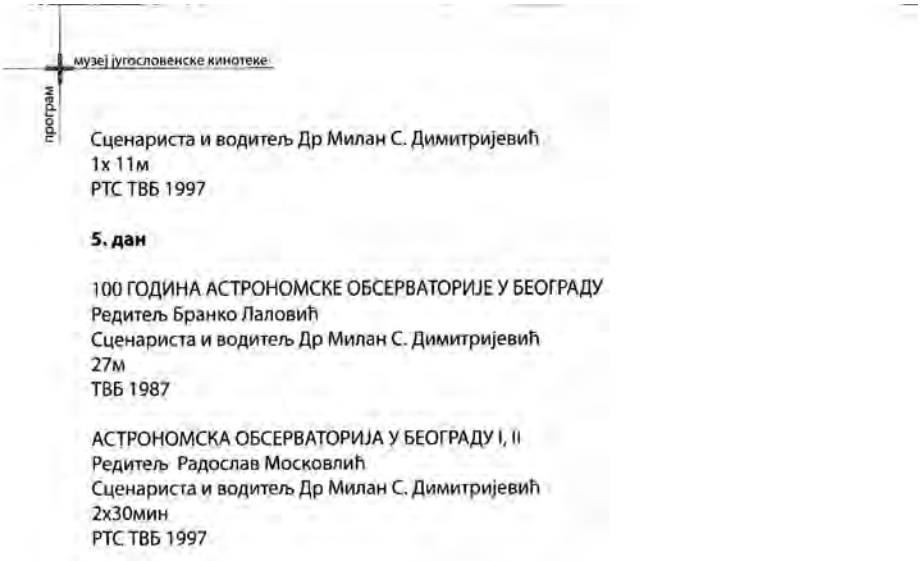
3. дан

АСТРОНОМСКА ПОЧЕТНИЦА
Редитељ Драшко Ђуровић
Сценариста и водитељ Др Милан С. Димитријевић
1x 11м
РТС РТБ 1992

4. дан
НАША ЗВЕЗДА СУНЦЕ
Редитељ Драшко Ђуровић

1

Слика 10.



Слика 11.

УРЕЂИВАЧКА АКТИВНОСТ

1. ВАСИОНА, Чланови Уређивачког одбора, М. С. Димитријевић, М. Дачић.
2. Библиотека DISSERTATIO, Задужбина "Андрејевић", Београд. М. С. Димитријевић председник Редакцијског одбора и члан Научног савета задужбине "Андрејевић". Задужбинари М. Дачић, Н. Миловановић. З. Симић, Анђелка Ковачевић.
3. Библиотека ACADEMIA, Задужбина "Андрејевић", Београд, М. С. Димитријевић члан Научног савета задужбине "Андрејевић". Задужбинари М. Дачић, Н. Миловановић. З. Симић, Анђелка Ковачевић.
4. Библиотека ПОСЕБНА ИЗДАЊА, Задужбина "Андрејевић", Београд, М. С. Димитријевић члан Научног савета задужбине "Андрејевић". Задужбинари М. Дачић, Н. Миловановић. З. Симић, Анђелка Ковачевић.
5. БИЛТЕН, ротари клуб "Београд Стари – Град", М. С. Димитријевић члан Савета председника.
6. Recent Patents on Space Technology, М. С. Димитријевић члан Editorial Advisory Board-a
7. The Open Current Process Chemistry Journal, М. С. Димитријевић члан Editorial Board-a
8. European Journal for Science and Theology, М. С. Димитријевић члан Editorial Board-a од вол. **1**, бр. 4, 2005. РЕДАКЦИЈА
9. Transdisciplinarity in Science and Religion, М. С. Димитријевић члан Editorial Board-a
10. Џон и Мери Грибин, «Колико далеко је горе?», Милан С. Димитријевић редактор превода, ИЦНТ, Београд 2008, 5.

РЕЦЕНЗИЈЕ

1. Анђелка Ковачевић, О одређивању маса астероида, рецензенти Милан С. Димитријевић, Жарко Мијајловић, Библиотека Dissertacio 245, Задужбина Андрејевић, Београд, 2008.
2. Петар В. Вуца, СУНЧАНИ САТОВИ У ВОЈВОДИНИ, рецензент Милан С. Димитријевић, ИП «Београд», Зрењанин, 2009.

НАГРАДЕ И ПРИЗНАЊА

На основу члана 14. тачка 17) Закона о научноистраживачкој делатности („Службени гласник РС”, бр. 110/05 и 50/06-исправка) и члана 6. став 2. Правилника о критеријумима и поступку за доделу звања заслужни научник,

Национални савет за научни и технолошки развој, на седници одржаној 16. априла 2009. године, донео је

О Д Л У К У

О ДОДЕЛИ ЗВАЊА ЗАСЛУЖНИ НАУЧНИК ЗА 2008 ГОДИНУ

I

Звање заслужни научник за 2008. годину, додељује се:

1. **др КРУНОСЛАВУ СУБОТИЋУ**, научном саветнику, Институт за нуклеарне науке „Винча”, Београд;

2. **др БИЉАНИ СТОЈАНОВИЋ,** научном саветнику, Институт за мултидисциплинарна истраживања, Београд;

3. **проф. др КОНСТАНТИНУ И. ПОПОВУ,** Институт за хемију, технологију и металургију, Београд;

4. **др МИЛАНУ ДИМИТРИЈЕВИЋУ,** научном саветнику, Астрономска опсерваторија, Београд;

5. **др СНЕЖАНИ БОШКОВИЋ,** научном саветнику, Институт за нуклеарне науке „Винча”, Београд;

6. **др ЂОРЂУ КРЊАИЋУ,** научном саветнику, Институт за заштиту биља и животну средину, Београд;

7. **проф. др ДРАГОСЛАВУ ДЕВИЋУ,** Факултет музичке уметности, Београд;

8. **проф. др РОКСАНДИ ПЕЈОВИЋ,** Факултет музичке уметности, Београд.

У Београду, 16. 04. 2009. године
Број: 660-00-14/2009-01

ПРЕДСЕДНИК НАЦИОНАЛНОГ САВЕТА

Проф. др Градимир В. Миловановић, дописни члан САНУ

Слика 12.

ДРУШТВО АСТРОНОМА СРБИЈЕ
Национални одбор за обележавање Међународне године астрономије 2009.



Додељује

ПРИЗНАЊЕ

МИЛАНУ ДИМИТРИЈЕВИЋУ

за допринос успешној реализацији активности на промоцији и популаризацији астрономије током Међународне године астрономије.

Београд, 27. 01. 2010.

Никола Божић,
Председник Националног одбора
за обележавање МГА у Србији

Слика 13.



Слика 14.

МЕНТОРСКА АКТИВНОСТ

1. Зоран Симић: 15. јули 2008, *Утицај судара са наелектрисаним честицама на профиле спектралних линија тешких метала у спектрима звезда класе A и белих патуљака*, Докторска дисертација, Математички факултет Универзитета у Београду, Београд, 2008 (руководилац тезе М. С. Димитријевић, ментор Анђелка Ковачевић).
2. Саша Симић: 5. мај 2008, *Променљивост светлосне криве гама блескова: Модификација модела ударних таласа*, Докторска дисертација, Природно-

математички факултет, Крагујевац (Члан комисије Милан С. Димитријевић).

3. Јелена Ковачевић: 26. јуна 2008, *Емисиони Fe II, [O III] и C IV региони у активним галактичким језгрима*, Магистарски рад, Математички факултет Универзитета у Београду, Београд, 2008 (Члан комисије М. С. Димитријевић).
4. Анђелка Ковачевић је руководила и била ментор мастер радовима Петра Глишовића, Биљане Самарџије и Драгана Јовановића.

ПРЕДАВАЊА НА ВИСОКОШКОЛСКИМ УСТАНОВАМА

Милан С. Димитријевић

1. АСТРОНОМСКА СПЕКТРОСКОПИЈА, Математички факултет, Катедра за астрономију и астрофизику, последипломске студије, друга година (од 1988. године).
2. УТИЦАЈ СУДАРА СА НАЕЛЕКТРИСАНИМ И НЕУТРАЛНИМ ЧЕСТИЦАМА НА ЗВЕЗДАНЕ СПЕКТРЕ, Математички факултет, Катедра за астрономију и астрофизику, последипломске студије, друга година (од 2000. године).

Миодраг Д. Дачић

1. ГЕОДЕТСКА АСТРОНОМИЈА, Грађевински факултет, Геодетски одсек, Универзитет у Подгорици (предавања и вежбе у зимском семестру 2008/09).

Анђелка Ковачевић

1. МЕХАНИКА, Математички факултет, Катедра за астрономију и астрофизику, изборни предмет на другој години у другом семестру.
2. ОДАБРАНА ПОГЛАВЉА МЕХАНИКЕ, Математички факултет, Катедра за астрономију и астрофизику, изборни предмет на другој или трећој години у првом семестру.
3. НЕБЕСКА МЕХАНИКА, Математички факултет, Катедра за астрономију и астрофизику, на 4. години у другом семесту.
4. ДИНАМИЧКА АСТРОНОМИЈА, Математички факултет, Катедра за астрономију и астрофизику, изборни предмет на докторским студијама.

МЕЂУНАРОДНА САРАДЊА (ПОТПИСАНИ УГОВОРИ И ИНОСТРАНИ КОАУТОРИ У РАЗМАТРАНОМ ПЕРИОДУ)

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ACTIVITIES OF PARTICIPANTS OF THE PROJECT 146001 "INFLUENCE OF COLLISIONAL PROCESSES ON THE ASTROPHYSICAL PLASMA SPECTRA" WITHIN THE PERIOD FROM 2008 UP TO 2009

The brief review of activities on the project 146001 "Influence of collisional processes on the astrophysical plasma spectra", supported by the Ministry of Science and Technological development from 1st January 2008 up to 31st December 2009 is given. Besides the bibliography of scientific results, other activities of the project participants, such as textbooks, activities in literature, editing, organization of scientific conferences, pedagogical work etc. are presented.

Зборник радова конференције "Развој астрономије код Срба VI"
Београд, 22-26. април 2010,
уредник М. С. Димитријевић
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"ТЕОРИЈА СВЕГА" БЕНЏАМИНА ЛЕЗБИОСА

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Резиме: Бенџамин Лезбиос или Бенџамин са Лезбоса био је учени монах грчког просветитељства, који је живео у време А. Кораиса, Т. Каириса и Е. Вулгариса. Био је под очигледним утицајем духа западноевропског просветитељства, па су га званичници православне цркве оптужили да учи новим знањима о природи и свету. Био је значајни филозофски мислилац грчког просветитељства и формулисао је пионирску унифицирајућу теорију природе – Пантахекинетон. У овоме раду описан је његов живот, дела и теорија коју је формулисао.



Слика 1: *Бенџамин Лезбиос*.

1. ЕЛЕМЕНТИ БИОГРАФИЈЕ

Млађи савременик Руђера Бошковића, Бенџамин Лезбиос, као и наш велики научник формулисао је једну унифицирану „теорију свега", што пружа могућности за различита упоређивања и паралеле. Рођен је у старом Пломарију, на острву Лезбос, 1759, или 1762. године. Био је син Амирисе и Јоаниса Георгантиса или Георгантелиса или Кареа. Крштено име му је вероватно било Василије и основно образовање је добио у своме селу. Када је имао 17 година, дошао је на Атос и закалуђерио се у манастиру Пантократор; тада је добио име свога ујака Бенџамина.

Године 1779, млади Бенџамин је послан у манастир Агиос Николаос (Св. Никола) у Кидониесу (данас Ајвалик у Турској), где је био његов ујак Бенџамин (Argyropoulou, 1983: 47). Онде је похађао лекције у цветајућој школи Иоаниса Економоса (Димитракелис) око годину дана, а пошто је постао ђакон и онда свештеник, Економос га је подстакао да оде на острво Патмос да настави са учењем. Онде је остао до 1786; следеће три године похађао је тада чувену Хиоску школу (1786-1789), где је међу осталим учитељима био Атанасиос Париос а ту је постао и пријатељ Доротеоса Пројоса, касније владике (ΕΕΕ, 1983: 239).

Још увек млад, отац Бенџамин се вратио у Ајвалик 1789, или 1790; ту је извесно време предавао у Економосовој школи. Јоанис Економос, посредовао је да за свога бившег ученика обезбеди финансијску помоћ од богатих чланова локалног друштва да би га послао на даље студије у Европу. Године 1790, уписао се, на препоруку Пројоса, на Универзитет у Пизи а затим на Екол Политекник у Паризу, где му је између осталих предавао Антоан-Лоран Лавоазје (Argyropoulou, 1983: 49). Упоредо са основним студијама природних наука и филозофије, Бенџамин је проучавао дела представника европског просветитељства. Пошто је у Паризу остао неколико година, ушао је у кругове учених Грка у дијаспори и упознао се са Адамантиосом Кораисом. Бенџамин је почео да пише чланке за часопис *Логиос Хермес*. Пошто је завршио циклус студија у Паризу, 1798. одлази на око годину дана у Енглеску, на чувену Гриничку опсерваторију, где је видео телескоп Виљема Хершела (Valetas, G., 1974: 280).

Године 1799, Бенџамин је одбио предлог да предаје на Хиоској школи Атанасиоса Париоса; вратио се у Кидониес (Ајвалик) и тамо почео да предаје у школи, која је 1803. реорганизована и названа „Академија Кидониеса“. Бенџамин је предавао филозофију (етику и метафизику), алгебру, геометрију, физику и астрономију, а нарочито у физици, наставу је допуњавао извођењем експеримената (ΕΕΕ, 1983: 239). Кораис из Париза га је снабдевао делом неопходних експерименталних уређаја и одговарајућих приручника. Предавао је на основу бележака и следећи тадашње педагошке методе, са честом употребом наставних помагала и експеримената. Његова предавања доприносила су ширењу славе Академије као високе наставне институције, где су долазили многи студенти са Балкана, чији је број премашивао шест стотина.

Садржај и методи ових предавања изазвали су реакције, које су, оснажене личним антагонизмом нарочито Атанасиоса Париоса, довеле до оптужби против Бенџамина у Васељенској Патријаршији у Константинопољу и од стране Патријарха Калиника IV.

Оптужбе су биле да Бенџамин предаје i) да се Земља креће а Сунце стоји непомично, ii) да су небеска тела настањена другим бићима и iii) да је Сунце тамно и осветљено рефлексијом.

Године 1803, Бенџамина је Синод Васељенске Патријаршије осудио *in absentia* да се одрекне својих теорија (Argyropoulou 1983: 59). Услед

интервенције утицајних пријатеља − међу осталима ефеског владике Дионисија Калиархеса, те фанариотског хегемона Александроса Мурузиса и његовог брата Деметриоса − осуда Патријаршије никада није спроведена. Коначно, Бенџамин Лезбиос је уз подршку својих студената и средње класе у Кидониесу (Ајвалику), наставио да држи наставу на Академији до 1812 (Valetas, 1974: 283). Ипак, од 1808. је изражавао жељу да да оставку и напусти град, због непрестане реакције конзервативних кругова и проблема у раду школе који су настајали услед тога.

Године 1812. Бенџамин Лезбиос је позван да води ништа мање него Школу Патријаршије у Константинопољу (Истамбулу)! Одбио је ову понуду одлучивши да се настани на родном острву Лезбосу и ту оснује сопствену школу (ЕЕЕ, 1983: 239). Упркос подршци острвљана и неколико његових студената из Кидониеса, планови нису успели па је одлучио да оде у Истамбул. Ту му је понудио гостопримство лекар Георгиос Десилас, у чијој је кући радио као приватни учитељ. У то време је позиван као предавач у Куручесмеу и у школи у Атини, коју је управо основало «Друштво Филомусос» (Argyropoulou, 1983: 64-68). Пошто је одбио ове предлоге, Бенџамин је 1817. прихватио позив владара Влашке Јоаниса Карацаса да реорганизује Академију у Букурешту. У овом послу за сарадника је нашао Александра Маврокордатоса, владаревог нећака (ЕЕЕ, 1983: 239). Рад му је био ускоро прекинут, после пада Карацаса у септембру 1818, Бенџамин одлази у Јаши. У Молдавији ће остати следеће две године, под заштитом владара Александра Калимахиса и у току тог периода постаће члан «Филики Хетерије» (Друштва пријатеља), тајне организације за ослобођење Грчке (Valetas, 1974: 288). Од тада па надаље, Бенџаминов наставнички рад биће комбинован са напорима за ослобођење Грчке од отоманске власти.

У овом контексту, Бенџамин Лезбиос се нашао септембра 1820. у Смирни (Измиру), где предаје у „Јеванђеоској“ (‘Евангелики’) школи за више образовање, док у исто време делује као локални повереник Филики Хетерије (ЕЕЕ, 1983: 239). Након избијања грчког Рата за независност прелази у Ајвалик да би, заједно са Папафлесасом, набавио муницију за борбу против отоманске власти. У лето 1821, путује на грчко копно преко острва Псаре, Хидре и Спецеса и настањује се на Пелопонезу. Ту учествује у раду Прве Народне скупштине у Епидаурусу (Децембар 1821), као један од 20 представника пелопонеског Сената, где политички подржава старог сарадника Александра Маврокордатоса. Године 1822, као члан Егејске комисије, Бенџамин обилази грчка острва организујући отпор, а у исто време сакупља новац за финансирање борбе. На Другој Народној скупштини у Астросу (Март-Април 1823) Бенџамин је изабран у деветочлану комисију за израду нацрта привременог Кривичног закона, а следеће године учествује у плановима за стварање више школе у Аргосу (ЕЕЕ, 1983: 239). Активност му је прекинута у септембру 1824, када у Науплиону на Пелопонезу умире од тифуса.

2. ДЕЛА БЕНЏАМИНА СА ЛЕЗБОСА

Дела Бенџамина Лезбиоса могу се разврстати у три главне групе: А) Филозофски радови. Б) Радови из физике и астрономије. В) Математички радови (Houzaios, G. M., 2009, 7). Детаљније:

А) Филозофска дела

1. *Apologia […] pros tas sykofantias tou neou philosophou* (Извињење због клеветања новог филозофа), без датума, 1-12

2. *Stoicheia ethikis* (*Елементи моралне филозофије*). У почетку необјављено, публиковано је post mortem са уводом и коментарима Р. Аргиропулоса, Центар за модерна грчка истраживања, Национална фондација за истраживања, Атина 1994, 1-302.

3. *Stoicheia tis metaphysikis* (*Елементи метафизике*). Беч, Аустрија, објавио Johannes Schneirer, 1820, 1-471.

Б) Дела из физике и астрономије

1. *Physiki*, објављено post mortem заједно са…
2. *Meteorologika* и *Astronomia*. 1 Лицеј у Волосу, 1991.

В) Математичка дела

1. *Stoicheia arithmitikis* (*Елементи аритметике*), том I, Беч, Аустрија, објавио Johannes Schneirer, 1818, стр. xiv + 197.

2. *Geometrias Euclidou Stoicheia* (*Елементи Еуклидове геометрије*), том II, Беч, Аустрија, објавио Johannes Schneirer, 1820, 1-255.

3. *Stoicheia Algebras* (*Елементи алгебре*). Необјављено.

4. *Trigonometria* (*Тригонометрија*). Необјављено.

Бенџамин Лезбиос је писао углавном уџбенике за предмете које је предавао у Кидониесу (Ајвалику). У све три претходне групе присутне су филозофске и научне теорије просветитељства, под лупом његовог личног критичког прилаза. Што се тиче Бенџаминовог општег погледа на филозофију и науку, у математици види основу чак и емпиријске науке и полазну тачку за филозофску мисао; природну филозофију сматра продужетком метафизике и укључује у њу, између осталог, хемију, астрономију и космологију. Језик који користи је уобичајени говорни облик грчког, али не оклева да уведе свој сопствени систем интерпункције и да се врати старом грчком да би изразио научне термине. Због оваквих иновација, био је оптужен да је „неписмени филозоф“ (Argyropoulou, 1983:55).

3. ПАНТАХЕКИНЕТОН ТЕОРИЈА

Садржај Бенџаминових рукописа пажљиво је проучавао физичар др Антонис Н. Андриотис, главни истраживач у Фондацији за истраживање и технологију, који је написао књигу на ову тему, неку врсту коментара под насловом: ***„Пантахекинетон“ теорија Бенџамина са Лезбоса: Од картезијанског етера до универзалности и дуалности феномена преноса енергије*** (2009).

Али зашто „од картезијанског“? Интерес за проучавање природе поново се рађа после италијанске ренессансе; полет му даје развој експерименталних наука у 16. и 17. веку. Први велики филозоф, следбеник ове еволуције, био је Рене Декарт или Cartesius (René Descartes, 1596-1650). Две основице његове филозофије, како је описао у своме делу *Расправа о методи* (*Discours de la méthode*, 1637), су: сумња и логичка мисао. Није хтео да се ослања на божанско откровење, али истовремено није прихватао без оклевања оно што нам нуде чула; то је оно што га је вероватно довело до чувене изреке: ‘cogito ergo sum’.

Овде треба поменути разлику коју је Хајзенберг правио између пресократовских филозофа и Декарта:

1. Пресократовци су тражили основну суштину или први принцип из кога је настао (и вероватно још настаје) Универзум; сви су полазили од онтолошког проблема.

2. За Декарта, основно је потрага за фундаменталним знањем. *Cogito* је чиста категорија природе знања.

Ипак, мало је погрешно рећи да је Декарт, својим новим филозофским методом, дао други правац људској мисли. Његов првенствени допринос теоријским и експерименталним наукама (упркос свим грешкама и домишљањима, као што је разлика између *res cogitans* и *res extensa*, што обележава ову филозофију), према Хајзенбергу је, што је омогућио физичарима да описују свет без помињања Бога или Ега, напредак који је пружио велико поверење у науку. *Ускоро се показало да је ова основа била готово неопходна општа претпоставка за све експерименталне науке.*

Представимо сада *Пантахекинетон* теорију. Бенџамин одбацује Њутнов закон [универзалне] гравитације и уводи појам ‘*пантахекинетона’*, флуидног субстратума који се слободно креће у свим правцима и узрок је свих природних и духовних појава (Valetas, 1974: 282). Према С. Куманудису (1988): “*пантахекинетон, извесни флуид, постоји у природи према Бенџамину Лезбиосу и стимулише чула и осећања”*.

Можда је Бенџаминов најважнији цитат: “*Пантахекинетон је флуид који непрекидно тече од једног тела ка другом, а његов долазећи и одлазећи флукс је пропорционалан запремини тела”* (*Physics*, §6). У следећем пасажу пише, (*Physics*, §64): “*Тако сам овом флуиду дао назив Пантахекинетон; и његово постојање може бити само пука хипотеза, ипак од сада ће сва*

пракса физике бити да докаже његово постојање и својства" (Andriotis 2009, p. 45). На основу Бенџаминових идеја у *Физици* и *Елементима метафизике* може се закључити да је *пантахекинетон* смело предложен као узрок свих појава у природи и души. Етимологија појма настаје од речи *пантахе* = свугде и *кинетон* = кретање (*Dictionary of Greek language*, Papyros ed., Athens, 2008).

Да ли је то метафизика? Они који су проучавали дело Бенџамина Лезбиоса − најзначајнија публикација о овој теми остаје докторска дисертација Роксане Аргиропулу, 1983 – сматрају да без обзира на исправност оригиналне теорије, његов космолошки модел је пре заснован на физици него на метафизици. Као што је сам Бенџамин изјавио, он је тако радио пошто му „природна радозналост" није дозвољавала да се заустави на резултатима, него га је '*вукла да трага за узроцима'*.

Проучавајући рукописе обе књиге Бенџаминове *Физике*, који се у добрим условима чувају у Лејмон манастиру, у Калонеу на Лезбосу, и у библиотеци клуба „Бенџамин Лезбијски" у Пломарију (који их је објавио као фототипско издање), Андриотис (2009) је издвојио и претставио главне тачке *пантахекинетон* теорије у своме раду. После тридесет година истраживања и проучавања, он карактерише *пантахекинетон* као «етеру сличан елемент» са особинама које омогућују квалитативни прилаз за већину области у физици познатих у време када се Лезбиос бавио наставом.

Пантахекинетон теорија може се применити на готово све основне појаве и величине у физици, насупрот теоријама које су тада преовладавале.

Основно истраживање др Андриотиса било је да установи да ли постоје било који елементи *пантахекинетон* теорије који су се задржали у модерној физици, што би оправдало дубљу студију ове области; Андриотис сматра да је ова теорија важан градивни елемент у развоју научног знања.

Пређашњи професор астрономије Д. Коцакис (1940) сматрао је да је *пантахекинетон* теорија 'несретна'. Ипак, према Андриотису (2009), Бенџамин предлаже побољшања старих теорија и истовремено даје нове идеје, у поступку који потсећа на начин како се то ради у модерним расправама и прегледним чланцима, у којима се предлагане теорије систематично, тачку по тачку упоређују са одговарајућим претходним.

Дубоко разумевање *пантахекинетон* теорије захтева пажљиву анализу Бенџаминових аргумената и њихово упоређивање са доминирајућим теоријама у то доба.

Андриотис је проучавао двотомно Бенџаминово дело *Физика*, које се састоји од 1450 параграфа и 758 страница, спасио га, пошто га је преписао, и пошто га је проучио сматра да је исто тако лако за читање као *Астрономија* Т. Каириса (Mavrommatis 1989).

Садржај Бенџаминове *Физике* је двострук: i) То је уџбеник и енциклопедија физике, од античких времена до његовог доба. ii) Она представља *пантахекинетон* теорију, унифицирани модел за представљање различитих природних појава.

Пажљиво проучавање Бенџаминовог дела показује да он није био пуки преводилац западних идеја у физици; имао је слободан и пионирски дух. Према њему, Бог није од исте ‘грађе’ (синаидос) као материја, него је Створитељ материје *ex nihilo* (Kavarnos, 1964). Бог је свемогућ (*пантодинамос*) а не ‘велике моћи’ (*мегалодинамос*); људска душа је субстанца независна од тела и нема облик или *еидос* тела, како је писао Аристотел.

Бенџамин са Лезбоса стваралачки се уклапа у нови талас мишљења, који на западу резултује у чисто аксиоматском и апстрактном разматрању свега, али такође доприноси едукационим потребама свога народа.

Бенџамин не оклева да додирне сам садржај метафизичких исходишта. На основу *пантахекинетон теорије*, покушава да објасни ‘зао поглед’ и разне друге феномене помешано духовне и телесне природе; али пре свега настоји да научи о ствараоцу објеката, Богу: *“Али пошто знање духовне природе захтева знање ствараоца бића, односно Бога, очигледно је да је неопходно учити о Богу* (тема коју додирује у *Physiki Theologia = Телогија Природе*, то јест метафизика).

Као што је Андриотис (2009) писао о *пантахекинетон* теорији, читајући Бенџаминову *Физику* постаје очигледно да је то добро урађен физички модел са консолидованом унутрашњом структуром и савршеном самоусаглашеношћу. Шта више, *пантахекинетон* теорија може да пружи одговоре на експерименталне резултате оног доба. *Пантахекинетон* теорија покушава да објасни природне појаве заједно са неким метафизичким на сличан начин, пошто су за њега психички феномени *епекеина* (продужетак) природних појава. Андриотис карактерише овај модел као «семи-космолошки».

Бенџамин помиње погледе античких пресократовских грчких филозофа, мада подржава хелиоцентрички систем. Проблем настаје са новим физичким астрономским идејама и језиком који користи. Због тога је називан ‘неписмени и безбожник’, пошто је доводио у сумњу библијску космологију, па је на крају био присиљен да напусти Ајвалик.

У истом временском периоду када и Бенџамин, физику су у Грчкој предавали Евгеније Вулгарис, Атанасије Псалидас, Нићифор Теотокис, Сергије Макреос, Константин Кумас, Константин Вардалахос, Димитрије Дарварис и његов ученик Теофил Каирис; другим речима, у Грчкој у отоманском ропству, постојао је низ „просветитеља“.

4. ТЕОРИЈЕ О ЕТЕРУ

Пантахекинетон по својој природи има карактер сличан етеру, мада се описује као нешто есенцијалније. Бенџамин наводи теорије о преносу енергије помоћу таласа, гравитације, магнетизма, електрицитета, светлости, топлоте и звука, да би лоцирао њихове слабе тачке, које остављају место за развој савршенијег или фундаменталнијег новог предлога за описивање ових појава.

Бенџамин са Лезбоса увек прво наводи тадашње погледе и теорије, онда их коментарише и на крају даје сопствено објашњење засновано на *пантахекинетон* хипотези, када је могуће.

Дакле Бенџаминова *Физика* је истовремено јасна и конзистентна презентација прихваћених модела у физици његовог доба, као и модела који су доминирали у прошлости, на пример у антици.

5. СУКОБ ИЗМЕЂУ ДВЕ „ШКОЛЕ“

Бенџаминов рад у физици одражава сукоб између две школе мишљења:

1. Њутнове, која прихвата деловање сила на даљину.
2. Картезијанске, која сматра да је потребан утицај медијума (као што је етар) да би сила деловала; ова школа уводи механицистичке моделе да би то објаснила.

У том контексту, *пантахекинетон* се јавља као сложени медијум са мултифункционалним особинама; он посредује у преносу гравитационог и електромагнетног међудејства, у преносу надражаја преко неурона и утиче на простирање светлости.

Полазећи од таласне природе простирања светлости, Бенџамин са Лезбоса, на основу погледа Роберта Бојла (који сматра да је светлост лонгитудинални талас у етеру, као звук у ваздуху), изражава мишљење да је *пантахекинетон* носиоц звука.

Андриотис (2009) повезује Бенџаминове погледе са научним знањем у физици његовог доба, са модерним унификационим теоријама Двадесетог века, као и са питагорејским теоријама о ‘*олкос* сфери’, аристотелијанском теоријом о етеру и картезијанском теоријом о вртложном кретању.

У четвртом поглављу *Физике* Бенџамин пише о гравитацији, критикујући Њутнове ставове. Износи своје гледиште да је гравитација резултат притиска фине, невидљиве супстанце, док је у контексту *пантахекинетон* теорије појам „односити са“ употребљен за објашњење гравитације и електричних и магнетних сила.

Бенџамин наставља са појмом „тежине“ у *пантахекинетон* теорији, називајући «куфа» тела која немају «тенденцију» да гравитирају.

У параграфу 93 *Физике*, помиње се инерција, која се, мада пропорционална маси, разликује од гравитације, пошто делује у сваком правцу.

Затим следе теорије о магнетном (магнетизму) и електричном (електрицитету) флуиду. Андреотис напомиње да је појам «истицања» електричног флуида последица његове идентификације са *пантахе-кинетоном*.

У студији Андриотиса (2009), поменуто је неколико великих природњака 18. века и старијих, као што су Декарт, Хајгенс, Њутн, Оле Ремер, Снелијус, Роберт Хук, астроном Бредли, Јунг, астроном Халеј (кога Бенџамин зове Алијус) Жан Антоан Ноле (кога зове „Докса Нолету“, т.ј. „Слава Нолета“),

Бенџамин Франклин (помињан као „Слава Франклија“), итд., а њихови погледи су упоређени са Бенџаминовим.

Према Бенџаминовом рукопису, после теорије звука, у одељку о „термогоно“ (топлоти), помиње се термин *„дијахорезис“*. Може се закључити да *дијахорезис* значи топлотни капацитет, а *‘красис’* температура (*термо-красиа* на модерном грчком). Затим у рукопису следи теорија светлости, где се помиње Касинијев резултат о растојању од осам светлосних минута између Сунца и Земље. Бенџамин ту даје и објашњење поларне светлости помоћу *пантахекинетон* теорије.

У петом поглављу је приказано гравитационо привлачење у светлу *пантахекинетон* теорије: *“Дакле, с обзиром на постојање пантахекинетона, овде је дато како гравитационе појаве треба да буду објашњене.”*

Постоје и одељци са насловима: *Моћ одржавања на површини и пантахекинетон, Инерција и пантахекинетон, Структура материје и пантахекинетон, Однос магнетног флуида (магнетизма) и пантахекинетона*. А увек следе и друкчији погледи: *Теорије Декарта и Халеја о Земљином магнетном пољу*.

У магнетној теорији, Бенџамин са Лезбоса прво доказује да се, према пантахекинетон теорији, Земља понаша као џиновски магнет, па је њено магнетно поље (геомагнетно поље) као код обичног магнета: *“Како се чини, Декартова хипотеза је хипотеза траженог. Пошто је питање шта је магнет, а Декарт је претпоставио да је Земља магнет.”* (*Физика*, §574).

Андриотис (2009) напомиње да описана интеракција између два обична портабл магнета има заједничке црте са Бенџаминовим објашњењем гравитационог привлачења (*Физика*, §65). Механизам привлачења је истоветан.

Коначно, Бенџамин пише о статичкој густини пантахекинетона и његовом току. После много година, налазимо да је «флукс поља» природна величина, која се односина интензитет поља (Гаусов закон). Према Бенџамину са Лезбоса «термогоно» (топлота) нити је матерјална супстанца (као што се распростањено сматрало у његово доба), нити појава; то је «флуид» исте природе као сунчеви зраци (*Физика*, §980). О ватри, топлоти и светлости пише: *“Ватра и топлота се не налазе у порама тела него у њиховим молекулима”* (§987). А осим тога:

“*… како нас чула обавештавају, сунчеви зраци нису ништа друго него топлота*” (*Физика*, §1019).

У оквиру *пантахекинетон* теорије, дат је и поступак одбијања светлости: “*Долази до диференцијације између сунчевог и земаљског флуида*” (*Физика*, §1316).

6. ЗАКЉУЧАК

Андриотис (2009) саопштава у епилогу (стр. 182): *"Добијени закључци ми дозвољавају да опишем пантахекинетон теорију као веома мудру и плодоносну комбинацију погледа на свет Картезијанске и Њутнове школе. Пантахекинетон теорија укључује многе оригиналне елементе, што уздиже Бенџамина са Лезбоса у статус оца концепта дуалне природе светлости и енергије (талас-честица), и унифицираног описа природних појава."*

Пантахекинетон теорија је заснована на дубоком разумевању познатих експерименталних провера својстава гравитације, електрицитета, магнетизма, оптичких појава, топлоте и звука. Не избегавајући указивање на озбиљне недостатке ове теорије, закључујемо заједно са Андриотисом да је „ингениозан предлог" Бенџамина Лезбиоса довољан да га идентификујемо као веома важну особу за историју покушаја унифицираног описа природе, што се данас често назива потрага за „теоријом свега".

Литература

***: 2008, *Lexiko tis ellinikis glossis*, Papyros publ., Athens [in Greek].

Andriotis, Antonios: 2009, *The theory of "Pantachekineton" of Benjamin Lesvios: From the ether of the Cartesians to universality and duality of the phenomena of energy transfer*, published by the author, Irakleio [in Greek].

Argyropoulou, Roxanne: 1983, *Benjamin Lesvios and the European thought of 18th century*, Ph.D. dissertation, Institute of Modern Greek Studies of the National Research Foundation (E.I.E.) (reprinted in 2003) [in Greek].

Descartes, René: 1637, *Discours de la méthode*, Laurence J. Lafleur trans.: *Discourse on Method and Meditations*. New York: The Liberal Arts Press, 1960.

EEE: 1983, *Ekpaideftiki Elliniki Enkyklopedia– Pagosmio Viografiko Lexiko (Greek Educational Encyclopedia – World Biographical Dictionary)*, Ekdotiki Athinon, vol. 2, Athens [in Greek].

Houzaios, G.M.: 2009, *Benjamin Lesvios and Contemporary Physics*, reprint from the 20th volume of the journal *Lesviakà* of the Society of Lesbian Studies, Mytilene [in Greek].

Kavarnos, K.P.: 1964, *Symbols and indications of immortal life*. Astir publ., Athens [in Greek].

Kitromilidis, Paschalis: 1999, *Modern Greek Enlightenment – The political and social ideas*, Morfotiko Idrima Ethnikis Trapezis (MIET), Athens [in Greek].

Kotsakis, Dimitrios: 1940, *The study of Astronomy in Greece during the 18th century*, published by the author [in Greek].

Koumanoudis, Stefanos: 1998, *Compilation of New Words – invented by scholars from the fall of Constantinople up to this day.* Series: Modern Greek studies; series supervisor: F. Iliou. Hermes publ., Athens [in Greek].

Mavrommatis, Konstantinos: 1989, *The Astronomy of Theophilos Kairis*. 1st Volos High School edition, Thessaloniki [in Greek].

Valetas, G.: 1974, "The persecutions against Benjamin and his turbulent struggle to enlighten the nation", *Aeolika Grammata* 4, p. 283-288. Kallithea [in Greek].

“THE THEORY OF EVERYTHING” OF BENJAMIN LESBIOS

Benjamin Lesbios or Benjamin of Lesbos was a scholar monk of Greek enlightenment, who lived in the age of A. Korais, Th. Kairis and E. Voulgaris. Clearly influenced by the spirit of Western European enlightenment, Benjamin was accused by Orthodox Church officials for teaching the new natural world knowledge. He was an important philosophical mind of Greek enlightenment and he introduced the *Pantachekineton*, a pioneering unifying natural theory.

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ДРЕВНЕ ПИРАМИДЕ У ГРЧКОЈ

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Резиме: Пирамиде, „Змајеве куће" ('Дракоспита') и мегалитске структуре уопште, увек су побуђивале посебно интересовање. Претпостављамо да су, као што је случај са „змајевим кућама" на Еубеји, пирамиде сличне структуре у Арголиди (источни Пелопонес) вероватно саградили Дриопси, пошто је познато да је овај прехеленски народ, осим Еубеје и неких Кикладских острва, настањивао и Арголиду, где је основао град Азине. Такође претпотављамо да су пирамиде у Арголиди, а посебно пирамида у селу Хеленикон, могле да буду не само надгробни споменици или стражаре, него и да служе за астрономска посматрања.

1. УВОД

Постојање пирамида, односно пирамидама сличних грађевина у Грчкој није широко познато, пошто већина људи, па и научника, знају само за египатске пирамиде.

Ипак, у јужној Грчкој постоји неколико античких грађевина сличних пирамидама, од којих је најимпресивнија структура близу села Хеленикон у Арголиди (источни Пелопонез).

Неке од ових грађевина имају значајна и непоправљива оштећења, пошто је њихово велико камење вековима коришћено као сиров матерјал за друге грађевине, као што су цркве, или чак за производњу креча у кречанама.

У литератури се у Грчкој помињу следеће пирамиде (Lazos, 1995):

Табела I

ИМЕ	МЕСТО	Примедбе
1. Хеленикон (Helli-nikon)	Хеленикон и Кефалари	Најбоље очувана
2. Лигурио (Ligourio)	Епидаурус	Постоји само њена основица
3. Даламанара (Dala-manara)	Епидаурус	Постоје само трагови
4. Камбиа (Kambia) = кула за сигнализацију ватром	Неа Епидаурус	Очувана до неке висине
5. Сикион (Sikyon) (?)	Коринтија (?)	Постоје само трагови (?)
6. Виглафија (Viglafia)	Неаполи (Лаконија)	Постоји само њена основица
7. Амфио (Amfio)	Близу Тебе	степената

Поврх тога, постоје две друге структуре, о којима се извештавало као о пирамидама сличним грађевинама: Купаста пирамида у Ханији (Крит) и стеновита пирамида која чини врх планине Тајгет; ипак последња је само природни планински врх, највиши на Пелопонезу (2407 м). Проф. И. Лиридзис (Liritzis 1995,1997) подржава мишљење да постоји преко 20 старих пирамида у Грчкој; што се односи на пирамидама сличне структуре у Астросу (у Кинурији, јужно од Арголиде), у Неохорију у Фтиотиди, у Агиос Андреасу на Парнасу, у Ватију (код Аулиса у северној Беотији), и на другим местима..

Од свих поменутих структура, само је пирамида у Хеленикону, на југоисточном рубу Аргоске равннице, очувана у релативно добром стању. За неке од таквих структура, подаци коришћени у овом раду узети су из описа и података старих путника, као што су на пример запажања и коментари Паузанија (1985) о пирамиди у Хеленикону, или страних путника из 19. века (Blouet, Ravoisié 1831, Curtius 1851).

2. ПОДАЦИ, СТУДИЈЕ И ИСКОПАВАЊА

Мада се пирамидама сличне грађевине у Арголиди истичу својим изгледом и обликом, подаци о њима, су чак и у античким грчким изворима прилично оскудни. Пирамиду у Хеленикону помиње само Паузанија, у свом делу *Corinthiaka* (1985, 2, 25, 7), писаном у другом веку:

"Путујући из Аргоса у област Епидауруса, са десна је грађевина која веома подсећа на пирамиду, на којој су рељефно уклесани штитови, који су по облику Арголидски. На овом месту се водила битка за престо између

Претуса (Proetus) и Акризија (Acrisius) и кажу да се битка окончала без победника; зато су се касније помирили, пошто ниједан није могао да постигне одлучујућу победу. Речено је да је то било први пут да се сукобе људи и војске опремљени штитовима; за оне који су пали у битци из обе војске, пошто су били земљаци и чак рођаци, на овом месту је саграђен заједнички гроб."

Дакле, према Паузанију, пирамида је била заједнички гроб, који су највероватније саградили Претус и Акризије за војнике који су погинули у битци; битци у којој су војници по први пут користили штитове. Ови подаци о митским личностима (Претус, Акризије) индицирају да се сматрало да је грађевина веома стара.

Паузанија такође помиње (*Corinthiaka* 2, 24, 7) да се у суседним областима налазе *polyandria* (масовне гробнице), као на пример Аргиваца убијених у битци против Спартанаца која се одиграла 699. пре н.е. у Хисијама (Hysiae – акропољ близу модерног села Ахладокампа - Ahladocampos):

"А овде постоји полиандрија за Аргивце који су победили у битци против Лакедемоњана близу Хисија".

Видимо да антички аутор сматра „пирамиду" као један од оваквих надгробних споменика. Други истраживачи су сугерисали различите могуће намене (Lord, 1939, стр. 78-84).

Пирамиде нађене у Грчкој су једини случајеви пирамидалне архитектуре у ширем европском простору. Облик грађевина сличних пирамидама, њихова статика и архитектура, вероватно смештају неке од њих у пре Пелазгички период (Lazos 1987,1995). Ипак, у земљи богатој археолошким налазима, рушевине ових структура нису привукле интерес истраживача. Сходно томе, њихова истраживања готово да не постоје и услед недостатка одговарајућих сазнања окружује их вео мистерије. Још увек постоји могућност да неки податак буде откривен у старим византијским текстовима. Тренутно, после Паузаније, први следећи познати податак о «грчким пирамидама» је из прве половине 19. века. Вилијам Мартин Лик (William Martin Leake) обишао је Пелопонез 1806, када је Грчка још била под отоманском влашћу, и помиње пирамиду у Хеликону, коју је посетио 14. марта 1806, у својој књизи *Travels on the Moréa* (вол. II, стр. 340, 344). У њој даје и два цртежа, предњи изглед грађевине и изглед одозго.

Године 1829, Француска научна мисија у Мореји (Пелопонез) проучава две пирамиде (у Хеликону и Лигурију) и објављује резултате 1831 (у три тома Abel Blouet и Ravoisié, Amable: *Expedition Scientifique de Morée*, vol. II, 107).

Године 1901, Т. Виганд (Th. Wiegand) врши прелиминарна ископавања (прво 1901, стр. 241-246) пирамиде у Хеликону. Виганд је уклонио наслаге

са пода пирамиде, а први грчки научник који ју је проучавао био је археолог Апостолос С. Арванитопулос (Apostolos S. Arvanitopoulos), 1916 (стр.72-99). Он верује да споменик потиче из Микенског периода (1600 - 1100 пре н.е.), док археолог Кристос Цунтас (Christos Tsountas 1857-1934), оснивач грчке преисторијске археологије, сматра да потиче из 6. века пре н.е. (Tsountas 1893).

Следећа ископавања пирамиде у Хеленикону изводили су Р. Ерих (Ehrich) и Ен Хоскин-Ерих (Hoskin-Ehrich), из Америчке школе за Класичне студије и Археологију у Атини, августа 1937, док је у готово исто време Р. Скрентон (Scranton), 1938. године, ископавао пирамиду у Лигуријy. Луис Лорд, тада директор Америчке школе за Класичне судије у Атини, уредио је извештај (1938, стр. 481-527) о овим ископавањима заснован на закључцима три горе поменута археолога, а затим је наставио сам истраживања и открио у Арголиди неколико грађевина, углавном древних квадратних кула, највероватније *полиандрија* Паузаније (Lord, 1939, стр. 78-84). Међу налазима у пирамиди у Хеленикону били су велики питос, под дугог ходника и просторије, изрезбарена од поправки улазна врата и делови зида, наслаге од ранијих ископавања и нешто керамике из Протохеладик II периода (2800-2500 пре н.е.), такође основице просторије, као и наслаге са керамиком класичног периода, као што су лампе, кућне ствари, неколко грубих крхотина неутврђене старости и неколко римских лампи. Слој на поду је био између 20-60 см (Lord, 1938, стр. 508-538).

Луис Лорд сматра да пирамиде нису биле гробови зато што су се њихова врата отварала изнутра; а да нису ни куле за сигнализацију помоћу ватре, пошто се не налазе на уздигнутим местима са широким погледом. Лорд сматра да су то постаје у које се може сместити стража од неколико људи, која може да контролише пут ка Тегеји. Ипак, он наглашава да је необична конструкција слична пирамиди нешто што остаје необјашњено (1938). Није било разлога за изградњу структуре оваквог облика за такву намену, зато што би стражара са обичним зидом била уобичајена ствар за тако нешто. Шта би могла бити сврха овакве једноставне, пирамиди сличне конструкције? Лорд такође сматра да пирамида припада рано Хеленистичком периоду односно касном 4. веку пре н.е.

Изгледало је да се ова прича затвара са археолошке тачке гледишта, пошто су амерички археолози ваљано урадили посао. Немачки археолог С. Оперман (Oppermann), је објавивши публикацију о њима на немачком (1971, стр. 45-52), упознао шири германофонски аудиторијум са пирамидама у Хеленикону и Лигуријy, без додавања нових садржаја овој области са истраживачке тачке гледишта.

После око 15 година, појавио се истраживач и аутор Кристос Лазос (Christos Lazos), са два рада о грчким пирамидама (1984, 1987), и чланак Хелене Фракје (Helena Fracchia) са Универзитета у Торонту (1985, стр. 683-689). Године 1986, професор И. Лиридзис је објавио књигу *Archaeometry – Methods of dating in archaeology* (Археометрија – Методи за датирање у

археологији), а године 1994, грађевински инжењер В. Кациадрамис (Katsiadramis) извео је статичку студију две пирамиде (1994, стр. 9215-9236). Године 1994, појавио се чланак професора Јоаниса Лиридзиса и рад Theocharis *et al.* (1994, стр. 399-405), као и две књиге, археометричара Јоаниса Лиридзиса (1995) и К. Лазоса (1995), који су исцрпли ово истраживачко подручје са дескриптивне тачке гледишта. Коначно, професор Лиридзис је 1997 објавио чланак о мистерији ових пирамида а о томе је писао и професор Теодор Спиропулос (Spiropoulos 2003).

У ствари, прави истраживачки рад почео је под руководством археометричара професора Лиридзиса у његовој групи. Ка одређивању старости пирамида приступило се кроз пет потпројеката:

1) Геофизичко истраживање унутар и око две главне пирамиде у Хеленикону и Лигурију, где су ови споменици откривени (Theocharis *et. al*., 1997, стр. 593-618).

2) Резултатима првог тима усмеравана су археолошка ископавања која је изводио археолог А. Сампсон (Sampson 1996, стр. 56-61) и археолози из Археолошког музеја у Науплиону (Pikoulas, 1996, стр. 60-63; Piteros, 1995, стр. 11-13, и Piteros, 1998, стр. 344-394). Међу новим налазима били су основе просторија, керамика, класичног, хеленистичког, римског и ранохришћанског периода, као и протохеладског II у спољашњим основама пирамиде у Хеленикону, изнад темеља. Такође је изведена упоредна студија грађевинских радова (Liritzis, 1995,1997, стр. 32-34).

3) Утврђено је да се астрономска оријентација дугог улазног ходника поклапа са изласком Орионовог појаса у периоду око 2000-2400 пре н.е. (Liritzis, 1998, стр. 10-21).

4) Одређивање старости неких делова великих мегалитских блокова у зиду изведено је помоћу новог метода термолуминесцентног датирања стеновитих површина. Узорци су, због њихове чврстине и одсуства изложености Сунцу, узимани са унутрашњих додирних површина, тако што је одвајано неколико милиграма праха са комада у чврстом контакту. Седам узорака дали су опсег старости од око 2000-2500 пре н.е. (Liritzis, 1994a, стр. 603-604; 1994b, 361-366; Theocharis *et al*. 1994, 399-405), док су се за два одломка керамике, један из пирамиде у Хеленикону а други из оне у Лигурију, датирана помоћу ТЛ (Термолуминесценције) и ОСЛ (Оптички Стимулисане Луминесценције) добила времена сагласна по обе методе од 3000±250 пре н.е. за први и 660±200 пре н.е. за други (Liritzis *et al*., 1994, стр. 189-198). Нови метод за одређивање старости објавили су Liritzis, et al. (1997, стр. 479-496); Liritzis и Galloway (1999, стр. 361-368); Habermann (2000, стр. 847-851); Greilich et al. (2005, стр. 645-665); Morgenstein et al. (2003, стр. 503-518); Liritzis и Vafiadou (2005, стр. 25-38).

5) Пажљиво је размотрена митолошка генеалогија Арголиде. Она укључује Инакуса (Inachus) и потоп, као и његове потомке Претуса и Акризија, који су, се према античком путнику Паузанији (2. век) борили за

превласт и после нерешеног исхода подигли Хеленикон пирамиду можда око 2800 пре н. е. (Zangger, 1993; Liritzis и Raftopoulou, 1999, стр. 87-99).

3. УПОТРЕБА ПИРАМИДА

Као што је очигледно из његових текстова, у Паузанијино време (око 150. године) намена пирамида је била заборављена, те он пише шта народ каже о томе, помињући претпоставке да су то били надгробни споменици или мале војне постаје.

Конструкција ових грађевина, њихове димензије и нагиб, уз чињеницу да није било налаза повезаних са гробовима (као што су кости или мртвачки украси), води ка закључку да су ове конструкције пре биле мале утврде или посматрачнице (Kalleyia, 1995).

Неки археолози (Leake, 1846; Lord, 1938; Fracchia, 1985; Piteros, 1998) их, на основу структуре зида, смештају у 4, век пре н.е.; они сматрају да пирамиде индицирају везе између Египта и Аргоса, чија је традиција била ојачана мисијом 3000 аргивских плаћеника у Египту 349. пре н.е.

Ипак, чини се да грчке пирамиде немају везе са египатским (унутрашњи план, градња, нагиб, величина), мада су између народа југоисточног Медитерана постојали трговачки контакти, који су забележени још у време раног присуства Минојаца, Микењана и касније, током грчке колонизације на западу, у Малој Азији, истоку и Египту, нпр. Тел Кабри, Аварис, Мегидо итд. (Barbara и Wolf-Dietrich Neimeier, 1997, стр. 763-802).

Лик (Leake 1846, стр. 334-483), Фишер Виљем (Vischer Wilhelm 1857, стр. 325-328) и други, подржавају теорију о надгробним споменицима, коју одбацује Виганд (Wiegand 1901, стр. 241-246), који сматра да то не могу бити гробови, због малтера који се користио у њиховој градњи, материјала који по њему указује да је време градње 1. век пре н.е. Други истраживачи сматрају да малтер вероватно није употребљен у оригиналној градњи, него при каснијим конзерваторским радовима.

Египатске пирамиде су биле фараонски гробни споменици, али су такође служиле за астрономске сврхе. Кеопсова пирамида је била нека врста великог меридијанског инструмента, највећег који је икада направљен, а његов главни правац проласка био је према звезди која је означавала Северни пол у то време, Тубану или Alpha Draconis (α Dra).

Хелена Фракја (Fracchia 1985) сматра да су арголидске пирамиде подигнуте за одбрану тога краја, као утврђења уклопљена у велике фарме, како је сматрала на основу својих истраживања фарми у Атици..

Грађевински инжењер В. Кациадрамис (1994), после статичке студије грађевине у Хеленикону, извео је закључак да је ова конструкција у свом првобитном облику вероватно била зарубљена пирамида висока 3.60 м. Он сугерише да пирамида није никада завршена до свога пројектованог врха са камењем или кровом неке врсте, односно да није била математичка пирамида попут египатских. Он додаје да је облик зарубљене пирамиде ‘*веома стара традиција у Грчкој код службе боговима… …управо такав*

облик грађевине у Хеленикону био је намерно изабран, пошто повезује статичке и естетске захтеве са грчком традицијом служења боговима' (Katsiadramis, 1994). Он дакле сматра да је грађевина служила за култне потребе, по његовом схватању то је било светилиште без крова.

Пирамиде у Арголиди продужавају да привлаче интерес истраживача. Професор И. Лиридзис у својој књизи (1995) сматра да је узрок нестанка пирамида у Астросу, Сикиону и Виглафији, о којима извештавају страни путници у раном 19. веку, што је њихово мегалитско камење било коришћено као грађевински материјал за цркве, као и за прављење креча. К. Лазос, аутор који се специјализовао за истраживање и описивање дела античке грчке технологије, у књизи *Пирамиде Грчке* (1995), даје потпуни списак грчких конструкција сличних пирамидама.

Наш тим је посетио пирамиде у Хеленикону и Лигурију и фотографисао их; архитекта Марко Кациотис измерио је димензије Хеленикон пирамиде, која је најбоље очувана, и нацртао њен изглед одозго, из перспективе, као и пресек.

4. ПИРАМИДА У ХЕЛЕНИКОНУ

Пирамида у Хеленикону се налази 5 до 6 км од југоисточног руба Арголидске равнице, у правцу старог пута за Аркадију, између села Хеленикон и Кефалари, где се налазе извори реке Еразинос (данас Кефалари). То је најбоље очувана пирамида (Сл. 1).

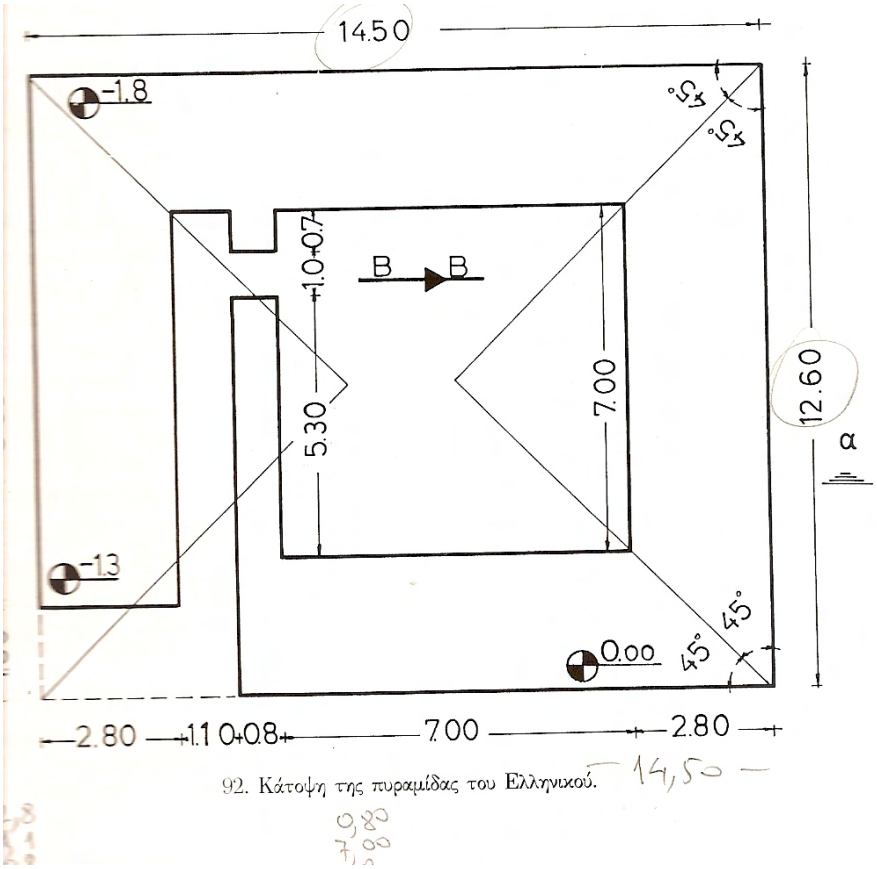
Димензије Хеленикон пирамиде су 14.50 × 12.60 × 10.80 × 10.60 м. Многи истраживачи су се питали да ли постоји нека веза са египатским пирамидама, на пример корелација у њиховом датирању. Традиционална археолошка истраживања, као што смо видели, смештају ове структуре у 4. век пре н. е., у много ближи период него египатске пирамиде. Ипак, археометријска мерења, заснована на оптичкој термолуминесценцији, која је извео И. Лиридзис у Лабораторији за Нуклеарно датирање Универзитета у Единбургу и у Археометријској лабораторији центра „Демокрит" (Theocharis и др. 1995) Показала су да је бар Хеленикон пирамида много старија и да је саграђена око 2700 пре н.е. Метод оптичке термолуминесценције је заснован на ласерској технологији и може бити примењен на камење из зидова; нажалост, овај метод, који Лиридзис користи од 1986, мада је теоријски прихваћен, у то време није био у потпуности калибрисан (1995) тако да се могу испољити резерве према оваквом датирању. Ако се сетимо Паузаније, који пише да је споменик саграђен у Микенском периоду, можемо претпоставити да би споменик могао бити саграђен негде у периоду 1600 -1100 пре н.е.



Слика 1: *Хеленикон пирамида.*

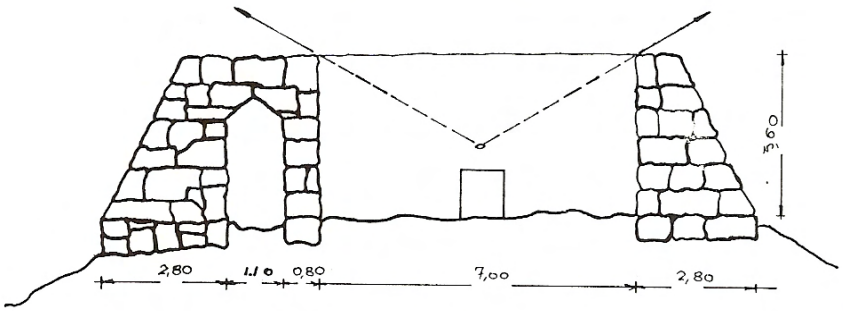


Слика 2: *Улаз у Хеленикон пирамиду са источне стране. Улаз је код југоисточног угла. Ширина му је 1.35 м, док се његов врх састоји од два конвергирајућа камена који чине велико грчко слово Λ.*

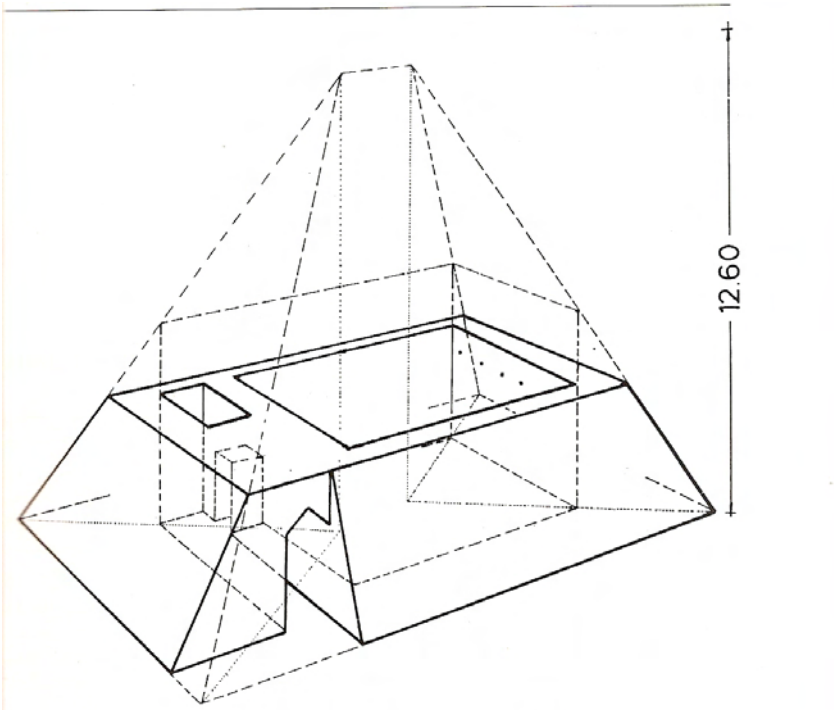


Слика 3: *Перспективни цртеж зарубљене пирамиде у Хеленикону који је начинио грађевински инжењер Василије Кациадрамис (Katsiadramis 1994, стр. 9222).*

Луис Лорд (1938) смешта Хеленикон и Лигурио пирамиду у почетак Хеленистичког периода, т.j. на крај 4. века пре н.е. Грчки археолози Е. Спатари, Хр. Питерос и Г. А. Пикулас су такође претпоставили (Chr. Piteros, 1995 и G.A. Pikoulas, 1996) да су обе пирамиде сграђене у касном 4. веку пре н.е. и да су биле стражаре или војничке постаје. Тх. Виганд (Wiegand 1901) смешта Хеленикон пирамиду у 1. век пре н.е. Ипак, ова датирања не треба да оснаже убеђење да су настале у каснијем периоду, пошто археолог и професор преисторијске археологије Универзитета у Атини Теодор Спиропулос (1981), који је открио пирамиду на Амфио брежуљку код Тебе, њу смешта у 2500. пре н.е.



94. Τομή α-α της πυραμίδας του Ελληνικού.



93. Προοπτικό της κόλουρης πυραμίδας του Ελληνικού.

Слике 4 и 5: *Цртежи зарубљене пирамиде у Хеленикону које је начинио грађевински инжењер Василије Кациадрамис (*Katsiadramis *1994, стр. 9222).*

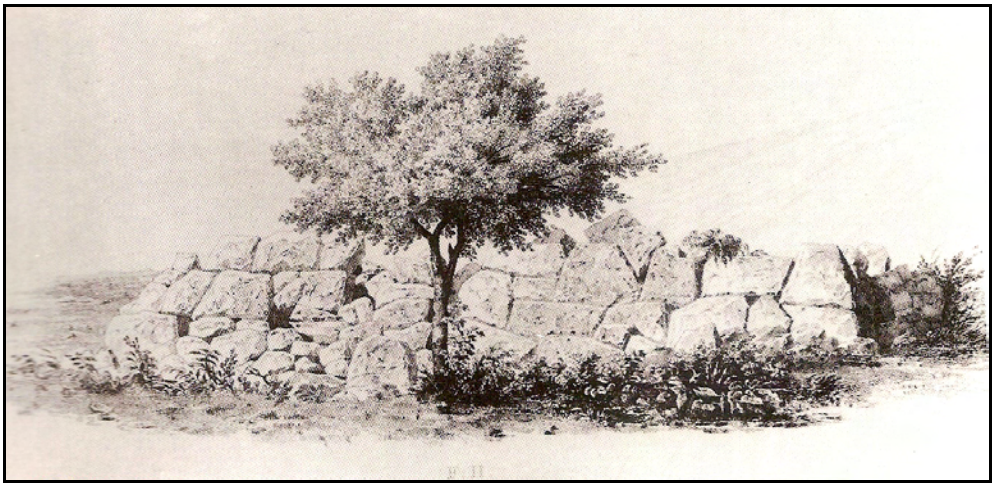
5. ПИРАМИДА У ЛИГУРИЈУ

Лигурио пирамида се налази у подножју планине Арахнео са леве стране пута који води из Аргоса у Епидаурус, 1,5 км западно од села Лигурио. Њене димензије су приближно 14 (северна страна) × 12 × 12 × 12 м. Паузанија не помиње ову пирамиду и први запис о њој сачинила је „Француска научна мисија у Морeји“ (Blouet, Ravoisié 1831). У годинама које су прошле од раног 19. века, стање пирамиде начињене од блокова пешчара се погоршало до таквог степена, да је данас готово сравњена са земљом. Само пар каменова је остао у оригиналном положају; остатак је искоришћен за зидање других грађевина у Лигурију, док су неки каменови уграђени у византијску цркву Агија Марина.

Прва ископавања у области извела је Америчка школа за класичне студије из Атине, од 9. до 18. децембра 1936, и касније од 1. до 9. августа 1937.

Међу налазима у току ископавања из 1937, која је водио Р. Скрентон (Scranton 1938, стр. 528-538), била је камена секира (*келтис*) која потиче из неолита, односно направљена је раније од 3000. пре н.е., веома интригирајућа чињеница која је побудила одређене конотације. Скрентон пише да је “*келтис изоловани преисторијски артефакт, који не доказује постојање неолитског насеља на овом месту. Вероватно је овде донет са удаљеног места као нешто занимљиво*”.

Ипак, неки истраживачи су скептични што се тиче овог закључка: Како је могуће да је неолитска секира остала сачувана на неком месту 2500 година, да би била пренета као нешто занимљиво у Лигурио пирамиду у 4. веку пре н.е. и затим сачувана на новом месту даљих 2300 година?



Слика 6: *Лигурио пирамида како је нацртана током „Француске научне мисије у Морeји“ (Expedition Scientifique de Morée 1831).*

Без обзира на то, већина истраживача датира Лигурио пирамиду заједно са оном из Хеленикона око 4. века пре н.е.

Године 1995, академик Петрос Теохарис са сарадницима најавио је да метод оптичке термолуминесценције даје за старост Лигуријске пирамиде 4100 ± 600 година, односно да је изграђена око 2100 пре н.е. и да је око 600 година „млађа“ од Хеленикон пирамиде када се њена старост одреди истим методом, премда су обе пирамиде веома сличне. Исти истраживачи сматрају да су обе ове пирамиде биле нека врста астрономских опсерваторија!

Насупрот томе, археолог Христос Питерос, чувар антиквитета у Науплиону, подржава (1995) датирање пирамида у 4. век пре н.е. – дефинитивно не раније од 450. пре н.е. Што се тиче њихове намене, он сматра да су то биле утврђене постаје и војне осматрачнице. Питерос је посебно критичан у односу на Теохарисове погледе (Theocharis и др. 1995). Сматра да су њихови ставови погрешни (!), пошто одбацују усаглашено мишљење археолога на основу ‘недоказаног физичког метода примењеног у чисто археолошком предмету расправе’.

Археолошка ископавања указују несумњиво на класични или хеленистички период, док А. Симпсон (1996, стр. 56-61) подржава овакво млађе датирање, али је јасна и његова резерва да одбаци старије.

Сходно томе, до данас нема задовољавајућег објашњења разлога за грађење неколико пирамида мањих размера у Грчкој, њихове сврхе и избора таквог облика. Да сумирамо, следећа гледишта о грчким пирамидама су изнета:

a) Сврха

1. Споменик на масовној гробници – полиандриа (Паузанија, 2. век пре н.е.; Leake, 1846; Vischer, 1857)

2. „Ознака гроба“, која указује постојање гроба важне особе у близини (брежуљак), или чак испод њега (Arvanitopoulos, 1916).

3. Утврђена војна постаја – стражара (Lord 1938,1939; Wiegand 1901; Fracchia, 1985; Spathari, Piteros, Pikoulas 1995,1996).

4. Куле за сигнализацију ватром или димом (Curtius, 1851).

5. Астрономске опсерваторије – са очигледном астрономском оријентацијом (Theocharis et al., 1994 & 1997; Kalleyia, 1995; Theodossiou et al., 2002).

6. Светилишта (Katsiadramis, 1994).

b) Датирање

1. 1600. до 1100. пре н.е. (Паузанија, 2. век пре н.е.; Arvanitopoulos, 1916)

2. Шести век пре н.е. (Tsountas, 1893; Curtius, 1851)

3. Четврти век пре н.е. (Leake, 1846; Lord, 1938,1939; Fracchia, 1985; Spathari, Piteros, Pikoulas, 1995,1996)

4. Први век пре н.е. (Wiegand, 1901)

5. Око године 2100. пре н.е. за Лигурио и 2730 пре н.е. за Хеленикон пирамиду (Theocharis et al., 1994, 1997).

ЗАКЉУЧАК

Када су у раним 1900-тим вршена ископавања око грчких пирамида, нађени су делови грнчарије из 4. века пре н.е., и претпостављено је да су и пирамиде тада сграђене; односно око доба Александра Македонског. Недавно датирање кристала са унутрашњих површина пешчарских блокова помоћу термолуминесценције помера време грађења пирамида за два миленијума. За Хеленикон пирамиду то је 2730 пре н.е. а за Лигурио 2100 пре н.е. То значи да су грчке пирамиде биле грађене грубо речено у истом временском оквиру као и египатске (Hammond, 1997).

Зашто су стари Грци желели да граде мале пирамиде? Паузанија је у Другом веку писао да је пирамида у Хеленикону била обележје гробнице за мртве пале у братоубилачкој битци пре 4 000 година. До сада нико није поверовао у његову причу (Corliss, 1998).

Време грађења и сврха нису са извесношћу познати чак ни за две главне грчке пирамиде. Оно што се може рећи је да су зарубљене а не степенасте; осим тога, разликују се од египатских и по нагибу.

Археолози су претпоставили да Хеленикон пирамида не може да буде грађевина из трећег миленијума пре н.е.; требало би да је направљена бар после 2100. пре н.е. Овај закључак се може извести, пошто је приликом ископавања вршених за Атинску Академију у основама грађевине пронађен протохеленски јарак. Протохеленски период се завршава око 2100. пре н.е., па археолози закључују да је пирамида сграђена после тог времена.

Археолози међутим такође наглашавају да на месту пирамиде није откривен ни један фрагмент керамике из два периода која следе непосредно после протохеленског, односно из мезохеленског и микенског периода. Ако је пирамида заиста конструкција из трећег миленијума пре н.е., то би био јединствени случај.

Велика већина археолога сматра да су пирамиде грађевине из 4. века пре н.е.

Стручњаци се не слажу ни око намене ових грађевина. Наш тим подржава мишљење професора Теохариса и његових колега да грчке пирамиде могу да имају и астрономски значај, вероватно као додатак уз њихову намену за гробно обележје или војну постају. Можда су арголидске пирамиде, а нарочито пирамида у Хеленикону, биле не само гробна обележја или стражарски објекти, него и нека врста првих „меридијанских опсерваторија“ (Theodossiou et al., 2002).

У прилог оваквом гледишту је случај једне друге грчке мегалитске структуре, „Drakospito“ (= змајева кућа) на врху планине Охе, која је проучавана и показано је да има астрономску оријентацију према изласку

Сиријуса (Theodossiou et al. 2009). Неколико астрономских веза је нађено и у случају египатских пирамида.

За грчке пирамиде, питање остаје отворено. Сматрамо да би усаглашени напори археолога, историчара, астронома, архитеката и археометричара могли да доведу до задовољавајућих закључака о овим грађевинама и њиховој намени.

Захвалност

Ова студија је део истраживања на Универзитету у Атини, на Катедри за Астрофизику, Астрономију и Механику, и захвални смо Универзитету у Атини за финансијску подршку преко Специјалног рачуна за истраживачке пројекте. Рад је такође помогло Министарство за науку и технолошки развој Републике Србије у оквиру пројекта 1460022 *Историја и епистемологија природних наука*.

Литература

Arvanitopoulos, A. S.: 1916, "Research in Argolis during the year 1916", *Proceedings of the Archaeological Society of Athens* [in Greek].

Blouet, Abel and Ravoisié, Amable: 1831, *Expédition scientifique de Morée, ordonnée par le Gouvernement Francais. Architecture, Sculptures, Inscriptions et Vues du Péloponèse, des Cyclades et de l'Attique.*, Firmin Didot, (3 volumes), Paris.

Corliss, W. R.: 1998, Science Frontiers #116, March-April.

Curtius, E. R.: 1851, *Peloponnesos, eine historisch-geographische Beschreibung der Halbinsel*, band II. Elibron Classics [in Geraman].

Fracchia, H.: 1985, "The Peloponnesian Pyramids Reconsidered", *American Journal of Archaeology (A.J.A.)*, 89.

Greilich, S, Glasmacher, G. A, Wagner, G. A.: 2005, Optical dating of granitic stone surfaces. *Archaeometry* 47, no. 3.

Habermann, J, Schilles, T, Kalchgruber, R, Wagner, G. A.: 2000, Steps towards surface dating using luminescence, *Radiation Measurements* 32.

Hammond, Norman: 1997, "Did the Early Greeks Simply Copy the Pyramids of Egypt?" *Lon*don *Times*, August 1.

Kalleyia, A.: 1995, in *Papyros-Larousse-Britannica Encyclopaedia*, vol. 33, p. 73 [in Greek].

Katsiadramis, V.: 1994, "The ancient pyramid-like structures of Hellinikon and Ligourio in Argos – A technical and archaeological study", *Davlos*, 156 [in Greek].

Lazos, C.: 1984, "The pyramids of Argolis", *Istoria Ikonografimeni*, 189 (March), [in Greek].

Lazos, C.: 1987, "The pyramids of Argolis", *Anexigito*, 33 (May) [in Greek].

Lazos, C.: 1995, *Pyramids in Greece*. Athens, Aeolos Publ. [in Greek].

Leake, W. M.: 1846, Peloponnesiaca: Supplement to *Travels on the Moréa*, vol. II. J. Rodwell, London.

Liritzis, I.: 1986, *Archaeometry – Methods of dating in archaeology*. Kardamitsas publ., Athens [in Greek].

Liritzis, I.: 1994a, A new dating method by thermoluminescence of carved megalithic stone building. *Comptes Rendus* (Academie des Sciences), t. 319, serie II, Paris.

Liritzis, I.: 1994b, Archaeometry: Dating the past. *EKISTICS*, t. 368/364.

Liritzis, I., Galloway, R. B. and Theocaris, P.: 1994 Thermoluminescence dating of ceramics revisited: Optical stimulated luminesccence of quartz single aliquot with green light emitting diodes. *J. Radioanal. Nucl. Chem. Letters* 188 (3).

Liritzis, I.: 1995, *The mystery of the Hellenic pyramids*. Academy of Delphic Studies publ. [in Greek].

Liritzis, I.: 1997, The mystery of the Hellenic pyramids. *AELLO* (Yacht Club of Greece) 9, Athens [in Greek].

Liritzis, I., Guilbert, P., Foti, F., Schoerer, M.: 1997, The Temple of Apollo (Delphi) strengthens new thermoluminescence dating method. *Geoarchaeology International*, vol. 12, no. 5.

Liritzis, I.: 1998, Bronze Age Greek Pyramids and Orion's belt. *Griffith Observer*, vol.63, n. 10.

Liritzis, I and Raftopoulou, M.: 1999, Argolid: connection of prehistoric legends with geoenvironmental and archaeological evidence. *TUBA-AR*, II.

Liritzis, I. and Galloway, R. B.: 1999, Dating implications from solar bleaching of thermoluminescente of ancient marble. *J. Radioanal. Nucl. Chem.* 241, 2.

Liritzis, I and Vafiadou, A.: 2005, Dating by luminescence of ancient megalithic masonry. *Mediterranean Archaeology & Archaeometry*, vol.5, no.1.

Lord, E. L.: 1938, "The Pyramids of Argolis", *Hesperia*, vol. 7 (vii), no. 4.

Lord, E. L.: 1939, "Watchtowers and Fortresses in Argolis", *American Journal of Archaeology (A.J.A.)*, vol. 43 (January-March).

Lord, E. L., Frantz, M. A., Roebuck, C.: 1941, Blockhouses in the Argolid, *Hesperia*, vol. 10, No. 2 (April - June), pp. 93-112.

Morgenstein, M. E, Luo, S, Ku, T. L, and Feathers J.: 2003, Uranium series and luminescence dating of volcanic lithic artefacts. *Archaeometry* 45.

Neimeier, Barbara and Wolf-Dietrich: 1997. Aegean Frescoes in Syria-Palestine: Alalakh and Tel Kabri, *Proceedings of the 1st International Congress of Minoan Paintings*, vol.II, Thera Foundation.

Oppermann, S.: 1971, "Pyramiden in Griechenland", *Antike Welt*, 2.

Pausanias, *Corinthiaka-Laconika*, 2, 24, 7 and 2, 25, 7 (in: *Pausanias' Guide to Ancient Greece*, translat. by Christian Habicht, Berkeley Univ. Press, 1985).

Pikoulas, G. A.: 1996, The 'pyramids' of Argolis, *Archaiologia and Tehnes*, vol. 59.

Piteros, Chr.: 1995, "The so-called 'pyramids' of Argolis: Myth or reality?", *Anagennisi*, issue no. 327 (March) [in Greek].

Piteros, Chr.: 1998 (published), The pyramids of Argolis, *Proceedings of the 5th International Conference of Pelloponesian Studies*, vol. III, p. 370. Argos-Nauplion, September 6-10 Σεπτεμβρίου 1995, published in Athens.

Sampson, A.: 1996. The pyramids of Argolid and their meaning. *Archaeology*, vol. 57 [in Greek].

Scranton, R.: 1938, "The pottery from the Pyramids", *Hesperia*, pp. 528-538.

Spiropoulos, Th.: 1981, *Study of the Site of the Amphion in Thebes*, Sparta [in Greek].

Spiropoulos, Th.: 2003, The big Hellenic pyramid, *Trito Mati*, pp. 34-47.

Theocharis, P., Liritzis, I., Galloway, R. B.: 1994. "Dating of two Hellenic pyramids by a novel application of thermoluminescence", *Jour. of Archaeol. Sci*. 24.

Theocharis P., Liritzis I., Lagios E., and Sampson A.: 1997. Geophysical prospection and archaeological test excavation and dating in two Hellenic pyramids. *Surveys in Geophysics*, 17.

Theodossiou, E., Niarchos, P. G. and Manimanis, V. N.: 2002, Are the unknown Greek Pyramids old Observatories? *Xth SEAC-2002 Conference: "Cultural Context from Archaeoastronomical Data and the Echoes of the Cosmic Catastrophic Events*". Tartu, 27 August - 1 September.

Theodossiou, E., Manimanis, V. N., Katsiotis, M., Papanikolaou, D.: 2009, "Study and Orientation of the Oche 'Dragon House' in Euboea, Greece", *Journal of Astronomical History and Heritage (JAH[2])*, 12, no. 2 (July), 151-156.

Tsountas Christos: 1893, Mycenae and mycenaean civilization, Estia Publ., Athens.

Vischer, W.: 1857, *Erinnerungen und Eindrücke aus Griechenland*, Basel.

Wiegand, Th.: 1901, Die pyramide von Kenchreai, *Athen. Mitteilungen*, (des Deutschen Archäologischen Instituts. Athenische Abteilung, Athen), xxvi.

Zangger, E.: 1993, Argolis I: the geoarchaeology of the Argolid. *Deutsches Archaologisches Institut*, Athen.

http://en.wikipedia.org/wiki/Pyramid_of_Hellinikon

THE ANCIENT PYRAMIDS OF GREECE

Pyramids, 'Dragon Houses' ('Drakospita') and megalithic structures in general create always a special interest. We postulate that, as happens with the Drakospita of Euboea, the pyramid-like structures of Argolis (Eastern Peloponnese) were probably constructed by the Dryops, since it is known that, in addition to Euboea and some Cyclades islands, this pre-hellenic people had also settled in Argolis, where they founded the city of Asine. We also propose that the pyramids of Argolis and in particular the pyramid of Hellinikon village were very likely, besides being a burial monument or guard house, might be served also for astronomical observations.

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АСТРОНОМИЈА И САЗВЕЖЂА У ХОМЕРОВОЈ *ИЛИЈАДИ* И *ОДИСЕЈИ*

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Резиме: *Илијада* и *Одисеја* су, осим највишег статуса стожера светске литературе, и богат извор информација о научном и технолошком знању старих Грка у прехомеровска и хомеровска времена. Две Хомерове епске песме, које потичу из 8. века пре н.е., укључују, *inter alia*, богатство астрономских елемената, те нам пружају податке о о Земљи, небу, звездама и сазвежђима, као што су Ursa Major, Boötes, Орион, Сиријус, Плејаде и Хијаде. Такође нам нуде претставу о много образованијем Хомеру, који одражава космолошке погледе свога доба. Модел Универзума који описује је непрекидан али има три нивоа: доњи, који одговара подземном свету, средњи Земљи и горњи небу. У раду је размотрен космолошки модел и астрономски елементи у *Илијади* и *Одисеји*.

1. УВОД

Илијада и *Одисеја* немају само изузетан литерарни значај, него су такође и богати извор података о историји и научним, технолошким и астрономским знањима старих Грка у пре-хомеровска и хомеровска времена. Ова два епска дела, настала у 8. веку пре н.е., укључују драгоцене информације о Земљи, небу, звездама и сазвежђима, као што су Ursa Major, Boötes, Орион, Сиријус, Плејаде и Хијаде, и дају могућност да се шире сагледају општији космолошки погледи тога доба.

Велики број аутора је разматрао различите астрономске аспекте, чињенице и алузије у *Илијади* и *Одисеји*, као на пример Walker (1872), Schoch (1926a,b,c), Neugebauer (1929), Lorimer (1951), Dicks (1970), Trypanis

(1975), Gendler (1984), Lovi (1989), Genuth (1992), Konstantopoulos (1998), Wood и Wood (1999), Flanders (2007), Baikouzis и Magnasco (2008), Minkel (2008), Varvoglis (2009). Све то сведочи о непрекидном интересовању за ову привлачну тему, па је наш циљ да анализирамо астрономске податке и алузије у Хомеровим еповима, да би боље сагледали модел Универзума, чији су елементи тамо дати, космолошки модел који ће потрајати миленијум после Тројанског рата. На пример Д. Р. Дикс каже: *'На основу Хомерових епова не можемо да обликујемо јасну идеју о облику и положају Земље у односу на небеса и подземни свет'* (Dicks 1970, стр. 10). Желимо да размотримо да ли нека идеја о томе ипак може да се обликује и да, на основу одговарајућих пасажа и астрономских података из *Илијаде* и *Одисеје*, утврдимо која су сазвежђа и небеске појаве били познати у то доба старим Грцима, као и да анализирамо имена звезда и сазвежђа, од којих су нека данас потпуно иста као и у хомеровска времена.

2. ПОЛОЖАЈ ОКЕАНА, ЗЕМЉЕ И НЕБА У ХОМЕРОВСКОМ УНИВЕРЗУМУ

Океан и Земља

Сматра се да су стара учења Орфеја основа прве мистичне грчке религије, са песмама и химнама велике лепоте. Готово сви стари грчки мудраци и писци црпели су инспирацију из тема у *Орфичким химнама*, и тако су били под њиховим утицајем при формулисању својих јединствених теорија и учења.

Осим *Орфичких химни*, Хомерови епови су богат извор историјских и технолошких чињеница. Заиста, астроном који детаљно проучава описе у *Илијади* и *Одисеји*, открће ризницу астрономских информација. Сматра се да је Хомер живео у гвозденом добу (период који се грубо протеже од 1200. до 550. пре н.е.), а његова прича се одиграва на крају бронзаног доба (око 12. века пре н.е.).

Како пише Емил Миро:

'Илијада и Одисеја садрже елементе старе Микенске цивилизације; у основи, оне се односе на догађаје из 12. века пре н.е., животе њихових јунака (друштвене, политичке, економске и породичне), њихове законе и обичаје… …. Све то одражава начин живота, о коме сведочи песник који је створио еп' (Mireaux 1959, стр. 9).

Две епске поеме су добиле коначни облик у јонским градовима Анадолије у 9. или 8. веку пре н.е.; прво долази *Илијада* а касније *Одисеја* (Tryanis 1975, стр. 92). Поеме описују културу, религиозна веровања, опште знање и навике Грчког становништва током овог периода. Такође описују космолошки модел који ће преовладавати следећи миленијум.

Земља хомеровског Универзума била је кружни, раван диск окружен огромном реком, Океаном, модел који се први пут појавио у Орфичкој химни 'Х. ПАНУ, *Кађење различитим мирисима*', стих 15: «*Стари Океане такође дубоко поштују твоју врховну наредбу, којом течне руке окружују чврсту земљу.*"

Ова митска „река" разликује се од мора: то је нешто што дефинише границе земаљског света. Пре свега, Океан је првобитни и оригинални стваралачки елемент, полазна тачка свих ствари: '*Могу да успавам токове и, ако хоћете, реком Океан, која је била почетак свега.*' (*Илијада*, XIV 245-246). Океан је мушки предак богова, чија је супруга, током Стварања, била Тетис: '*Ићи ћу до крајева Земље да нађем оца свих богова, Океан и мајку Тетис.*' (*Илијада*, XIV 200) [Сви коришћени енглески преводи су из Loeb издања ако није другачије речено.].

Ова митска „река" нема извор ни ушће, она је 'апсороос', т.j. кружно се креће. Њен ток се враћа назад, где је и почео, у непрекидном и вечном кретању. Од Океана, поменутог 33 пута у Хомеровим делима (19 пута у *Илијади* и 14 у *Одисеји*), настале су све друге воде на Земљи, мора, реке и језера. То се помиње у *Илијади*: '*Свемоћни Океан, дубоког тока, од кога су сва мора, реке, извори и сваки дубоки бунар*' (*Илијада*, XXI 195-197).

У *Одисеји*, Океан се описује као ужасан и застрашујући: '…*зато што има дубоке токове и велике реке које нико не може прећи без брзог брода*' (*Одисеја*, xi 160). Ипак, није дат коначни опис тачног облика или величине Океана, само смо сазнали да је од воде.

Д. Р. Дикс пише: '*На основу Хомерових епова не можемо да обликујемо јасну идеју о облику и положају Земље у односу на небеса и подземни свет*' (Dicks 1970, стр. 10). Мада је то истина, може се рећи да је у хомеровском космолошком моделу, Земља између неба и подземног света. Њена тачна структура и облик нису познати, само претпостављамо да је то кружни диск пошто је окружен циркуларним воденим Океаном. У *Илијади* (VIII 13-16), је дат супротан поглед о Тартару ("дубоком месту" испод неба, Земље и мора), када Зевс прети боговима да ће их тамо послати: '*или ћу га бацити доле сопственим рукама, у мрак Тартара, далеко у дубине света, који има челичне капије и бакарни под, под Хадом далеко као што је небо од Земље*' (*Илијада*, VIII 13-16).

Паралелно, Хомер замишља Хад у дубинама Земље: '*и ако идеш на крај Земље и мора, где Јапет и Хронос бораве, и ветрови не дувају на њих, осветљава их сунчева светлост а дубоки Тартар окружује са свих страна*' (*Илијада*, VIII 480). Може се закључити да Хомер сматра да а) Хад је испод Земље, окружен Тартаром, б) Земља је центар Универзума и живота, и в) Земља подржава звездано небо (*Одисеја*, ix 534).

Небо

Небо, са сјајним звездама, претстављено је као полусферна купола, која тачно покрива равну

Земљу (*Одисеја*, xi 17). То јест, Космос оног времена био је замишљен као небески свод преко земљиног диска који плива на води. Тада се сматрало, како је саопштено у *Одисеји*, да небо, наслоњено на стубове, носи Земља, а њих, који одржавају цео свет у равнотежи, држи и чува митолошки Атлас: *'Ћерка Атласа, који познаје дубину сваког мора и сам диже високе стубове који деле Земљу и Небо на двоје'* (*Одисеја*, l 53-54).



Слика 1: *Хомеров Универзум. У Универзуму хомеровских времена, могу се видети планине које се уздижу са површине великог диска Земље и Океан који се шири око њих, а центром доминира планина Олимп, која се диже до небеса. На највишем врху је свевидећи Зевс на престолу, који надгледа како бесмртне богове, тако и смртне људе и с времена на време их награђује или кажњава. Изван Олимпа шире се небеса, која држе Атласови стубови. На небу су Месец, звезде и сазвежђа (али не према Хомеру): Hydra, Corvus, Crater, Cancer, Leo, Gemini, Taurus, као и отворено звездано јато Плејаде (цитирано у Cotsakis 1976, стр. 18).*

За старе Грке, небо је било купола начињена од чврстог материјала, гвожђа или бакра, коју су придржавали високи стубови или, по друкчијем виђењу, неки џин. Хомер комбинује ова два погледа тако што Атлас придржава стубове. Хезиод у *Теогонији* (517e) пише да је Зевс дао ову дужност Атласу.

За Хомера небо је направљено од бакра, како је описано у *Илијади*: '*Ахејци, до темена бели од прашине, коју су коњи својим стопама дизали до бакарног неба'* (V 504).

Или други пасаж: *'Борили су се онде и гвоздена бука грмела је кроз ваздух до бакарног неба'* (XVII 424-425). У другим деловима хомеровских дела, небо се такође назива 'полихалкис', т.ј. 'од много бакра' (*Илијада*, V 504,

Од. iii 2, *Илијада*, II 458, XVI 364, XIX 351). У *Одисеји* (xv 329 и xvii 565) помиње се и гвоздено небо, али се незна да ли је то употребљено као метафора или у неком другом контексту.

Закључујемо дакле да је код старих Грка представа о небу била да је то нешто чврсто али недостижно. Његова незамислива удаљеност често је коришћена у поређењима да дочара огромност. На пример, слава Несторовог златног штита досеже небеса: *'и тада ћемо узети Несторов штит, чија слава досеже звезде'* (*Илијада*, VIII 192-193). Слично, слава Пенелопе, такође допире до широког неба (*Од*. xix 108).

Простор између неба и Земље на почетку је био испуњен густим ваздухом: *'до ваздуха су се протезале његове огромне гране'* (*Илијада*, XIV 288).

Преко овог слоја и у правцу неба био је чисти и прозирни „етар", лакши од ваздуха. Етар је есенцијално „виши ваздух", кроз који се може видети небо: *'и до звезда, које трепере у етру без ветра, очаравајући око светлог Месеца – сваки врх, свака ивица, свака страна је видљива, као пространи етер отворен небом, који чини видљивим све звезде на радост пастира'* (*Илијада*, VIII 554-559).

Изнад етра, на врховима Олимпа који допиру до неба, бораве богови: *'… и принео је много жртава боговима који столују на небесима'* (*Од*. i 68-69), и: *'Без мишљења богова који бораве на небу, …, али сада је попут богова који уживају небеса'* (*Од*. vi 242-245). Богови се описују као «Олимпијски» или „небески", зато што се чини да највиши врх Олимпа додирује небо: *'Наш отац, син Хроноса, први од небесника'* (*Од*. i 46). Коначно, помиње се да је изнад етра «полихалкис» небо (*Илијада*, II 458, XVI 364, XIX 351).

Свакако, не треба претпоставити да је хомеровско небо пуста метална купола; оно је, како Хомер пева, пуно живота, живота звезда и сазвежђа. Тако су стари Грци небо називали „пуним звезда" ('астероис') (*Илијада*, VI 108, XV 371), и украшено звездама (*Од*. ix 535), што је природно за људе који живе у земљи са малим процентом облачнх ноћи. Небеским сводом путује Хелиос, бог Сунца, тако да се описује придевом „уранодромос" (по небу путујући): *'Пропали су због сопствене грешке, грешници, јели су волове по небу путујућег Хелиоса, који их је лишио дана доласка кући'* (*Од*. i 7-9). То је само једно од 119 помињања Сунца у хомеровским еповима: 42 пута у *Илијади* и 77 у *Одисеји*. Као бог, Хелиос се јавља 34 пута (8 у *Илијади* и 26 у *Одисеји*). То је у великој супротности са Месецом /Селене) која се у *Илијади* (VIII 554, XVII 367, XVIII 484) помиње само три а у *Одисеји* (iii 46 и ix 144) два пута. Још једном, Месец се помиње у *Илијади* (XIX 374) под својим архаичним именом „мене". Могуће објашњење ретког помињања Месеца, је да се главни догађаји у *Илијади*, т.ј. битке, одигравају током дана. У *Одисеји* пак, месец је обично сакривен иза облака: *'Јер била је густа тама наоколо и месец, сакривен у облацима, није сијао на небу'* (*Од*. ix 144).

Пре него што пређемо на разматрање звезда и сазвежђа код Хомера, занимљиво је да се представе неки метеоролошки и климатолошки елементи

како се јављају у *Илијади* и *Одисеји*. Ваздухом између неба и Земље пролазе ветрови и облаци, помоћу којих, свемогући Зевс покрива небо, шаље кишу на Земљу и баца муње и громове (*Илијада*, XVI 364-365, XII 25-26, *Од*. 303, xxiii 330).

Како се помиње у Рапсодији V *Илијаде*, капије неба и Олимпа начињене су од густих облака. Њихови чувари су Хоре (Часови), богиње годишњих доба, које подешавају временске услове: *'и Хера силно бичем тера коње; пред њима се уз грмљавину отвара капија неба, коју Хоре, чувари огромног неба и Олимпа, запречавају облацима или их уклањају'* (*Илијада*, V 749-751).

3. ЗВЕЗДЕ И САЗВЕЖЂА У *ИЛИЈАДИ* И *ОДИСЕЈИ*

Сада ћемо ближе испитати сва Хомерова помињања сазвежђа, звезда и планете Венере.

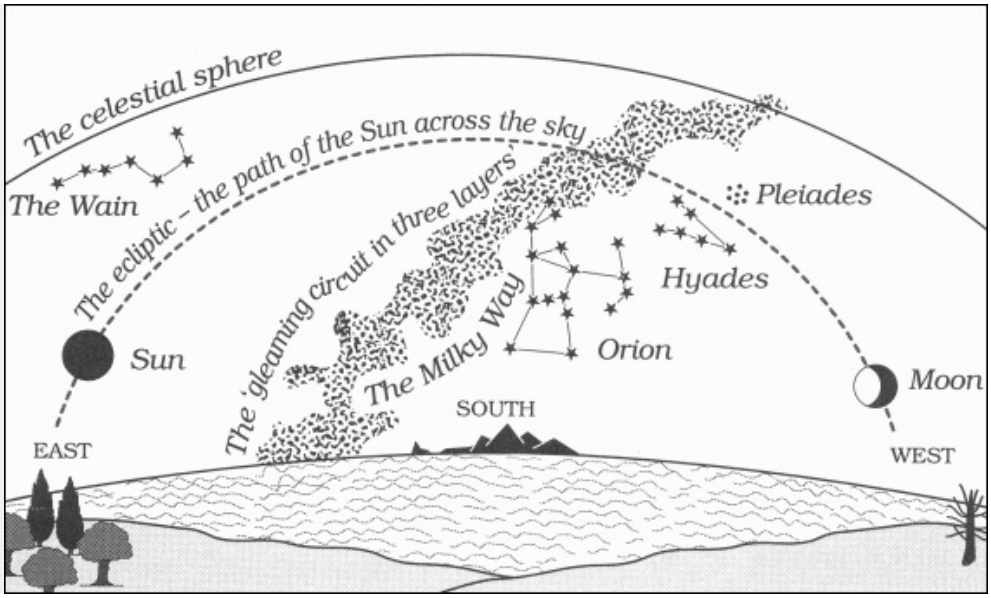
У *Илијади*, Хомер помиње „јесењу" звезду: *'Тада Атина даде снагу и храброст Диомеду, тако да би у грчком мноштву био изванредно хваљен и свуда сијао славом. Са његовог шлема и штита видео се пламен. Који је без одмора изсијавао светлост, попут јесење звезде, што се купа у Океану и сија пуном светлошћу'* (*Илијада*, V 1-5).

„Јесења звезда" је уствари Сиријус, најсјајнија звезда на ноћном небу. На географској ширини Грчке, сваке године се појављује крајем јула или почетком августа. О томе пише и Ричард Х. Ален:

'Хомер је у Илијади наговестио Сријус као Οπωρινός, Јесењу звезду; али одговарајућа сезона су последњи дани јула, цео август и део септембра – каснији део лета. Грци нису имали тачну реч за нашу „јесен" до 5. века пре н.е., када се појавила у списима приписаним Хипократу. Лорд Дерби је превео овај славни пасаж: Жестока светлост синула је онде, као јесења звезда; која најсјајније сјаји. Када се наново диже са свог океанског купања' (Allen 1963, стр. 120).

Мада се не може устврдити са сигурношћу, хомеровски човек је поимао Земљу, као раван кружни диск окружен Океаном, сматрао је да се Сунце, Месец и већина звезда издижу из Океана и поново залазе у њега. Идеја о сферној Земљи појавила се много касније, са питагорејским филозофима (5. век пре н.е.).

У *Илијади* се помиње да су по наредби Ахилове мајке Тетис, на његовом штиту, који је начинио бог Хефест (Вулкан), била насликана сазвежђа: *'И прво је направио моћан и велики штит, вештином и троструки круг около. Овај штит је направљен са пет превоја а на њему је нацртао различите слике својим мудрим знањем: Земљу, небо, море је нацртао, неуморно сунце, пун месец, звезде које са свих страна крунишу небо, снагу Ориона, Хијаде, Плејаде, Медведа, кога такође зову Кола, што стално се окреће на истом месту, гледајући Орион, јединог који се не купа у Океану'* (*Илијада*, XVIII 478-488).



Слика 2: *Хомеровски Универзум према Флоренс и Кенету Вуд чији су астрономски елементи насликани на Ахиловом штиту*. Извор: Florence & Kenneth Wood (1999). *Homer's Secret Iliad: The Epic of the Night Skies Decoded*. London: John Murray, Albemarle Street, стр. 199.

Хијаде и Плејаде, које су уствари два отворена јата, стари Грци су звали „сазвежђа“ – данас су оба укључена у сазвежђе Бика. Њега Хомер не помиње, мада говори о суседном Ориону, са наглашеним исказом „Орионова снага“. То је управо начин како Ориона спомиње Хезиод (*Works and Days*, 598, 615, 619). Оба аутора упућују на «снагу» сазвежђа, алудирајући на његов привидан сјај.

Хомер завршава са звездама, циркумполарним сазвежђем Ursa Major, које заиста „гледа“ на Ориона. Ursa Major се не купа у Океану, т.ј. никада не „додирује“ море, пошто га положај близу северног небеског пола држи даље од хоризонта док се Земља окреће.

Хијаде и Плејаде се помињу заједно са другим звезданим формацијама, као што су и сама „сазвежђа“, како у *Илијади* тако и у *Одисеји* (272-277). У првој поеми Плејаде су поменуте само једном, заједно са Хијадама (у горњем пасажу, XVIII 485), и једном у *Одисеји* (272).

Заиста, у *Одисеји* се помињу све више наведене звезде и сазвежђа: *‘Тада је радосни Одисеј поставио једра, и седећи за крмом, вешто је крманио; сан му није затварао очи док је гледао Плејаде, Пастира, који касни у залажењу, и Медведа, кога многи зову и Кола, што се окреће увек на истом месту и гледа на Ловца, једини који се не купа у таласима Океана. Јер му је Калипсо казала да увек ту звезду држи са леве стране док плови’* (*Од.* 270-277).

Како Р. Х. Ален (1963, стр. 96) пише: "*Хомер је сазвежђе Boötes карактерисао као 'οψέ δύων', са значењем касни у залажењу, мисао и израз који је постао обичан због честог понављања. Аратос је то користио:'И када је заморен преко дана,задржава се више од пола ноћи'.*

Хомер каже да сазвежђе Boötes „касни у залажењу" односно споро залази а Аратос да се „развлачи више од пола ноћи", пошто је веома дугачко, релативно уско и дугом страном је оријентисано у правцу север-југ на небеској сфери. Зато Boötes излази „својом дугом страном", одједном цело, а залази готово вертикално (полазећи, за небо Атине, од доњег десног угла и постајући све вертикалније); прво залазе ноге, па струк и на крају горњи део тела, тако да му треба кратко време да изађе а веома дуго да зађе.

Треба напоменути да се у овим стиховима, први и једини пут у еповима помиње употреба сазвежђа за оријентацију на мору. Калипсо саветује Одисеја, да, како би задржао прави курс, мора увек да држи са леве стране Медведа (Ursa Major). Свакако, то значи да ако му је са лева северно сазвежђе, плови ка истоку. Тако је Хомер поставио Калипсино острво Огигију западно од целе Грчке, пошто је и сама Итака, за коју је био везан, била на западу ове земље.

Пошто је Хомер сматрао да је Земља раван кружни диск, окружен Океаном, био је сигуран да Сунце, Месец и звезде излазе из, и залазе у њега; само Ursa Major не залази за старе народе који су живели на северним обалама Медитерана. У грчкој митологији, Зевс се заљубио у нимфу Калисто. Хера, његова жена, претворила је због љубоморе нимфу у медведа. Зевс је касније поставио заједно са сином Ареасом на небо и они чине сазвежђе Ursa Major. Аристотел помиње да је медвед једина животиња, која због дебелог крзна може неустрашиво да лута леденим северним поларним областима. Циркумполарни карактер сазвежђа Ursa Major је у наше време само делимичан: док у прото-историјска времена, када је Alpha Draconis (Тубан) била 'поларна звезда', ниједна од седам најсјајнијих звезда у Ursa Major није залазила. Данас, услед прецесије Земљине осе, Алкаид (Eta Ursae Majoris, последња звезда у репу) остаје испод северног хоризонта Атине, Итаке и централне Грчке у општем, приближно три сата. Само у северној Грчкој и на местима са географском ширином већом од φ = 40.1° су све најсјаније звезде овог сазвежђа циркумполарне. Ален (1963, стр. 419) саопштава о овоме на следећи начин: '*Сер Џорџ Корнуол Луис пише – за Хомеров правац Арктоса, јединствене звезде која се никада не купа у таласима океана (услед прецесије тада је била много ближе полу него сада)'*. Разлика у деклинацији Алкаида (η UMa) у хомеровска времена и данас је више од 15 степени, тако да је у антици цео Ursa Major био циркумполаран чак и на најјужнијем крајичку Грчке.

Хомер пак, не помиње Великог медведа експлицитно, тако да модерни коментатор може да претпостави да је уствари мислио на Малог медведа, Ursa Minor, или на комбинацију оба. То је највероватније означавало

Великог медведа, пошто има много сјајније звезде, много је веће и импресивније сазвежђе, а Малог медведа је (према традицији) код Грка увео Талес из Милета у 6. веку пре н.е., дакле два века после Хомера. Ursa Minor је још увек, како се види из Грчке, потпуно циркумполарно сазвежђе.

Последње сазвежђе поменуто у пасажу из *Одисеје* је Орион, Ловац. Његова појава на ноћном небу, сваке године се подударала са почетком најкишнијег и најолујнијег дела године, па је Орион називан «олујни» и деструктиван. Хезиод и Аристотел помињу да је излазак Ориона одређено упозорење за морнаре да долазе олује (Hesiod, *Works and Days* 598, 615, 619 и Arist. *Meteor*. 2.5.4).

У Рапсодији XXII *Илијаде*, помињу се Орион и Сиријус. Најсјајнија звезда Сиријус, наводи се као Орионов пас; данас је познат као најзначајнија звезда сазвежђа Великог пса (Canis Major), Alpha Canis Majoris. Хомер претставља Сиријус као злослутан знак на небу, пошто је сваког лета повезан са такозваним «пасјим врућинама»:

‘*… као звезда која нам долази у јесен, натсијавајући све своје другове на јесењем небу – зову је Орионов пас, и премда је најсјајнија од свих звезда не предсказује добро доносећи много грознице нама, сиротим смртницима*’

[*The Iliad*, trans. by E.V. Rieu, Penguin Books,
New York 1950 (Ch. 22, v. 25-31)].

‘Пасје врућине’ и ‘пасји дани’

У антици, хелијакални излазак Сиријуса повезан је са изузетно топлим периодом године, *‘κυνικά καύματα’* (‘пасја врелина’). То, у медитеранском крају, одговара касном јулу, августу и раном септембру. Римљани су такође за ове дане знали као за ‘dies canicularіae’, најтоплије доба целе године, повезано са сазвежђем Великог пса, и ловчевим (Орионовим) псом, Сиријусом. Стари Грци су претпостављали да вишак топлоте потиче од додавања Сиријусовог зрачења сунчевом.

У фолклору старе Грчке, народ је летње дане после хелијакалног изласка Сиријуса, називао „пасје врелине“ без повезивања са Пасјом звездом или сазвежђем, већ са псима уопште, мислећи да су само пси толико луди да иду напоље, када је толико топло. Ово веровање је истрајало кроз векове и може се наћи у модерном грчком фолклору у веровању да су за време врелих јулских и августовских дана, нарочито између 24. јула и 6. августа, псећи уједи посебно заразни (Theodossiou, Danezis 1991, стр. 115).

Према старом миту, становници острва Кеа умирали су од глади услед суше коју је око 1600. пре н.е. донела пасја врућина. Тада је бог Аполон дао пророчанство да се позове Птија Аристеј, божји син, да им помогне. Пошто је дошао на Кеу, Аристеј је извео ритуале, очишћења и жртвовања Зевсу Икмејском, господару киша и неба, и Аполону. Оба бога су слушали њихове

молбе и послали су Етезијске ветрове, северне ветрове који четрдесет дана дувају преко целог Егејског мора средином лета, тако да људи могу да преживе неподношљиву врелину. Након тога, народ Кее, подстакнут Аристејем, принео је жртве сазвежђу Canis Major и Сиријусу; да би памтили његово доброчинство, славили су Аристеја као „Аристеја Аполона“ и стављали његову главу на једну страну новца, а на другу Сиријуса са круном са зрацима.

Бивши професор и академик са Националног техничког универзитета у Атини Перикле С. Теохарес пише: *‘Овај мит алудира на однос Сиријуса са Земљом. Жртве су приношене Зевсу Мејлихију, богу времена, сунца и кише, и Сиријусу, који ствара пасје врућине на Земљи; сматрали су да за велику летњу топлоту није одговорно само Сунце, него такође и Сиријус када дође после Сунца. То је вероватно било веровање градитеља арголидских пирамида, који су оријентисали њихове улазне ходнике према азимуту Сиријуса’* (Theochares, 1995).

У старој поезији Сиријус се помиње као звезда са посебно негативним утицајем, што је очигледно из Хомерових стихова ‘*…не предсказује добро…..нама сиротим смртницима’* (*Илијада*, XXII 25-31). Пошто су запазили да људи постају троми током пасјих дана; учврстили су веровање да Сиријус има успоравајуће деловање на људске активности. Зато чак и Хипократ саопштава о лошем утицају ове звезде на људе: Хипократ је, у делима *Epidemics* и *Aphorisms*, писао доста о утицају моћи ове звезде на време, и последичне физичке ефекте на људе (Allen 1963, стр. 126).

Планета Венера

Венера се помиње и у *Илијади* и у *Одисеји*. У Рапсодији XXII (стих 317) *Илијаде*, Хомер помиње Хесперус, Вечерњу звезду, а у XXIII (стих 226) Еосфорус (Lucifer на латинском), Јутарњу звезду, која доноси светлост зоре. У оба случаја у ствари се помиње Венера, мада их Хомер вероватно сматра за две посебне звезде: *‘И као што међу звездама излази сјајна вечерња звезда, најлепша међу звездама на небу, тако је сијало копље, бачено његовом десном руком према божанском Хектору са злобном намером, гледајући да нађе непокривени део његовог меког тела’* (*Илијада*, XXII 317-321). Слично у другом пасажу: ‘*Када Луцифер најављује светлост и златни Еос (Зора) излази из морских дубина, огањ бледи и пламенови се заустављају’* (*Илијада*, XXIII 226-228).

Пасаж у Хомеровој *Одисеји* опет нас доводи мору: *‘Како је изронила свесјајна звезда, која долази да прва најави светло Зоре рођене из ноћи, брод се пенећи од среће приближавао острву’* (*Од.* xiii 98-100). Значи да је Одисеј досегао Итаку пре зоре, у време када се појављује Венера, најсјајнија звезда која «долази» пре зоре.

Солстиције

У *Одисеји се такође јасно помињу солстиције као „окретања Сунца“*: *‘Они једно острво зову Сирија – ако сте икада чули за њега – где је Сунце више него у Ортигији, када се окреће’* (*Од.* xv 403-404).

Други стари аутори о звездама, сазвежђима и Сиријусу

Хомерови епови су несумњиво утицали на друге старогрчке песнике и ауторе у помињању звезда и сазвежђа на небу. Највише је присутна најсјајнија звезда, Сиријус.

Захваљујући сјајној привидној величини (-1.46), Сиријус је имао посебно место у митологији, легендама и традиији већине народа на Земљи. Само његово име на грчком значи „блештави“, „пламени“ или „горећи“, успламтео; ово име је веома старо, пошто је присутно у орфичкој *Argonautics*: ‘*када је три дана за редом изгубила светлост пламена звезда*’ (*Argonautics*, 121-122, Petrides, 2005), као и код Хомера (*Илијада*, XXII 25-32 и *Od.* 4).

У приближно истом времену са Хомером, или мало касније, Хезиод у својој чувеној књизи *Радови и дани*, помиње неколико сазвежђа која су сељацима потребна да би пазили на свој свакодневни рад, а три пута наводи и солстиције. На пример, Хезиод сугерише да жетва треба да почне када Плејаде изађу (хелијакални излазак), а сетва када су при заласку. Хезиод говори о свим звездама и сазвежђима које помиње Хомер, са посебним нагласком на Сиријусу. Заиста, Сиријус помиње у три различита пасажа. У првом даје савете брату Персу о берби грожђа: *‘А када Орион и Сиријус досегну средину неба и рујнопрстаста зора гледа Арктурус, тада Персе, обери сво грожђе и донеси га кући’* (Хезиод, *Works and Days* 609), док у друга два говори о пасјој врућини: *‘Тада звезда Сиријус напредује сваког дана мало више изнад глава смртника и узима већи део ноћи’* (ibid., 417). *‘Јер Сиријус суши главу и колена и тело је суво од топлоте’* (ibid., 587).

Друго Хезиодово дело, *Аспис Ираклеус* (*Херкулов штит*), је у извесном степену имитација *‘Аспис Ахилеос’ (Ахиловог штита)* како је описан у *Илијади* (XVIII 468-817). У овом делу, такође, Хезиод два пута помиње сјајну звезду Сиријус: *‘Њихове душе силазе у Хад да би биле прекривене земљом, док су њихове кости, када је кожу око њих истопио пламенои Сиријус, иструлеле у црној земљи’* (*Shield of Hercules*, 151). И: *‘Када бучни, плавокрили цврчак, седећи лети на зеленој грани, почне да пева људима, а његова храна и пиће је мека роса, и током целог дана, почевши у зору, пушта свој глас по најстрашнијој топлоти, када Сиријус сагорева тело, почињу да се јављају младице на просу посејаном у лето”* (ibid., 391).

Песник трагичар Есхил (525-456 BC) у трагедији *Агамемнон* такође помиње пса Сиријуса (стих 967).

Аполоније са Родоса (3. век пре н.е.) пише у делу *Argonautics*, великом епу који преобликује у поетску форму митску експедицију Аргонаута из Тесалије у Колхиду на Црном мору. Аполоније такође помиње Сиријус у

вези са неподношљивом летњом врућином: *'Када минојско острво са неба загреје Сиријус и за дуго време његови становници не могу наћи никакав спас од тога…'* (*Argonautics*, Песма III, стих 517). И касније: *'Опет се појавио као Сиријус, који се уздиже на висине са руба Океана'* (Песма III, стих 956).

Теогнис (570-480 пре н.е.), значајни песник елегичар из Мегаре, написао је неколко гозбених песама, изузетних по достојанству и поштовању богова. Чак даје правила за пијење вина, додајући обавештења за период око изласка Сиријуса: *'Неразумни су они људи, и глупи, који не пију вина ни када Пасја звезда почиње…'* (Wender, 1984, *Theognis*, 1039-1040).

Ератостен (276-194 пре н.е.) користи реч 'сириос' као придев, пишући на пример: *'Такве звезде астрономи зову сириос због треперавог кретања њихове светлости'*.

Грчки епски песник из 5. века Нонус, из египатског града Панополиса, пише у својој *Дионизијака* о пасјим врелинама Сиријуса: *'Послао је супротни удар ветра да пресече врелу Сиријусову грозницу'* (*Dionysiaka*, 275).

У византијском периоду, принцеза Ана Комнина у свом *Алексијасу* пише: *'…премда је било лето и сунце је прошло кроз Рака и било је пред уласком у Лава – сезона у којој, како кажу, излази звезда Пас'* (*Алексијас* I, Књига 3, XII.4).

4. ОПИС ПОТПУНОГ ПОМРАЧЕЊА СУНЦА У *ОДИСЕЈИ*

У Рапсодији XX *Одисеје* налази се следећи пасаж: *'Улаз и цело двориште испуњени су сенима мртвих, које се крећу у мраку. Сунце је нестало са неба и свугде је била слаба видљивост'* (XX 356-357).

Овај пасаж, вероватно описује астрономску појаву, можда најстарији опис потпуног помрачења Сунца на Западу. Како је то релативно ретка астрономска појава за дато место, и јавља се у просеку једном у 360 година, ако је област ограничена, може се одредити вероватан датум овог помрачења (Varvoglis, 2009).

Мада се помрачења Сунца и Месеца не помињу директно у хомеровским текстовима, претходни стихови су мотивисали два астронома, Константина Бајкузиса (Constantino Baikouzis) из Лабораторије за математичку физику на Рокфелеровом универзитету у Њујорку и Марчела Мањаска (Marcelo Magnasco) са Proyecto Observatorio, Secretaría de Extensión, Observatorio Astronómico de La Plata, да покушају да тачно одреде датум када се Одисеј вратио на Итаку. Претпоставили су (2008) да Хомер у *Одисеји* XX 356-357 говори о потпуном помрачењу Сунца које се догодило на дан истребљења Пенелопиних просаца.

Наговештај предвидљивој природи оваквог догађаја је дат: Пророчанство Теоклимена је упозорило просце да ће: *'Сунце бити избрисано са неба, и несрећна тама ће испунити свет када се домаћин врати и крв ће бити нађена у њиховим тањирима'* (*Одисеј*, XX 350-355).

Ово навођење, Бајкузис и Мањаско су упоређивали са другим помињањима древних помрачења Сунца у старим текстовима и нашли су извесне сличности. У хомеровским текстовима, постоје још четири астрономске ознаке у вези Одисејевог повратка на Итаку.

Прва је месечева фаза; Хомер помиње више пута да је било време младог месеца, тако да је први услов за потпуно помрачење Сунца, према Бајкузију и Мањаску (2008) задовољен.

Друга се односи на Венеру, која је шест дана пре покоља просаца била видљива високо на небу: *'Како је изронила све-сјајна звезда, која долази да прва најави светло Зоре рођене из ноћи, брод се пенећи од среће приближавао острву'* (*Од.* xiii 98-100).

Трећа ознака је о звездама и сазвежђима, које је Одисеј видео када је напустио Калипсино острво, 29 дана пре разматраног догађаја, после заласка Сунца виделе су се Плејаде и сазвежђе Boötes.

Четврта се односи на бога Хермеса (Меркур) који је „стигао" на острво Огигију 34 дана пре помрачења. Према Бајкузису и Мањаску (2008) то се односи на планету Меркур, која је била у западној елонгацији када се види на истоку пре свитања а „стигла" је у тренутку свог хелијактичког изласка, односно када је први пут постала видљива што се догодило 13. марта 1178. године пре н.е. Када је у западној елонгацији, Меркур се види ниско на небу пре изласка Сунца и има ретроградно кретање близу источног руба своје привидне путање што се дешава једном сваких 116 дана.

Харис Варвоглис (2009), професор Астрономије на Универзитету у Солуну, примећује да, ако претпоставимо да се последњи пасаж односи на планету Меркур, то се заједно са три остале астрономске ознаке, поклапа једном у 2000 година. Пошто је, на основу археолошких ископавања Троје, познато да је разорена око 1190 пре н.е., јасно је да ако се у деценијама пре или после ове године догодила таква астрономска коинциденција, то би била независна потврда године разарања Троје (Varvoglis 2009, стр. 3).

Бајкузис и Мањаско, знајући вероватну годину разарања Троје и комбинујући поменуте астрономске информације које даје Хомер, размотрили су 1684 младих месеца између 1250 и 1125 пре н.е. и, користећи планетаријумски софтвер, истражили су астрономску прошлост области Јонског мора. Открили су да се потпуно помрачење догодило 1178 пре н.е. и да је било видљиво са Итаке. Након прецизнијих прорачуна добили су да би по Јулијанском календару дан истребљена просаца био 16. април 1178. пре н.е. Ако је то тачно, и ако су Одисејева лутања трајала заиста десет година, како саопштава Хомер, освајање и разарање Троје догодило се 1188. пре н.е.

Бајкузис и Мањаско кажу да њихово истраживање не може без сваке сумње потврдити време Одисејевог повратка на Итаку, али свакако показује да је Хомер знао за извесне астрономске појаве које су се догодиле вековима пре његовог доба. Ако су у праву и ако је Хомер стварно „везао" овај датум за астрономски догађај који се може проверити, онда то може помоћи историчарима да са великом прецизношћу одреде време пада Троје.

Могући контрааргумент овом ставу је да би Хомеру, који је живео у 8. веку пре н.е., било тешко да опише астрономску појаву која се догодила пре више од четири столећа. Такође, мада изгледа да речи Теоклимена описују помрачење Сунца, песник вероватно жели да да општу слику, везујући га за мрачну судбину Пенелопиних просаца. Или је можда Хомер спевао овај пасаж на основу помрачења које је сам видео, и повезао то са општом ситуацијом око масовног убиства. Ц. Р. Минкел пише у часопису *Scientific American*: *'Истраживачи кажу да се позивањем на планете и сазвежђа у „Одисеји", описује помрачење Сунца које се догодило 1178 пре н.е. скоро три века пре него што се сматра да је Хомер саздао причу. Ако је то тачно, налаз би указивао да је древни песник имао изненађујуће детаљно познавање астрономије… Грчки учени људи Плутарх и Хераклит истичу идеју да је Теоклименов говор поетски опис помрачења. Они наводе помињања у причи да је дан пророчанства био млад месец, што би било тачно за једно помрачење. У двадесетим, истраживачи су спекулисали да је Хомер могао имати на уму стварно помрачење, после прорачуна да је потпуно помрачење (када месец потпуно заклања сунце) било видљиво 16. априла 1178. пре н.е.изнад Јонских острва, где се догађаји из Хомерове поеме смештају. Ипак, идеја није заживела, пошто су се први грчки астрономски записи појавили вековима после тога'* (Minkel 2008).

Напомињемо да се неодређено помињање „неких истраживача" из двадесетих година у горњем пасажу уствари односи на Шоха (Schoch, 1926a,b,c), који је први одредио 16. април 1178. пре н.е. као датум потпуног помрачења Сунца, повезаног са Теоклименовим речима, као и на Нојгебауера (Neugebauer, 1929).

5. ЗАКЉУЧЦИ

Хомеров космолошки модел, који бележи погледе његовог времена, или можда чак и старије, преживео је у Јонији вековима после његове смрти.

Стварајући највероватније у 8. веку пре н.е., Хомер претставља Земљу као диск са свих страна окружен воденим Океаном. Звездано небо је чврста купола која се мора придржавати да не би пала, док испод Земље постоји подземни свет Хад, који је исто толико далеко од Земље као и небо.

У Хомеровим еповима не спомињу се све планете познате у антици, али постоји убедљива чињеница да су њихове особине и повезаност са променом изгледа неба са проласком времена биле широко познате после великог броја емпиријских посматрања.

Може се рећи као закључак, да хомеровски извори показују да су поједина сазвежђа и небеске појаве били познати старим Грцима тога времена. Известан број звезда је био именован и биле су тако познате да су коришћене за поређења у односу на богове и људе. Занимљива је чињеница да постоје звезде и сазвежђа, које Хомер помиње под потпуно истим именима као што су данашња.

У *Илијади*, први пут се нека звезда помиње у Рапсодији 5 (5), где је Сиријус представљен као јесења звезда; изгледа природно да је прва поменута звезда најсјајнија на ноћном небу. Богатији астрономски садржај је у опису Ахиловог штита (XVIII 478-488). Хомер каже да су на њему били насликани Орион, Хијаде, Плејаде и Медвед или Кола, *'која се окрећу увек на истом месту, гледајући на Орион'* и никада не додирујући Океан. То је изгледа јасна назнака да је ово сазвежђе циркумполарно и увек видљиво са географских ширина где се епска прича одиграва. То Медведа чини погодном, лако видљивом помоћи за оријентацију, тако да би његово укључивање у популарну поему било практично и корисно за заједницу. Када идемо према крају *Илијаде*, Хомер опет помиње Сиријус, називајући га Орионов пас (XXII 29).

У *Одисеји* се помињу циркумполарне звезде и уобичајена сазвежђа (279-287); овога пута, додато је и Boötes.

Тако Хомер помиње укупно три сазвежђа (циркумполарно Ursa Major, Орион и Boötes), два отворена звездана јата тада позната као сазвежђа (Плејаде и Хијаде), индиректно и најсјајнију звезду Сиријус (као јесењу звезду, Орионовог пса и „лошу звезду" која људима доноси пасје врућине) и планету Венеру као звезду са старим грчким именима за Вечерњу и Јутарњу звезду.

Математичар Константин Мавроматис (Konstantinos Mavrommatis, 2000) претпоставља да је „звезда" која се без имена помиње у *Одисеји* (*Јер му је казала да увек ту звезду држи са леве стране док плови'* (*Од.',* 276) вероватно поларна звезда тога доба. Астроном Харитон Томбулидис (Chariton Tomboulidis, 2008) помиње да се у *Илијади* IV богиња Атина пореди са „бљештавом" звездом: *'Са врхова Олимпа она је јурнула као звезда коју су Хроновићи бацили људима као знак… …сјајна звезда и безбројни бљескови што су бачени'* (IV 75-78). Вероватно Хомер овде алудира на падајућу звезду или метеор; такве „звезде"требале би много чешће да се виде на веома тамном небу старе Грчке.

У *Одисеји* такође се веома јасно помињу солстиције (xv 403-404) и један вероватни опис треперења звезда (xii 318).

Коначно, мада помрачења Сунца и Месеца нису експлицитно помињана у хомеровским еповима, било је сугерисано (Baikouzis и Magnasco, 2008) да у *Одисеји* (XX 356-357) Хомер алудира на потпуно помрачење Сунца одакле се чак може извући датум Одисејевог повратка на Итаку. Ту треба бити опрезан да се не би помешале поетичке метафоре са стварним астрономским догађајем, пошто је Хомер живео четири века после помрачења од 16. априла 1178. пре н.е.

Чињеница је да постоји само један случај да се користе звезде или сазвежђа за оријентацију у хомеровским текстовима (*Одисеја*, 271-277). Задатак да се астрономија доведе до практичних примена предузео је Хезиод, пола столећа касније, својим делом *Радови и дани*, које је пружило Грчком народу први календар земљорадничких послова, водич за сезонске

активности заснован на хелијактичком изласку или заласку различитих звезда, сазвежђа или јата Плејада.

Хомеровску астрономску књижевну традицију следило је неколико старих грчких аутора, као што је Хезиод са својим делима *Радови и дани* и *Херкулов штит*, песник трагичар Есхил у трагедији *Агамемнон*, Аполоније са Родоса у *Аргонаутици*, Ератостен из Кирене, Нонус и чак византијска принцеза Ана Комнина у *Алексијасу*.

Сва ова навођења указују да бар од древне Грчке, почевши са *Орфичким химнама* и Хомеровим еповима па до наших дана, неке звезде и сазвежђа носе потпуно иста имена.

Литература

Aeschylus: 2000, *Agamemnon*. Daedalus-Zacharopoulos Publications, Athens [in Greek].

Allen, R. H.: 1963, *Star Names - Their Lore and Meaning*, Constable & Co., London.

Apollonius of Rhodes: 1988, *Argonautics*. Kardamitsa Publications, Athens [in Greek].

Aristotle: 1952, *Meteorologica*. Heinemann, London (The Loeb Classical Library; English Translation by H.D.P. Lee).

Baikouzis, C. and Magnasco, M. O.: July 1, 2008, "Is an eclipse described in the Odyssey?", *Proceedings of the National Academy of Sciences*, 105: 8823.

Bible: *The New International version Bible*: 1984, Zondervan Bible Publishers, Grand Rapids, Michigan, U.S.A.

Comnene, Anna: 2005, *Alexias*, Books I to XV. Agra Publications, Athens [in Greek].

Cotsakis, D.: 1976, *The Pioneers of Science and the Creation of the World*. Zoe Publications, Athens [in Greek].

Dicks, D. R.: 1970, *Early Greek Astronomy to Aristotle*. Thames & Hudson, United Kingdom.

Flanders, T.: 2007, "Did the Greeks, in Homer's time, name a constellation or asterism after Achilles?", *Sky and Telescope*, Vol. 114, No. 8, p. 82.

Gendler, J. R.: 1984, "Jupiter-Saturn Conjunctions in Homer's Odyssey and Iliad", *Bull. American Astron. Soc.*, Vol. 16, p. 49.

Genuth, S. S.: 1992, "Astronomical imagery in a passage of Homer", *J. Hist. Astron*., Vol. 23, p. 293.

Eratosthenes: 1997, *Catasterismoi*. Trans. By Theony Contos in *Star Myths of the Greeks and Romans: A Sourcebook*. Phanes Press, Grand Rapids.

Hesiod: 1914, *The Homeric Hymns and Homerica (Theogony)*. Heinemann, London (The Loeb Classical Library; English translation by Hugh G. Evelyn-White, reprinted 1954).

Hesiod and Apollonius of Rhodes: 2005, *Theogony, Works and Days, Shield of Hercules, Argonautics*. Zetros Publications, Thessaloniki [in Greek].

Homer: 1924, *The Iliad*. Heinemann, London (The Loeb Classical Library; English translation by A.T. Murray, 1954).

Homer: 1919, *The Odyssey*. Heinemann, London (The Loeb Classical Library; English translation by A.T. Murray, revised by G.E. Dimock, reprinted 1995).

Kirk, G. S., Raven, J. E. and Schofield, M.: 1995, *The Presocratic Philosophers*. A critical History with a selection of Texts, Cambridge University Press (First printed 1883)

Konstantopoulos, P., 1998, *Homeric Greeks*, 2 vols. Metron Publications. Athens [in Greek].

Lorimer, H. L.: 1951, "Stars and Constellations in Homer and Hesiod", *The Annual of the British School in Athens*, vol. 46, pp. 86-101.

Lovi, G.: 1989, "Stargazing with Homer", *Sky and Telescope*, Vol. 77, No. 1, January, p. 57.

Mavrommatis, K.: April 2000, *Ouranos* No. 35, Volos, p. 114 [in Greek].

Minkel, J. R.: June 23, 2008, "Homer's Odyssey Said to Document 3,200 Year-Old Eclipse – Clues in the text hint that the poet knew his astronomy". *Scientific American* (http://www.scientificamerican.com/article.cfm?id=homers-odyssey-may-document-eclipse).

Mireaux, E.: 1959, *Daily Life in the Time of Homer*. Transl. Iris Sells, The Macmillan Company, New York.

Nonnus, *Dionysiaca*, (s.d.), Transl. E. Darviri, Ancient Authors Series, Georgiades-Elliniki Agoge Publications, Athens, [in Greek].

Neugebauer, P. V.: 1929, *Astronomische Chronologie*, Verlag W. de Gruyter, Berlin.

Orphic Hymns: 2006, Ideotheatro Publications, Athens [in Greek].

Petrides, S.: 2002, *The Orphic Hymns – Astronomy in the Age of Ice*, (author's publ.), Athens.

Petrides, S.: 2005, *Orpheus' Argonautica – A dissertation on seafaring of the late Pleistocene*, (author's publ.), Athens.

Schoch, C.: 1926a, "The eclipse of Odysseus", *The Observatory*, 49, p. 19.

Schoch, C.: 1926b, *Die Sterne*, 6, p. 88.

Schoch, C.: 1926c, Die sechs griechischen Dichter-Finsternisse, Steglitz, Selbstverlag, Berlin.

The Iliad: 1950, Trans. by E.V. Rieu, Penguin Books, New York.

Theochares, P.: 12-13 May, 1995, *The pyramids of Argolis and their dating*, 11th Panhellenic Conference, Nafplio [in Greek].

Theodossiou, E., Danezis, E.: 1991, *The Stars and their Myths – Introduction to Uranography*, Diavlos Publications, Athens [in Greek].

Theognis: 1997, *Lyrical poems III*. Epikairotita Publications, Athens [in Greek].

Tomboulidis, C.: April 2008, *Ouranos* No. 67, Volos, p. 132 [in Greek].

Trypanis, K. A.: 1975, *The Homeric epics*. Prometheus-Hestia Publ., Athens [in Greek].

Varvoglis, H.: Sunday September 6, 2009, "Pharmacology and Astronomy in Odyssey". *BemaScience*, History, p. 3 [in Greek].

Walker, G. J.: 1872, "Astronomical allusions in Homer, Dante, Shakespeare and Milton", *The Astronomical Register*, No. 118, 229.

Wender, D.: 1984, *Hesiod and Theognis*, Penguin Books, New York.

Wood, F. & Wood, K.: 1999, *Homer's Secret Iliad: The Epic of the Night Skies Decoded*. London: John Murray, Albemarle Street, p. 199.

ASTRONOMY AND CONSTELLATIONS IN HOMERIC *ILIAD* AND *ODYSSEY*

The *Iliad* and the *Odyssey*, in addition to their supreme status as cornerstones of world literature, they are a rich source of information about the scientific and technological knowledge of ancient Greeks in both pre-Homeric and Homeric times. The two Homeric epic poems, dated in the 8th century BC, include, *inter alia*, a wealth of astronomical elements, informing about the Earth, the Sky, the stars and constellations such as Ursa Major, Boötes, Orion, Sirius, the Pleiades and the Hyades. They also offer a more erudite image of Homer, which reflects the cosmological views of his period. The model of the Universe that is presented is continuous and has three levels: the lower level corresponds to the underworld, the middle one to the Earth and the upper one to the sky. The cosmological model and astronomical elements presented in *Iliad* and *Odissey* are considered in this work.

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ГЕА, УРАН, ХЕЛИОС И СЕЛЕНА ТРИ ГЛАВНА НЕБЕСКА ТЕЛА И НЕБО У СТАРОЈ ГРЧКОЈ КОСМОГОНИЈИ

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Резиме: У овоме прилогу разматра се улога три главна небеска тела, Земље (Геа), Сунца (Хелиос), и Месеца (Селена), као и Неба (Уран) у Космогонији античке Грчке. То је урађено на основу анализе античких грчких текстова, као што су *Орфичке химне*, и писаца и филозофа, као Есхил, (Псеудо) Аполодор, Аполоније Родоски, Аристотел, Еурипид, Хезиод, Хомер, Хигинус, Нонус, Паузанија, Пиндар и Софокле, као и уз помоћ анализе текстова римских писаца попут Цицерона, Овидија и Плинија.

1. УВОД

Наш циљ је, да на основу античких грчких и римских текстова, анализирамо улогу у античкој грчкој Космологији три главна небеска тела, Земље (Геа), Сунца (Хелиос) и Месеца (Селена), као и Неба (Уран).

Од најдаље прошлости, људи су обожавали првобитни божански пар, богињу Геу (Геа – Земља) и бога Урана (Небо). Хезиодова '*Теогонија*' почиње са Геом и завршава се са политеистичком владавином Олимпијаца. Постанак елемената природе и персонификованих божанстава која се понашају као људи, одвијао се паралелно: "у почетку су рођени богови и Геа" (*Theog*., 105). Она се спарила са Ураном, који је окружавао и оплодио.

Упоредо са Геом, која је деификација наше планете, Мајка Земља је обоготворење тла, чији производи помажу људску егзистенцију, и која даје простор на коме се рађају, живе и умиру.

Поред космичког божанског двојства, Урана и Гее / Мајке Земље, људи су обожавали и Хелиоса (Сунце), који даје светлост и живот, извор опстанка свих живих бића на Земљи. За народ у свим крајевима Земље, Сунце, Небо и Земља су вечни сведоци човекових активности и природни осветници нарушавања закона. Од времена настанка грчке филозофије, долази идеја да су сунчеви зраци, који падају на влажну Мајку Земљу створили прва жива бића, а проучаваоци митова су посматрали Сунце и Мајку Земљу као прогениторе свих ствари.

Месец је дао првобитне јединице за мерење времена: дефиницију лунарног (синодичког) месеца и недеље; његова улога је дакле суштинска за проналазак првих календара, који су служили као основица свих древних религија.

У овом прилогу, разматра се и анализира улога Гее / Мајке Земље, Урана, Хелиоса и Селене у старој грчкој митолошкој Космогонији.

2. ГЕА

Према космогонији Орфичара, Геа је постојала пре свега другога, заједно са Хаосом и Еросом-Фанесом, у току стварања Универзума. Ова три божанска бића су рођена из космичког јајета, које је или настало *ex nihilo* или га је створила Никс (Ноћ).

Геа, једно од примарних божанстава, је космогонијски симбол материјалног аспекта Универзума, а не само земља као тло (Demetrakos, *Mega Lexikon*, 1964, вол. 3, стр. 1534). Хаос симболизује простор Универзума, а Ерос мотивацију и снагу стварања света, која уједињује и трансформише Универзум.

У најстаријој орфичкој космогонији, Геа је рођена интервенцијом („енергијом“) овог космогонијског Ероса, који „све спаја заједно“ (*Orphic Fragm*. Kern, 1922, 1). У каснијој верзији, Геа и Небо (Уран) су настали из две половине огромног космичког јајета, које је родио ванвременски Хронос (Време) (*Orphic Fragm*. Kern, 1922, 57).

У Хезиодовој *Теогонији*, примарни ентитет Универзума је Хаос: “… *прво је настао Хаос*” (*Теог.* 116), који је био безоблична маса без било какве структуре; амбис или „неукрашени“ простор. После стварања Хаоса, рођени су Ереб (Тама) и Никс (Ноћ); Никс је родила Етер и Химеру (Дан).

Након тога, «широкогруда» Геа, како је карактерише Хезиод, један од три првобитна елемента Универзума – заједно са Хаосом и Еросом – родили су Урана, Понт (море) и планине (*Теог.* 123+).

Друга верзија поистовећује хаос са Ураном и тако га, заједно са Геом, дефинише као први космичко-божански пар Стварања. Стари Грци почињали су настанак богова и природе, женским ентитетом, Геом, која се

појавила после Хаоса и пре Ероса. Геа је истовремено природни елемент који ствара и подржава свет, и Мајка Земља, после рођења Урана, Океана и других водених божанстава.

У почетку, божанска репродукција је безполна, односно Геина плодност није повезана са неким богом. У другој фази пак, Геа се спаја са прворођеним сином Ураном (*Теог.* 147), кога је створила без интервенције мушког ентитета. Он је најпогоднији, пошто је потпуно окружује и предодређен је да буде боравиште богова. Тако су Геа и Небо створили први божански пар. Када год Ноћ следи иза Дана, Уран се сједињује са својом сопственом мајком. Геу оплођују као сперма, његове капи кише, тако да је родила много деце (*Homeric Hymns*, 30, 17 и *Теог.* 127): шест Титана (Океан, Крej, Хиперион, Јапет, Кеј и Крон-Хронос), шест Титанида (Теја, Реа, Темис, Мнемосина, Фебе и Тетис), три Киклопа (Арг и Стероп = муња, Бронт = гром) и три Хекатонхира, огромних створења са по сто руку: Бриарej (= снажни), Гиј или Гиг (= џин, великих удова) и Кот (= бесан, љутит).

Уран је почео да се брине због броја и снаге своје деце која је стално расла; бојао се да би га једног дана могли гурнути у страну. Зато их је затворио у Тартар, мрачно и хладно место у дубинама земље. Геа, незадовољна Урановим насилним понашањем према њиховој деци и свакодневним силовитим насртајима, произвела је из своје унутрашњости оштар срп или косу и дала га својим синовима, тражећи да осакате оца, лишавајући га репродуктивне моћи. Хронос-Крон (*Kronos*),најмлађи од свих Титана, одлучио је да лично казни божанског оца, и сва његова полубраћа и полусестре, изузев Океана, сложили су се са тим. Када је пала ноћ, Уран, пун страсти, распростreo је своје пространо тело преко Гее, а Хронос му је тада, ограбивши прилику, одсекао гениталије уз помоћ Геиног српа / косе. Од капљица крви које су из ране пале на земљу, били су рођени: три Фурије (Алекта = неуморни ловац криваца,Тисифона = она која кажњава убиство, и Мегара = зла), Гиганти (Енцелад, Порфириј, Палас, Полибиот, Ефиалт, Клитиос, Хиполит, Еурит, Гратион, Агриос, Теон, Алкионеј, Атос, Весвик, и Ехион) и Нимфе Мелијаде, духови мржње и насиља (*Теог.* 182+). Коначно, од пене семена и божанске сперме која је пала у море, изронила је Афродита на обалу Кипра (*Теог.* 187-206).

Уран је видео издају и схватио да је изгубио силу: рањен и пошто је остао без репродуктивне моћи (и сходно томе без божанске снаге), повукао се високо на небески свод, где је заувек остао проклевши Хроноса: да такође изгуби власт од сопственог потомства.

Код Хомера, моћна и праисконска Геа помиње се као надгледник заклетви: богиња Хера је позива заједно са Ураном и светим водама Стикса, када се заклиње (Хомер, *Илијада* XV 36-38). Хомеровски хероји, као што је Агамемнон, такође призивају Геу у својим заклетвама, заједно са Зевсом, Хелиосом и Фуријама (*Илијада* XIX 258-265). Менелај, пре двобоја са

Парисом, тражи да потврди заклетву њиховог споразума жртвујући два јагњета, бело и црно, Хелиосу (Сунцу) и Геи (*Илијада* III 103+).

На крају, постоји и верзија према којој се Геа, после «абдикације» Урана, придружила Океану и родила богове и богиње вода. Ипак, Геа и Уран се не сматрају само родитељима богова, него и људи, као што хомеровска химна Геи «мајци богова», помиње: *"Моли се мени, мајци богова и свих људие"* (*Homeric Hymns*, 1914).

Геа је у уметности ретко претстављена са целим телом. Обично се приказује од струка на горе, чињеница која указује да је остатак њеног тела тло, односно сама земља, чија је она обоготворење.

3. УРАН

Уран, чије име долази од грчких речи *орос* и *ано* (Demetrakos, *Mega Lexikon*, 1964, вол. 10, стр. 5289), што значи онај који је изнад планина (Aristotle, *On the Heavens* (*De Caelo*) 400a, 7), био је у грчкој митологији персонификација небеског свода или куполе, праисконске космогонијске снаге. Био је владалац прве генерације бића на Земљи. Зато Уран има важну улогу у Хезиодовој *Теогонији*, док према псеудо-Аполодору: *"Уран је био први који је владао целим светом"* (*The Library* (*Bibliotheca*), 1921, A, 1, 1).

У Орфичкој традицији, Уран се помиње као син Никс (Ноћи) и брат Гее, док се на другим местима јавља као син Етера и Гее или Никс. У оба случаја, припада првој генерацији бића, најстаријим међу боговима и елементима природе. Према Хезиоду, у преовлађујућој верзији, он је прворођени син Гее, која је затруднела када је спавала близу Ероса, без оплодње, *"да је окружи и буде вечно и сигурно станиште богова"* (*Теог.* 486). У грчкој митологији, Уран је први мушки елемент и отац богова.

Већ смо поменули како је Уран изгубио своју моћ и повукао се на небески свод, где је заувек остао. Тако реч *уранос* на грчком значи небо или небески свод, где се налазе звезде и крећу сва небеска тела: небеса, која се простиру од зенита до хоризонта, посматрана као полулопта смештена изнад земљине површине и придржавана на њој стубовима, дуж линије хоризонта. (*Илијада* VI 108). *Уранос* је место где се одигравају све небеске појаве. Према Хомеру, звезде су причвршћене на њему и крећу се заједно са њим: небески свод је оно што се непрекидно окреће (*Илијада* XVII 425). Свакако, данас знамо да је ова перцепција потпуно погрешна и да «небо» у таквом смислу не постоји.

Пошто је преузео власт, Хронос је ослободио своју полубраћу и полусестре из Тартара. Мало касније, Киклопи и Хекатонхири почели су да доводе у питање његову власт и постали су опасни. Хронос их је зато поново бацио у Тартар и поставио страшно чудовиште, Кампе (= гусеница) да их чува. Ово је време друге генерације бесмртних божанстава, где Хронос влада са супругом Реом и Титанима. Али, растућа окрутност и неправда Хроноса, који је прождирао своју сопствену децу да би избегао да га скину са престола, коначно је навело Геу да помогне Зевсу (грчком аналогу римском

Јупитеру) против Титана, дајући му напитак који ће приморати Хроноса да поврати децу-богове које је прождрао. Овде треба напоменути, да праисконска Геа још увек утиче на токове ствари, појављујући се са решењем у извесним преломним тренуцима.

По савету Гее, Зевс је ослободио и Киклопе и Хекатонхире. Три Киклопа, са њиховим убитачним оружјем, муњама и громовима, и три Хекатонхира са укупно триста руку, успели су да постигну одлучујућу победу против Титана на планини Отрис. Титани су поражени и бачени дубоко у Земљу у Тартар, где их чувају Хекатонхири.

Према професору геологије на Универзитету у Атини, Мариолакису Елиасу: *"Крај Титана значи: i) релативно смањење земљотреса и вулканске активности, и ii) крај директног и одлучујућег утицаја природног окружења на живот преисторијских људи. То је период када су сакупљачи хране и ловци постали фармери и одгајивачи животиња* (Mariolakos, E., 2009, *Geomythotopoi*, стр. 5).

Треба додати да стара грчка уметност није узимала мит о Урану као тему, али ипак, у Ватиканском музеју постоји његова древна представа на кочијама Хелиоса – бога Сунца.

Према алтернативној грчкој традицији, чак вероватно старијој од доминирајућег мита, у почетку су Уран и Геа били веома блиски. Али због његових честих неверстава и незаконите деце са другим женама, Геа се као земља, на крају одвојила од њега и сложила се да га среће само у извесним временским периодима. Са астрономске тачке гледишта, ова традиција је изванредан покушај да се објасни циклус годишњих доба и место Земље у Универзуму, пошто су други дружбеници и деца Урана биле планете и звезде на небеском своду (*Helios Encyclopaedia*, 1957, вол. 4, стр. 920).

Постоје и друге традиције о Геи, попут оне коју помиње Диодор са Сицилије (1935), према којој је то била лепа смртна жена, чије је име Титаја. Њу је волео Уран и имали су 18 деце, који су названи Титани према мајци. Пошто је Титаја била мудра жена, која је учинила многе услуге људима, после смрти, они су је обоготворили и дали јој име Мајка Земља.

4. МАЈКА ЗЕМЉА

Специјално и важно место имао је култ Мајке Земље и врховне богиње, коју су због тога Грци звали *Хипертатан Ган*. Ово пак обожавање, било је упућено Земљи, али не као небеском телу, нити као персонификованом Божанству са људском појавом, него пре свега као хтонској земљи, као делу природе са својим тлом, земљом и подземљем, које храни и одржава људе. Песник-трагичар Софокле (5 век пре н.е.) оптужује човека што се усуђује да узнемирава врховну богињу, пошто не оклева да је повређује *„орући је плугом ,и непрекидно браздајући из године у годину"* (Софокле, *Антигона*, вол. II., стих 330+).

Перцепција земље-природе као свемоћне Мајке Земље треба да је почела у време када су се развила прва пољопривредна друштва и њихови фестивали, пуни мистицизма о основном животном циклусу (клијање – рађање плодова - зрење - труљење - семе - сејање - поновно рађање). Ипак, почевши од преисторијског времена, може се рећи да су први људи, од тренутка када су почели да посматрају живот на Земљи, разумели да су они, као и остатак животињског и биљног света, везани за триптих живот-репродукција-смрт. Преживљавање људи зависило је од земљине вегетације, пошто су дарови природе хранили како њих, тако и животиње које су ловили. (Eliade, 1978).

Пажљиво посматрајући биљни животни циклус, засејавање Мајке Земље после чега је наступало клијање потпомогнуто Урановим кишама, примитивни људи су открили одговарајући циклус животињске сексуалне репродукције. Сходно томе, било је закључено да је земља жива и да би дала живот требала је да дође у додир сса мушким ентитетом. Због тога су људи персонификирали Земљу као женски ентитет, док је оплођујући мушки, било небо са кишом, или нека велика река, као што је у Египту божански Нил (стара египатска религија је једина у којој је небо персонификовано као женско божанство Нут, види Theodossiou 2007, стр. 28).

Мајка Земља (Terra Mater) је, услед широког карактера њеног култа, у грчкој литератури понекад идентификована као Реа, Хестија, Хера, али углавном као Деметра, чије име долази од Ге-метер = Земља-мајка, означавајући материцу која окружује семе. Заиста, култ Гее као богиње Мајке Земље опадао је са временом, али никада није потпуно ишчезао, и био је замењен боље дефинисаним култом Деметре као богиње земљорадње; Геина улога је тако сведена на ону која даје сан, прича приче и храни биљке и децу.

Чудесни божански спој Урана-Неба и Земље, из кога су рођени богови, људи и сва жива бића, рефлектован је у узвику Елеузијских мистерија *‘хие, кие (hye, Kye)’*; којим су учесници позивали Небо да проспе оплођујућу кишу, тако да земља (персонификована као Деметра) може да употреби своју материцу да створи све врсте плодова.

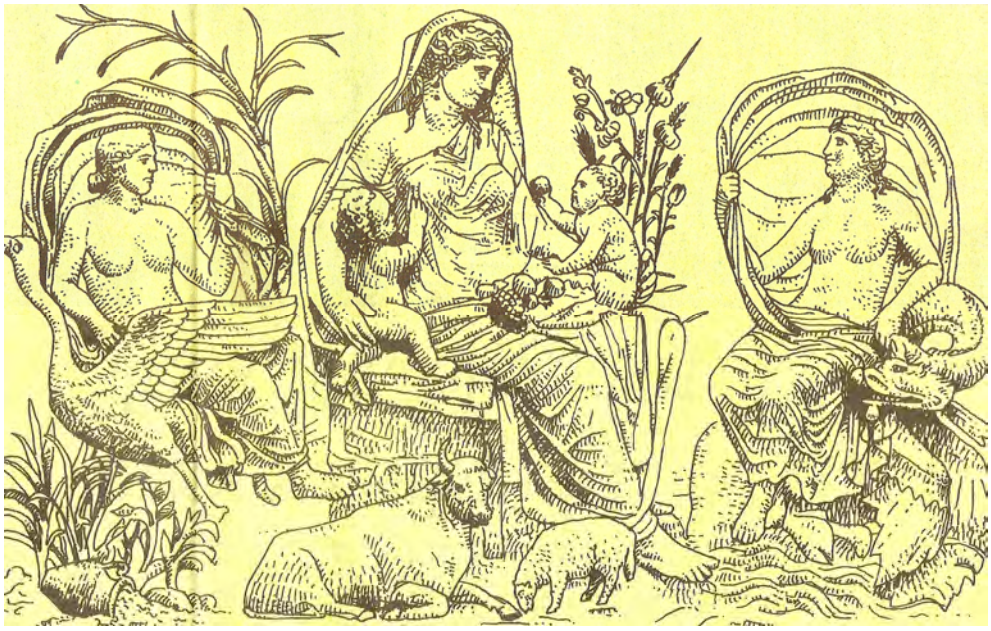
Насупрот Геи, која је деификација нашег света-планете, Мајка Земља је у суштини обоготворење тла-земљишта, чији производи одржавају људе и дају им простор на коме су рођени, живе и умиру.

Присуство Гее као првобитног елемента-субстанце и божанства, види се и у оснивању првог пророчишта које се обраћало само боговима. Касније је идентификована са Мајком Земљом а њено пророчиште је основано у Делфима; због чега су је такође називали ‘протомантис’ = прва пророчица (Aeschylus, *Eumenides, Pythias* 2). Пророчиште у Додони такође је посвећено Геи; ту је обожавана са Зевсом као „она која даје плодове и мајка“ (Pausanias, *Phocis* 12, 10).

Плиније Старији пише у *Naturalis Historia* да Небо припада боговима а Земља људској раси. Земља нас дочекује када смо рођени, храни нас да би

порасли и прихвата нас у своја недра када умремо. Земља пати од људских активности, када разарају њену површину и засецају њено тело када траже злато, сребро, бакар и олово; људи отварају окна у њене дубине тражећи драго камење и копајући по њеној унутрашњости (Pantermalis, *Ancient Greek mines*, 1995, стр. 42).

Коначно, питања о Земљи, како их је сумаризовао Аристотел (*On the Heavens*, II 293a, 15+), кулминирају питањима о месту Земље у Универзуму, њеном тачном облику и размерама.



Слика 1: *У време императора Августа (1 век) људи су сликали Земљу, као милу мајку са двоје деце у наручју, у цветајућем природном окружењу. У 'Naturalis Historia' Плиније Старији је нагласио неке претеће моменте: писао је да људи ископавају Земљину утробу ријући рударска окна изнад којих живимо; чудимо се када се отварају процепи или тло се тресе, као да ти знаци нису израз гнева свете мајке. Унутар мрачних ходника трагамо за благом, као да тло на површини земљишта није довољно богато и дарежљиво.*

5. ПАР НЕБО И ЗЕМЉА

Може се навести као закључак да се у грчкој космогонији, као и у митовима о стварању код других индоевропских народа, велика стваралачка активност која се непрекидно одвија у природи описује следећом једноставном сликом: Божански пар, први при стварању, рађао је и још рађа

сва бића. Оплођујући «отац» је у овом случају Уран а рађајућа «мајка» Геа, која такође храни своју децу.

Овај први божански пар је спојио Ерос, и у еротско-космогонијском симболизму Небо-Уран грли и оплођује Земљу-Геу помоћу кише. Њихово спајање је претстављено као свемогућа репродуктивна способност, која умножава број богова, што је славио Орфеј (Проклус у *Tim.* 3, стр. 137, 11) као стварање првобитног Хаоса (или Ереба) и Дана (*Orphic Hymns* IV: *Incense to Uranus*, и XXVI: *Incense to Earth*).

Иза овог истог симболизма је и спајање Семеле (која персонификује Земљу) и Зевса, небеског бога који оплођује вољену жену мућом, претечом кише. 'Земаљску' Данају је на исти начин оплодио „небески" Зевс претворен у златну кишу. Метафорично, небески бог је својом благотворном водом омекшао сасушену материцу Земље ради развијања живота.

Пошто су Мајка Земља и Уран били прародитељи живота, људи (који зависе од земљине вегетације) треба да стишавају или пак изазивају бога Урана да се чешће спаја са Мајком Земљом због богатије производње.

Космогонијска тема првобитног пара Неба и Земље налази се не само код старих Грка, него и код скоро свих старих цивилизација. Према неким научним чињеницама, многа преисторијска друштва била су у матријархату ('matriarchy' у *The New Encyclopaedia Britannica*, 2007)

Прва људска друштва била су интимно свесна природе. Веровала су да људи, животиње, биљке, стене и минерали, сви потичу од Мајке Земље, и да сходно томе све има душу и свако живо биће има иста права на живот.

У праскозорју историје, људска друштва су поштовала друге облике живота пошто су знала да су разлике само морфолошке. Народ је веровао да је киша спајање Неба и Земље (мушког и женског). Знали су да све зависи од тога догађаја, укључујући преживљавање других форми живота на Земљи.

Треба додати да су грчки пресократовски природни филозофи сматрали да су Земља и Небо непрекидно тело спојено на крајевима хоризонта.

Земља хомеровског Универзума била је кружни раван диск опкољен огромном реком, Океаном, модел који се први пут појавио у *Орфичкој химни* Х. ПАНУ, *Кађење различитим мирисима'*, стих 15: *"Стари Океане такође дубоко поштују твоју врховну наредбу, којом течне руке окружују чврсту Земљу."* Ова митска „река" разликује се од мора: она је нешто што дефинише границе земаљског света. Пре свега, Океан је првобитни и оригинални стваралачки елемент, полазна тачка свих ствари (*Илијада*, XIV 246). Ова митска «река» нема извора, нити ушћа, она је «апсорроС», т.ј. циклично се креће или тече уназад. Њен ток враћа се где је почео у непрекидном и бесконачном кретању. Океан подржава небо, које је изнад Земљиног кружног диска као огромни свод.

У *Орфичким химнама*, Небо је поменуто као владалац Света, који окружује Земљу као сферу; оно је станиште богова и окреће се као вртећа лопта; персонификовано, штити све, не само на своме месту него и на Земљи: *"Уране владару света, који се вртиш као лопта око Гее, доме*

благословених богова, који се крећеш вртложно, чувајући свакога на небу и земљи" (*Орфичке химне*: IV, *Тамњан Урану*).

Са друге стране, Небо је за старе Грке било метални свод начињен од бакра или гвожђа који држе веома високи стубови, или, према другом гледишту, неки див. Хомер комбинује ова два погледа и има Атласа који придржава стубове (Хомер, *Одисеја* i 53-54). Хезиод у *Теогонији* (517e) пише да је Зевс доделио ту дужност Атласу. Небо је према Хомеру било начињено од чврстог металног матерјала званог «полихалкис» т,ј. «од много бакра» (*Илијада* V 504, *Одисеја* ii 458, iii 2, *Илијада* XVI 364, XIX 351), «бакра» (*Илијада* XVII 424-425) или «гвожђа» (*Одисеја* xv 329 и xvii 565).

Простор између неба и Земље, према погледима које је забележио Хомер, прво је био испуњен густим ваздухом: *аер* (*Илијада* XIV 288). Преко овог слоја и у правцу неба, био је чист и прозиран «етер», лакши од ваздуха. Изнад њега било је «полихалкис» небо.

Свакако, не треба претпостављати да је хомеровско небо било јалова метална купола; како Хомер пева, оно је било пуно живота, живота звезда које га украшавају: он небо назива „пуним звезда" („астероеис") (*Илијада* VI 108, XV 371) и украшено звездама (*Одисеја* ix 534-535). На овој небеској куполи, Хелиос, бог Сунца, креће се својом путањом, тако да је описан придевом «уранодромос» односно «по небу путујући» (*Одисеја* i 7-9).

6. СУНЦЕ И БОГ СУНЦА ХЕЛИОС

Од преисторијских времена, људи су се дивили ноћном звезданом небу, са хиљадама голим оком видљивих звезда које трепере на његовом своду. Али њихова радост је била највећа у зору, "рујнопрстаста (ружичастопрста) Еос-Еја" (Хезиод, *Works and Days*, 609), када је дифузна сунчева светлост постепено надвладавала таму ноћи пуне страха. Природно су обожавали Сунце које даје светлост, пошто су схватали да све на Земљи дугује постојање и живот деловању његових зрака.

Према археологу Хр. Г. Думасу: *"Реч „алс" код Хомера значи море када се посматра са копна. Присуство овог корена на таблицама са списима линеарним Б писмом као компоненте других речи, индицира дуготрајну употребу, у току које је еволуирао у вишезначну именицу треће деклинације, која се лако спаја са другим кореновима… чињеница да се оригинални корен толико много и на различите начине употребљава у грчком језику, нпр. Алиос / хелиос [= сунце], показује како блиску повезаност егејског друштва са морем, тако и велики утицај течног елемента на историју и културу тога времена."* (Doumas, 2010, *The ancient monuments of the names*, стр. 16).

"Заиста од „алс" (генитивни облик „алос") долази придев „алиос" који, мада се препознаје као дорски облик за „хелиос" = сунце, у суштини значи онај који је повезан са морем... Сликање Сунца на прото-Кикладском посуђу различитих облика из трећег миленијума пре н.е., вероватно указује на

значај који су му давали Киклађани тога времена. Острваљани Егејског мора и становници источних обала Грчке видели су сунце како се сваког јутра диже из мора" (Doumas, 2008, *The aligenes Aegean Sun*, стр.15), како је описано у првим стиховима Рапсодије iii у *Одисеји: "Када се Сунце, напуштајући језеро, уздигло према свебакарном небу да би сијало како бесмртницима тако и смртницима на животодавној Земљи…"*.

Сунце је „зрачеће", „пламено" и као такво симболизује небеску представу универзалног оца, и у суштини представља Божији дух. (Demetrakos, 1964, вол. 7, стр. 3250). Појава Сунца ујутро, кулминација у подне и величанствени нестанак током ноћи (или за време помрачења) веома су утицали на људску мисао. Тама, која је падала свако вече после заласка Сунца, испуњавала је душу примитивног човека узнемирујућим питањима. Временом су му придодали натприродна, божанска својства, пошто се „Он" као бог могао појавити и нестајати по вољи, како дневно, тако и за за време много ређих помрачења.

Сви стари народи обожавали су светло- и живото-давно Сунце. Оно је било Самас за Асирце, Бел за Семите, Бел-Мардук за Вавилонце, Ел или Уту за Сумере, Баал за Феничане и Хананце, Молох за Амоните, Химох за Моабите, Амон-Ра за Египћане, Сурија за Индусе, Митра за Персијанце, Инди за Инке, Тонатиух за Ацтеке, Сол за Римљане, Дајбог или Дажбог за Словенска племена, Беленос за Келте, Хелиос и Феб-Аполон (симбол сунчеве светлости) за Грке. Култ Сунца био је универзалан и доминантан, пошто је за старе народе оно било извор живота, светлости и топлоте, гарант небеског поретка часова у току дана и годишњих доба у току године, стваралачка сила за природу, и много свакодневније, помоћ при оријентацији. Софоклеовски исказ *"свако обожава кружећу сунчеву лопту"* (Achilles Tatius, 1917, frag. 672 Nauk[2]), тачан је за сва времена **(**Sophocles, *Trachiniae*, 738, 2).

7. СУНЦЕ-ХЕЛИОС У ГРЧКОЈ МИТОЛОГИЈИ

У Хомеровој *Илијади* и *Одисеји* (око 8. века пре н.е.) спољашњи аспекат сјајне појаве Сунца посебно је наглашен заједно са појмовима повезаним са његовим изласком и заласком. Према Хезиоду, бог Сунце Хелиос, био је син Титана Хипериона и Теје (*Теог.*, 371-372), или Хипериона и Еурифесе (*Хомеровска химна Хелиосу* 31, 2), док су му сестре биле Селена (богиња Месеца) и Еос (Еја персонификација зоре). Пиндар слави Теју као Хелиосову мајку у петој *Истмијској оди*:

"Мајко Сунца, Тејо са много имена, због тебе људи одају почаст злату као најмоћнијем од било чега другог; и кроз вредност коју си му даровала, о краљице, процењују бродове…"

Као Титани, Теја и Хиперион (= онај који иде изнад Земље) припадају истој генерацији као и Хронос; сви су деца Гее и Урана (Patsi-Garin, 1969).

Хомер назива Хелиоса „Хиперионид“ (*Одисеја* xii 176), наглашавајући његове конкретне везе са животом, пошто од рођења, људи посматрају сунчева свитања: живе *“под звездама неба и светлошћу Сунца”* (*Илијада* IV 45), радујући се када виде *“сјајно светло Сунца”* (*Илијада* V 120). Када неко умре *“он напушта светлост Сунца“* (*Илијада* XIX 2).

За Хомера је Сунце бог који *“све види и све чује”* (*Илијада* III 277). Ово његово својство наглашава се придевом *„панoптес*“ (Aeschylus, *Prometheus Bound* 91), *„надгледник свега*“ (Aeschylus, *The Libation Bearers*, 982-986), “*доминирајући погледом*“ (Sophocles, *Trachiniae*, 101). И у многим другим референцама старих грчких песника-трагичара наглашава се ова „свевидећа“ способност, која га претвара у гаранта држања заклетва; Хелиос је увек био сведок истине (*Homeric Hymn* 3, 381, Sophocles: *Oedipus Tyrannus* 660), *“путоказ правде, чувар држања заклетве, око правде (Орф. Химна* 16).

У грчкој митологији уопште, Сунце се представља као бог који путује око Земље и надгледа дељење правде, просипајући светлост на добро и зло (Segal, C.P., 1992, стр. 3-29, McCarthy, D.J., 1978, стр. 185, West, M.L., 1997, стр. 20).

Сматрао се као врло важан бог, и Хомер наводи да су жртве приношене Геи и Хелиосу (*Илијада* III 104, 276). Што се тиче његових осталих атрибута, Хелиос је обожаван у Коринту (Pausanias, *Corinth* књига II, 3:2, 4:6 и 5:1) као бог непогода, грмљавине и других небеских сила.

Осим тога, сугерисано је да је „Коњ споменик“ (Pausanias, књига III 20, 9) са седам *“стубова… … које су кажу статуе планета”*, припадао његовом култу. У Хермиону се такође налази храм посвећен овом богу (Pausanias, вол. II, 34, 10). Заиста, у хришћанској цркви у Таксиархесу, нађен је део кружног олтара из 3. века са следећим натписом: *“Хелиосу краљу богу, Хипериону олтар…”* (Jameson, M. and Runnels C.N., 1959, стр. 15).

Специјалан положај Хелиоса у односу на Олимпијске богове (мада није један од 12 њих), повезан је са његовим значајем за живот Олимпијаца. Диодор (*Bibl. Histor.* V 71) пише да је пре битке са Гигантима Зевс принео жртве Хелиосу, Урану и Геи. Зато Есхил каже да је он «*надгледник свега*» (Aeschylus, *Eumenides,*).

Од око 5. века пре н.е. и касније Хелиос губи свој статус у потпуности јединственог божанства и почиње да се меша са Аполоном, олимпијским богом сунчеве светлости. После битке са гигантима, био је идентификован са Зевсом, који је, као небески и олимпијски бог повезан са небеском светлошћу, укључио његову божанску супстанцу. Ипак, постепено увећање Зевсове силе, принудило је Хелиоса да од њега одвоји своју супстанцу коју је онда преузео Аполон да би постао божанство са више карактеристика правог бога Сунца. Идентификација Хелиоса са Фебом-Аполоном (фебус = сијајући) је трасирана кроз целу античку грчку литературу после Парменида

и Емпедокла (Diels, 1996, *Vorsokratiker*, I^2 108, 29.157, 10 и DK –Diels-Kranz, 1996, 28 A 20, 31 A 23), све до Плутарха и Крата Асконда из Тебе.

Ератостен извештава о томе (Spandagos, 2002, 24) пишући да Есхил, у једном од својих радова, сугерира да је Орфеј идентификовао Хелиоса са Аполоном и поставио га у средиште свога култа, одбијајући да слави Дионизија. Слично је, у *Сатурналијама* Макробија, написано: '*Item Orpheus Liberum atque Solem unum esse deum eundemque demonstrans de ornatu vestituque eius in sacris Liberalibus ita scribit'* (*Saturnalia* 1.18.22, фраг. 238).

Али без обзира што ова Хелиос-Аполон идентификација почиње бар од 5. века пре н.е., није била широко прихваћена вековима касније.

Према Хомеру, Хелиос почиње своје путовање из источног океана или из Етиопије, земље „људи опаљених сунцем", сваке зоре (*Одисеја* I 24-26); он прелази небо у својим двоколицама које вуку четири лепа крилата коња којима из ноздрва излази ватра: Еус, Етиопс, Бронта и Стеропа (Hyginus, *Fabulae* 183):

"Еус; он окреће небо. Етиопс, када баца пламен прљи зрневље. Ови коњи су мужјаци. Женке носе јармове: Бронта коју зовемо Гром, Стеропа, коју зовемо Муња"

Ова имена коња алудирају на снагу Бога, сукцесију небеских појава и сазревање воћа. Неки аутори извештавају о другим именима Сунчевих коња: Лампон, Етопс, Етон и Флегон (Gelling & Davidson, 1969, стр. 14+; Glob 1974, стр. 99-103, и Green 1991, стр. 64-66, стр. 114+). Сваке вечери Хелиос заокружује своје путовање и одмара се на Западу у земљи Хесперида.

Појам 'ватрености' или 'пламене' природе Хелиоса је веом присутан код грчких песника трагичара: *"испечен ватром сунца"* (Aeschylus, *Prometheus Bound* 22), *"Високо изнад земље, где његову вечну ватру…"* (Euripides: *Ion* 34), *"Врели пламен Краља"* (Euripides, *Phaethon* 776). Еурипид описује излазак Сунца на следећи начин: *"Сада пламте зрачећа кола Сунца / високо изнад земље, где његову вечну ватру / звезде у светој ноћи понављају"* (Euripides, *Ion* 82-84). Овај опис је често упоређиван са представом Хелиоса на грчкој вази из 5. века пре н.е., која се чува у Британском музеју; овде је он претстављен са зрацима окруженом главом, како се вози се на двоколицама са четири крилата коња, и излази из мора, у коме пливају особе дечјег изгледа, што означавају звезде које иду да се сакрију.

Пошто употпуни свој дневни пут преко небеског свода, сваке ноћи се одмара на златном кревету начињеном чекићем бога Хефеста (Вулкана), да би следећег дана опет обасјао свет.

Хелиос је имао много синова и кћери. Са Океанидом Персејом имао је троје деце: Кирку, Пасифу и Аетес (Apollonius, *Argonautica* 3, 1, 2 и Хомер, *Одисеја* XII 3). Кирка је била чувена због магичних моћи и љубави према Одисеју (*Теогонија*,957). Пасифа, жена краља Миноса са Крита, поистовећивана је са Месецом и сматрана за првобитно божанство светлости, како њено име показује (пасифеса = јавља се свима). Захваљујући Пасифи култ Хелиоса је широко распрострањен на Криту, где је он био

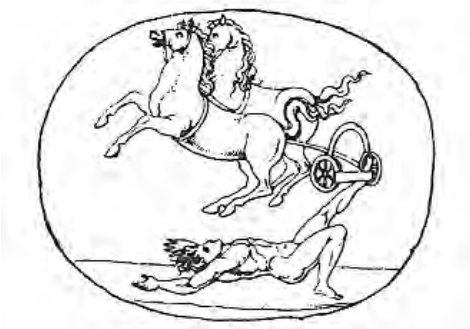
представљен у облику бика (Bekker, 1814-1821, *Anecd. Gr*. 344, 10). Мит о Пасифи која се заљубила у бика (Зодијакално сазвежђе Taurus = Бик) одражава веома стару традицију, према којој су светим браком сједињени бог-сунце у облику бика и богиња-месец у лику краве.



Слика 2: *Цртеж тушем: Излазак Сунца са његовим двоколицама са четири крилата коња. Ишчезавајуће ноћне звезде су претстављене као деца која нестају у мору (Грчка ваза, 435 пре н.е. – Британски музеј).*

У другом миту, Етес је био краљ Еје, који је одбио да да Златну стрелу (симбол сунчеве светлости) Јасону и Аргонаутима.

Хелиос је и са Клименом имао две кћери, Фетусу и Лампетију и сина Фаетона. Једном је Фаетон добио дозволу од свога оца да пређе преко неба у његовим колима. Када је видео огромно сазвежђе Шкорпију уплашио се и изгубио контролу. Коњи су се узнемирили и кола су почела да иду горе доле претећи да униште Земљу. Да би спасао свет Зевс је муњама убио Фаетона. Тело му је пало на обалу реке Еридан. Његове сестре, Хелијаде, које су га жалиле, претворене су у тополе, свето дрвеће бога Хелиоса, а њихове сузе су постале ћилибар.



Слика 3: *Цртеж тушем: Пад Фаетона.*

‘Фаетон’ је такође било име које је Хелиос дао себи због зрачеће светлости (*Илијада* XI 730, *Одисеја* v 479, xi 15, *Homeric Hymn* 31.2). У *Теогонији*, Хезиод пише о Фаетону и Хипериону као ‘супстанцама’ бога

Хелиоса (*Теог.* 987 и Nagy, 1990, стр. 235). Осим тога, Фаетона помињу и Нонус (*Dionysiaka* 38.167) и Овидије (*Metamorph.* 2007, 1.747-79: *Phaethon's parentage, struggle with Epaphos* и 2.42: *Phaethon and his father*).

Хелиос је према грчкој митологији, такође одржавао и бројне везе са другим женама, тако да је имао још много синова и кћери, који су у старој грчкој литератури заједнички називани Хелијади.



Слика 4: *Цртеж тушем метопа Атининог храма у Илиону (Троја) са рељефом који приказује Хелиоса чија је глава окружена зрацима, који стоји на двоколицама, вероватно заснован на старијем раду Лизипа (Градски музеји, Берлин).*

Чувени центар Хелиосовог култа био је Родос; како извештава Пиндар (*Olymp. Ode* 7, 69), припадало му је цело острво. Чувени Колос био је џиновска статуа Хелиоса (она је била једно од седам чуда старог света), дело родоског вајара Хареса са Линдоса (Pliny, *Historia Naturalis* 34.63), Лизиповог ученика (3. век пре н.е.). Сваке четири године на острву се славио фестивал Сунца, који се звао Али(ej)а или Хелиеја (Nilsson, 1906, стр. 427), за време кога су му жртноване четворопреге двоколице, које су бацане у море. Хелиос је боравио на Родосу са Нимфом Родос, Афродитином ћерком, са којом је имао седам синова који су се звали: Охим, Керкаф, Актис, Макар, Кандал, Триоп и Тенаг, а њихову мудрост је славио Пиндар (*Olymp. Ode* 7, 72-75).

У грчкој уметности, персонификовано Сунце је често представљано у облику младог човека који носи венац са зрацима и тунику, и стоји на двоколицама са четири коња, као на метопу Хеленистичког храма у Илиону (Троја).

Од већег астрономсог интереса је Хелиосова статуа у Ватикану. Ту је представљен као млади човек који носи венац са зрацима, и има широки појас са симболима зодијака.

Осим тога, постоји традиција, коју међу осталима помиње и Хомер (*Одисеја* xii 127), да је на острву Тринакрији (Сицилија), Хелиос имао седам стада говеда и седам стада оваца, од којих је свако имало по педесет грла. Она су ишла на пашу сваки дан, не добијајући никад више или мање. Према

објашњењу које је дао Аристотел, лунарна година се састоји од 50 недеља, од којих свака има 7 дана и 7 ноћи, па сходно томе 50 пута 7 говеда и 50 пута 7 оваца означава 350 дана и 350 ноћи, што чини лунарну годину коју су према оригиналним прорачунима (Theodossiou & Danezis, 1995, стр. 315), користили стари Грци.

Култ бога Сунца био је универзалан, а веома старе активности, повезане са њим, као што је оријентација храмова више религија према истоку, до данас су се сачувале у свести људи.

8. СЕЛЕНА, МЕСЕЦ

Према Хезиодовој *Теогонији*, Селена је била кћер Хипериона и Теје и сестра Еос - Еје (Зоре) и Хелиоса, који је вечно осветљавају захваљујући њиховим односима као полубраће. Реч *селене* долази од *селас* = светлост (Demetrakos *Mega Lexikon*, 1964, вол. 13, стр. 6489). У грчкој митологији, Селена или Селана (Pindar, *Olymp. Ode* 10, 75) је прво и једино месечево божанство, бар у пре класичној и класичној поезији, такође називано Егла, Пасифа, Мена, Титанида (као ћерка два Титана) и Феба, као сестра Феба-Хелиоса. Како се грчка митологија развијала, друге богиње су повезиване са Месецом: Хеката, Артемида и Хера.

Селена је обично представљана у женском облику са полумесецом као круном, како јаше коња или у двоколицама са два крилата коња (дифрос). Понекад се описује како води стадо стоке, тако да њена круна у облику полумесеца подсећа на рог бика. Њен брат Хелиос вози се на двоколицама са четири крилата коња, а Селена са два; они имају једну страну белу а другу црну, метафора која значи да је само једна страна Месеца осветљена сунчевом светлошћу.

Према различитим локалним традицијама Селена је са Аером (ваздух) имала кћер Дросу (јутарња роса). У Атичкој традицији родила је Пандију, Зевсову ћерку (*пан* + *диа* = све-божанска), која је заједно са својом мајком обожавана на Пандијском фестивалу. У Аркадијској традицији Месец је била љубавница бога Пана и заједно са њим обожавана је на аркадијској планини Ликајо. У Елису и Карији веровали су да је била заљубљена у смртног човека, Ендимиона, са којим се сваке ноћи сретала на планини Латмос, и да је са њим имала 50 кћери, колико лунарних месеци има у једној Олимпијади.

У традицији касне антике коју наводи Квинт Смирнеус (*Fall of Troy*, 10. 334 ff*)*, Селена је имала љубавну везу и са братом, Хелиосом. Најстарија позната представа бога Сунца у грчком вајарству је на источном забату Партенона, где је представљено рођење богиње Атине. Хелиос и Селена такође уоквирују композицију рођења Афродите, на престолу Зевсове статуе у Олимпији (Pausanias, вол. II, Elis 1, књига 5, 11, 8) а на сличну представу алудира „залазак сунца“ на забату храма у Делфима, који помиње Паузанија (Pausanias, *Phocis*, Vol. IV, књига X 19, 4: *The temple at Delphi*).

Култ Селене био је распрострањен широм Грчке, али нарочито на Пелопонезу. Познато је из историје Персијских ратова, да су Спартанци, приликом отпочињања војних похода, озбиљно узимали у обзир месечеве фазе. Близу града Таламеса било је познато Селенино пророчиште, где су спартански ефори остајали преко ноћи тражећи њен савет; а локални извор је добио име по њој (Pausanias, *Laconica*, вол. II, књига 3, 26, 1).

Пар Хелиос-Селена довођен у везу и са олимпијским паром Аполон-Артемида, коме су приписиване сличне карактеристике, заједно са истим симболима: за Селену то је било сребро, рогови бика и полумесец.

На симболичком нивоу, Месец је женска компонента стварања света и улаз (захваљујући његовом „тајном“ појављивању ноћу) према апокрифној природи човечанства и Универзума, т.j. према ономе што се не може изразити уобичајеним посматрањем природе. Месец је светлосна слика цикличног времена; представник непрекидног тока свега. Бесконачни млади месеци симболизују бесконачне тренутке времена сваког краја који најављује нови почетак.

Селена је хтонско божанство у антитези Сунце-Земља, светло-тама. Са друге стране, она је богиња са белим рукама која разгони таму ноћи када је пуна. Рујнопрстаста Еос-Еја (зора), Селенина сестра, доноси прву светлост новог дана. Хеката, хтонско божанство са три облика, је још један њен вид; Хоре, Часови или годишња доба, сматрају јој се за кћери. Друга метафора Месеца је огромна сјајна *клепсидра*, водени сат, који се пуни за време његовог раста а празни за време опадања. Помоћу смене својих мена он даје и меру времена.

Старогрчки песници трагичари претстављали су Селену-Месец као веома лепу младу жену пред којом су бледеле све друге звезде, када се њена сребрнаста фигура појави на небеском своду.

9. ЗАКЉУЧЦИ

Од најстаријих времена људи су обожавали примарни божански пар, богињу Геу и бога Урана, који су били преци других богова што су дали своја имена планетама Сунчевог система. Хезиодова *Теогонија* почиње са богињом Геом и завршава се политеистичком владавином олимпијских богова.

Уран окружује Геу и оплођује је. Супротно богињи Геи, деификација наше планете, Мајка Земља, је у основи обоготворење тла и земљишта, чији производи одржавају људе и пружају им простор на коме живе и умиру. Настанак природних елемената одвија се паралелно са рађањем богова, који се метафорички понашају као људи. Хронос симболизује Време, Реа ток а Хера (анаграм од Аер) ваздух заједно са променама времена.

Светлост дајући Хелиос, Сунце је извор свих облика живота на Земљи. За све људе, Небо, Сунце, Земља и Месец (нарочито пун Месец ноћу) чине се као одговарајући вечни сведоци човекових дела и природни осветници

преваре. С друге стране, зраци Сунца који падају на Мајку Земљу после кише-сперме са Неба, створили су прва жива бића.

Од астрономског значаја је небески свод, где у време дана влада свевидећи Хелиос а ноћу се виде звезде и бледи лик Селене-Месеца.

У далекој прошлости, Месец је био узрок дефиниције месеца и недеље, и стварања првих (лунарних) календара; његова улога је била суштинска за проналазак религијских календарских система старих народа, што се и до данас одржало у исламском свету и у одређивању датума хришћанског Ускрса и јеврејске Пасхе.

Литература

Achilles Tatius: 1917, са енглеским преводом: S. Gaselle, Heinemann, London & G.P. Putnam's Son, New York.

Aeschylus: 1989, *Eumenides*. Ed. Alan H. Sommerstein, Cambridge University Press, Cambridge.

Aeschylus: 1983, *Prometheus bound*, Greek and Latin Classics. Ed. Mark Griffith, Cambridge University Press. Cambridge.

Aeschylus: 1984, *The Oresteia: Agamemnon, The Libation Bearers, The Eumenides.* Ed. and Intr. by W.B. Stanford, trans. by Robert Fagles, Penguin Press. New York.

(Pseudo)Apollodorus: 1921, *The Library* I (*Bibliotheca*), trans. by J. G. Frazer. Vol I Books 1-3.9, Vol. II, Book 3.10-to end. Epitome. The Loeb Classical Library, Harvard University Press, No. 122, Heinemann, London (reprint 1995).

Apollonius Rhodius: 1962, *Argonautica*, trans. by R. C. Seaton, The Loeb Classical Library, Harvard University Press, Heinemann, London.

Aristotle: 1956, *On the Heavens* (*De Caelo*), trans. by W.K.C. Guthrie, The Loeb Classical Library; Harvard University Press, Heinemann. London. (reprinted 1936, 1947, 1953, 1956).

Bekker, A. I. (ed.): 1814-1821, *Anecdota Graeca*, 3 vols., Berolini.

Demetrakos, D.: 1964, *Mega Lexikon olis tis ellinikis Glossis*, Publ. Ch. Tegopoulos - B. Asimakopoulos, Athens [на грчком].

Diels, H.: 1996, *Die Fragmente der Vorsokratiker*, Herausgegeben von Walter Kranz. Erster Band - Zweiter Band, Weidmann, Zürich.

Diodorus Siculus: 1935, *Bibliotheca Historica*. *Library of History* (Books III - VIII), trans. by C. H. Oldfather, The Loeb Classical Library Volumes 303 and 340. Harvard University Press. Heinemann. London.

Doumas, Ch. G.: 2008, "The aligenes Aegean Sun" in: *Kathimerini - Technes & Grammata*, December 7, Athens [на грчком].

Doumas, Ch. G.: 2010, "The ancient monuments of the names" in: *Kathimerini - Technes & Grammata*, February 14, Athens [на грчком].

Eliade, M.: 1978, *A History of Religious Ideas*, vol. I, *From the Stone Age to the Eleusinian Mysteries*, trans. by W. Trask, IL: University of Chicago Press. Chicago.

Euripides: 2004, *Ion*, transl. by Robert Potter, ebooks@Adelaida, on line: http://classics.mit.edu/Euripides/ion.html.

Euripides: 1996, *Phaethon*, Ekdoseis tou 21ou, Athens [на грчком].

Gelling, P. and Davidson, H. E.: 1969, *The Chariot of the Sun*, Dent. London.

Glob, P. V.: 1974, *The Mound People*, Faber. London.

Green, M.: 1991, *The Sun-Gods of Ancient Europe*, B.T. Batsford, London.
Helios Encyclopaedia: 1957, Edition of Helios, Athens [на грчко].
Hesiod: 1914, *The Homeric Hymns and Homerica (Theogony)*, trans. by H. G. Evelyn-White. The Loeb Classical Library, Heinemann, London (reprinted 1954).
Hesiod: 2006, Volume I, *Theogony*. *Works and Days*. *Testimonia*. Ed. & trans. by Glenn W. Most. The Loeb Classical Library, No. 57N, Heinemann, London.
Homer: 1919, *The Odyssey*, trans. by A. T. Murray, revised by G. E. Dimock. The Loeb Classical Library, Heinemann. London (reprinted 1995).
Homer: 1924, *The Iliad*, trans. by A. T. Murray. The Loeb Classical Library, Heinemann. London (reprinted 1954).
Homeric Hymns: 1914, by Hugh G. Evelyn-White, Cambridge, M.A., Harvard University Press. Heinemann. London.
Hyginus, 1993, *Fabulae. Editio altera*. Ed. Marshall, P. K. (corrected ed. 2002), K. G. Saur, Munich.
Jameson, M. H. and Runnels C. N.: 1959, *A Greek countryside: the southern Argolid from prehistory to present day*. Stanford University Press, Stanford, California (repr. 1994).
Kern, O.: 1922, *Orphicorum Fragmenta*, Weidmann. Berlin.
Macrobius: 1969, *Saturnalia*, trans. by Percival Vaughan Davies, Columbia University Press. New York.
Mariolakos, Elias (ed.): 2009, *Geomythotopoi – Geomythological courses of Phthiotis*, Publ. of the Local Union of Boroughs and Communes (TEDK) of Phthiotis Prefecture [на грчком].
McCarthy, D. J.: 1978, *Treaty and Covenant* 2, Pontifical Biblical Institute, Rome.
Nagy, G.: 1990, *Greek Mythology and Poetics*, Ithaca. London.
Neoteron Encyclopedicon Lexicon Iliou, 1957, vol. 4, Ilios Publications, Athens [на грчком].
Nilsson, M. P.: 1906, *Griechische Feste von religiöser Bedeutung mit Ausschluß der Attischen*, B. G. Teubner, Leipzig.
Nonnus, *Dionysiaca*: 1940, Vol. I, Books 1-15, trans. by W. H. D. Rouse. The Loeb Classical Library No. 344. Heinemann. London.
Orphic Hymns: 1997, Ideotheatro Publications-R. Anastasakis, Athens [на грчком].
Ovid: 1857, *The Metamorphoses*, trans. by Nathan Covington Brooks, 5th ed., A. S. Barnes & Co., Cincinnati; H. W. Derby & Co., New York.
Pantermalis, D.: 1995, "Ancient Greek mines", in *Kathimerini*, April 9, Athens [на грчком].
Patsi-Garin, E.: 1969, *Epitomo Lexikon Ellinikis Mythologias*. Editions Hari Patsi, Athens [на грчком].
Pausanias: 1918, *Description of Greece*, Books I & II. *Attica and Corinth*, Edit. & trans. by W. H. S. Jones, The Loeb Classical Library, Heinemann. London.
Pausanias, *Description of Greece*: 1935, Vol. IV. Arcadia, Boeotia, Phocis and Ozolian Locri, Books 8.22-10, trans. by W.H.S. Jones. The Loeb Classical Library No. 297. Heinemann, London.
Pausanias: 1935, Description of Greece, Volume II (Laconia, Messenia, Elis 1) Books 3-5, trans. by W. H. S. Jones and H. A. Ormerod. The Loeb Classical Library No. 188. Heinemann, London.
Pindar: 1997, *Nemean Odes*, *Isthmian Odes*, *Fragments*. Edit. & trans. by W. H. Race, The Loeb Classical Library No. 485. Heinemann, London.
Pindar, *Olympian Odes*, trans. by T. K. Hubbard, via the Perseus Project at Tufts University.

Pindar: 1997, *Olympian Odes*, Pythian Odes. Edit. & trans. by W. H. Race, The Loeb Classical Library No. 56. Heinemann, London.

Pliny: 1971, *Natural History* (*Historia Naturalis*), trans. by H. Rackham, The Loeb Classical Library. Harvard University Press. Heinemann, London.

Proclus: 1820, *The commentaries on the Timaeus of Plato*, 5 Books. Edit. & trans. in English by Thomas Taylor, London.

Quintus Smyrnaeus: 1913, *The Fall of Troy*. Trans. by A. S. Way. The Loeb Classical Library Vol. 19. Heinemann, London.

Segal, C. P.: 1992, "Divine Justice in the Odyssey: Poseidon, Cyclops and Helios", *American Journal of Philology* (*AJP*) **113**, pp. 3-29.

Sophocles: 1892, *Trachiniae*, Ed. & trans. by R. C. Jebb, Cambridge University Press, Cambridge [on line: trachiniae.10.zip].

Sophocles: 1994, Vol. I. *Ajax*. *Electra*. *Oedipus Tyrannus*. Edit. & trans. by W. H. S. Jones, The Loeb Classical Library No. 20. Harvard University Press. Heinemann, London.

Sophocles: 1994, Vol. II. *Antigone*. *The women of Trachis. Philoctetes. Oedipus at Colonus*. Edit. & trans. by W. H. S. Jones, The Loeb Classical Library No. 21. Harvard University Press. Heinemann, London.

Spandagos, E.: 2002, *Catasterismoi of Eratosthenes of Cyrene*, Aithra publ., Athens [на грчком].

The New Encycloaedia Britannica On line: http://www.britannica.com/, entry: matriarchy.

Theodossiou, E.: 2007, *The dethronement of the Earth – The dispute between geocentric and heliocentric systems*, Diavlos Publ., Athens [на грчком].

Theodossiou, E. and Danezis, E.: 1995, *The Odyssey of the Calendars – vol. I: Searching for the roots of Knowledge*, Diavlos Publ., Athens [на грчком].

West, M. L.: 1997, *The East face of the Helicon: West Asiatic Elements in Greek Poetry and Myth*. Clarendon Press. Oxford.

GAIA, OURANOS, HELIOS AND SELENE
THE THREE PRINCIPAL CELESTIAL BODIES AND THE SKY
IN ANCIENT GREEK COSMOGONY

We consider in this article the role of the three principal celestial bodies, the Earth (Gaia), the Sun (Helios) and the Moon (Selene) as well as the Sky (Ouranos) in ancient Greek Cosmogony. This is done by the analysis of ancient Greek texts like *Orphic Hymns* and writers and philosophers like Aeschylus, (Pseudo) Apollodorus, Apollonius Rhodius, Aristotle, Euripides, Hesiod, Homer, Hyginus, Nonnus, Pausanias, Pindar and Sophocles, as well as by the analysis of texts of Roman writers like Cicero, Ovid and Pliny.

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СИРИЈУС У СТАРОЈ ГРЧКОЈ И РИМСКОЈ ЛИТЕРАТУРИ: ОД ОРФИЧКЕ *АРГОНАУТИКЕ* ДО *АСТРОНОМСКИХ ТАБЛИЦА* ГЕОРГИЈА ХРИЗОКОКЕ

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Резиме: Најсјајнија звезда ноћног неба је Сиријус, Alpha Canis Majoris (α CMa). Због своје интензивне светлости, имао је једну од доминантних позиција у митологији, легендама и традицији. У овом раду су размотрена дела старих класичних аутора и песника, Грка и Римљана, који су помињали Сиријус, а дискутован је и проблем његове "црвене" боје који произилази из ових списа.

1. УВОД

Сиријус, Alpha Canis Majoris (α CMa), је најсјајнија звезда ноћног неба, видљива из целе Грчке, нарочито за време јасних зимских ноћи. Захваљујући свом сјају, има једно од најзначајнијих места у митологији, легендама и традицији већине античких народа. А ни Грци нису изузетак: Оригинално грчко име „Сеириос" значило је искричави, сијајући, огњени или горећи.

У овом раду, биће размотрена грчка, римска и поједина византијска дела у којима се помиње Сиријус, пошто и његово само име долази из старогрчког језика и постало је познато преко грчко-римске литературе. То се односи и на митове и класичне традиције повезане са њим; класични фолклор у вези са Сиријусом постао је познат и био је обогаћиван делима знаменитих латинских стваралаца. На тај начин, како име тако и митови ушли су у културу Запада и тако опстали. Такође ће бити испитан и

размотрен проблем Сиријусове «црвене» боје, што се јавља на основу писања старих аутора.

2. СИРИЈУС У САЗВЕЖЂУ CANIS MAJOR

Canis Major је јужно сазвежђе средње величине са 95 звезда видљивих голим оком. Његова најсјајнија звезда, Сиријус, је скоро четири пута сјајнија од свих других које се виде на географској ширини Атине (38°, централна Грчка). Да би се посматрала следећа по сјају, Канопус (Canopus је најсјајнија звезда у сазвежђу Carina, Alpha Car), упола мањег сјаја од Сиријуса, треба отићи јужније од 37° N, на Родос или Крит.

Осим тога, Сиријус је једна од Земљи најближих звезда, удаљена само 2.64 парсека (8.60 светлосних година) и има привидну величину m = –1.46. То је двадесет пута сјајније од Сунца када бисмо га посматрали са такве даљине. Канопус је на много даљем растојању од 96 pc (313 с.г.) и сија са привидном величином –0.72.

Од свих видљивих небеских тела, од Сиријуса су сјајнији само Сунце, Месец, Венера, Јупитер и Марс, мада само када је близу опозиције, приближно сваке две године.

Сиријус (α CMa), Прокион (α CMi, најсјајнија звезда у сазвежђу Canis Minor) и Бетелгејз (α Ori, најсјајнија звезда у сазвежђу Орион) чине велики троугао на јануарско-мартовском небу, такозвани „зимски троугао“, који је готово једнакостраничан. Данас, Сиријус се прво јавља пред зору (хелијактичко јављање), неколико недеља касније него у античка времена (данас око 10. августа а тада близу летњег солстиција). То се дешава услед прецесије равнодневичких тачака у току „клаћења“ Земљине осе са периодом од 26 000 година.

Сиријус је уствари троструки систем. Његов пратилац, Сиријус B, је бели патуљак отприлике величине Земље, а већина његове масе је тако сабијена да би кубни сантиметар таквог материјала на Земљи тежио неколико тона (и стотине тона на површини белог патуљка). Сиријус B сија осамдесет пута слабије од теоријске границе за видљивост голим оком, али чак и када би је достигао, интензивни сјај суседног Сиријуса A учинио би његовог пратиоца невидљивим. Због тога је прво откривен 1844. индиректно, на основу поремећаја положаја Сиријуса, које изазива; откриће до кога је дошао немачки астроном Фридрих Вилхелм Бесел. Тек 1862, га је оптички посматрао амерички астроном и градитељ телескопа Алвен Г. Кларк (Alvan G. Clark) у току тестирања једног рефрактора изузетног квалитета. Године 1994, Жан Луј Дивен (Jean-Louis Duvent) и Данијел Бенест (Daniel Benest) са Опсерваторије у Ници открили су, такође индиректно, још једног пратиоца ове звезде, Сиријус C (Duvent, Benest, 1995).

Захваљујући великом сјају, Сиријус је имао истакнуто место у митологији, легендама и традицији већине народа, па такође и код старих Грка. Његово име, *Сеириос*, на грчком значи искричави, огњени или горући,

пламени, пржећи или „пржилац“; овај епитет датира бар од 6. века пре н.е., пошто је забележен у орфичкој *Аргонаутици* (Demetrakos 1964, вол. 13).

Грчко име	**Транскрипција**	**Латинска транскрипција**	**Превод**
Σείριος	Сеириос	Sirius	искричави
Αστήρ Κύων	Астер Кион	Aster Cyon	звезда Пас

Claudius Ptolemaeus (Птолемеј, 2. век) у *Алмагесту*[1] помиње Сиријус као „онај у њушци“ [пса], најсјајнији, Пас и *хипокиррос*. Мало различито, Јохан Бајер у *Уранометрији* смешта га у губицу великог пса (Bayer 1603, Leaf 38).

Сиријус се може видети из сваког настањеног дела Земљине површине. У наше време, најбољи период да се посматра је око 1. јануара, када у поноћ досеже меридијан. Око 500. године пре наше ере то је било око 11. децембра.

3. СИРИЈУС У ГРЧКОЈ И РИМСКОЈ МИТОЛОГИЈИ

Canis Major вероватно претставља Лелапса, верног пса ловца Ориона, који је суседно сазвежђе. Заиста, Сиријус се може наћи на небеској сфери ако продужимо линију коју чине три звезде Орионовог појаса на исток.

У причи из грчке митологије, Орион је био у љубави са богињом Артемидом – грчким еквивалентом Дијане. Аполон, да би окончао везу смртног Ориона са његовом сестром близнакињом, послао је велику шкорпију – претстављену данас помоћу Сазвежђа Scorpius – која је убила несрећног ловца. После Орионове смрти, његова вољена Артемида поклонила је Лелапса Прокриси, кћери Ерехтеја и једне од Нимфи, њених пратиља. Прокрис је касније дала Лелапса своме мужу Цефалу, који је такође био чувени ловац.

> *“У раним класичним данима просто је Canis, претстављао пса Лелапса, Актеоновог или Дијанине нимфе Прокрис, или оног кога је Аурора дала Цефалу, што је, чувен због брзине, тако угодио Јупитеру да га је пребацио на небо.”*
>
> (Allen 1963, стр. 117)

Према Ератостену/Псеудо-Ератостену,[2] Лелапс је пас кога је Зевс поклонио Европи; њихов син, Минос, краљ Крита дао га је касније Прокрис зато што га је излечила од неке болести; Прокрис га је пак, даровала своме мужу Цефалу. Када је несрећним случајем Цефал убио Прокрис, Зевс је ставио њиховог пса у истоимено сазвежђе.

[1] *Almagest*, 1903, стр. 142.
[2] *Catasterismoi*, 1997, 1897

Мање позната верзија доводи Сиријус у везу са Кербером, дивљим троглавим псом који је чувао капије подземног света (Хада), или са једним од ловачких паса Актеона, славног ловца и хероја из Тебе, који је имао несрећу да буде на месту где се купала Артемида. Када је видео голу, она га је претворила у јелена и пустила своје псе да га убију.

Сеириос је у митовима идентификован на разне начине. Неки кажу да је то Маира, кћер Титана Атласа, или према римском песнику Овидију (43 пре н.е. - 17), то је Маира, верни пас краља Икарија – кога представља Boötes.

Сиријус такође повезују са Ортхросом (= јутарњи сумрак), псом Гериона,[3] гиганта са Запада. Пас-звезда је вероватно такође била повезана са богињом-псом Хекатом, ћерком Титана Перса и Астерије.

Такође се сматрало да је на небу представљен Орионов ловачки пас како прогони зеца (Lepus) или помаже Ориону да победи Бика (Taurus); тако га наводе Аратус, Хомер и Хезиод (Theodossiou, Danezis, 1990, стр. 114).

Стари Грци помињу само једног пса, али у римска времена, Canis Minor се јавља као други Орионов пас (Allen, 1963, стр. 132). Према Алену, два додатна имена за Canis major била су у Риму:

> *"Custos Europae* [што] *је алузија на причу о Бику, који је, без обзира на будност пса однео девојку; и Јанитор Летеј, чувар пакла* [што] *га чини јужним Кербером чуварем доњих небеса, која су у раној митологији посматрана као станиште демона."*
>
> (Allen, 1963, 118)

4. СИРИЈУС У СТАРОЈ ГРЧКОЈ И РИМСКОЈ ЛИТЕРАТУРИ

I. Стара грчка литература

У Орфичкој *Аргонаутици*, у сцени где се Зевс спаја са Алкменом (Херкуловом мајком) наводи се:*"…када је Сунце губило Сиријусу сличан троструки сјај на своме путу и црна ноћ се ширила одасвуд"*;[4] или: *"управо када је за три узастопна дана изгубило свој сјај пламено Сунце ('Сеириос Сунце')"* (Petrides 2005).

Хомер помиње Сиријус у *Илијади* (1924, V 1-5, XXII 25-32) и *Одисеји* (1919, v 4) као „опоринос", јесењу звезду, и као Орионовог пса:

[3]Герион, син Хрисаора и Калирое и унук Медузе, био је див са острва Еритеје (Хезиод, Theogony 979 ff) далеко на западу Медитерана. Према Хезиоду (Theogony 287 ff), Герион је имао једно тело и три главе, док је према традицији коју је следио Есхил имао три тела (Aeschylus, Agamemnon 869 ff). Имао је стадо величанствених црвених говеда, које је чувао двоглави пас Ортрус или Ортрос, брат Кербера. У *Библиотеци* Псеудо-Аполодора је записано (Pseudo-Apollodorus 2. 5. 10) да је десети Херкулов задатак био да се домогне Геріонових говеда.

[4]Apollonius Rhodius, *Argonautics*, 1962, стих 121.

"Тада је Атина дала снагу и храброст Диомеду, тако да међу грчким мноштвом буде изванредно слављен и свугде задобије сјајну славу. Са његовог шлема и штита био је видљив пламен, који лије светлост без престанка, као што јесења звезда, окупана у Океану, сјаји пуном светлошћу." (*Илијада*, V 1-5).

„Јесења звезда" је уствари Сиријус, и за географску ширину Грчке, јавља се сваке године касно у јулу или рано у августу пре свитања. То такође помиње Ричард Х. Ален, који пише:

"Хомер алудира на то у Илијади као на Οπωρινός, јесењу звезду; али намера је била да су то последњи дани јула, цео август и део септембра — каснији део лета. Грци нису имали реч управо за нашу „јесен" до 5. века пре н.е., када се она јавља у списима који се додељују Хипократу. Лорд Дерби је превео овај чувени пасаж као: „Огњена светлост. Онде обасја, као јесења звезда, која најсјајније сија. Када се наново уздигне са свога океанског купања..."

(Allen 1963, стр. 120)

У рапсодији XXII *Илијаде*, помињу се како Орион тако и Сиријус. Најсјајнија звезда Сиријус, наводи се као Орионов пас. Хомер га представља као злокобан знак на небу, пошто је сваког лета повезан са такозваним „пасјим врућинама":

"…као звезда која нам долази у јесен, натсијавајући све
своје садруге на вечерњем небу — зову је Орионов пас, и
мада је најсјајнија од свих звезда не слути на добро
доносећи много грознице нама сиротим смртницима"

(*The Iliad*, превод E.V. Rieu, гл. 22, v. 25-31)

У приближно истом периоду као и Хомер, или мало касније, Хезиод,[5] у својој чувеној књизи *Послови и дани*, дискутује све звезде и сазвежђа што их помиње Хомер, са специјалним нагласком на Сиријусу. Заиста, Сиријус наводи у три различита пасажа. У првом даје савете своме брату Перзу о берби грожђа:

"Али када Орион и Сиријус дођу на пола неба, а руменопрста Εος [Зора] *види Арктура, тада Перзе*[6] *сеци све гроздове и носи их кући."*

(*Works And Days*, 1914, v. 609ff)

[5]Hesiod, 1914, *The Homeric Hymns and Homerica (Theogony)*.

[6]Перз је био Хезиодов брат. Помиње се у *Пословима и данима*. Перз игра улогу Хезиодовог неодговорног брата, који будаласто управља наслеђем које су му предале неправедне судије. У *Пословима и данима*, Хезиод је применио различите методе да убеди брата Перза у предности праведног и доброг живота.

У друга два пасажа говори о пасјим врућинама: *"Тада звезда Сиријус пролази изнад глава људи, који су рођени у беди, само мало по дану а узима већи део ноћи"* (ibid. 417) и *"јер Сиријус исушује главу и колена и тело је суво од врелине."* (ibid. 587).

Друго Хезиодово дело, *Аспис Ираклеус* (*Херкулов штит*), у неку руку подражава *Аспис Ахилеос* (*Ахилов штит*) како је описан у *Илијади* (XVIII, 468-817). Хезиод и у овом делу два пута помиње Сиријус:

"Њихове душе прошле су испод земље и дошле су у Хадову кућу; а њихове кости, када је кожа око њих иструлела, мрве се на мрачној земљи под исушујућим Сиријусом."

(*The Shield of Hercules*, 1914, v. 139ff)

"И када тамнокрили зујави скакавац, смештен на зеленом изданку, почне лети да пева људима –његова храна и пиће је нежна роса– и његов глас се излива по цео дан од зоре, по најубиственијој врелини, када Сиријус пржи тело, тада „брада" расте на просу, које људи сеју лети."

(ibid, v. 391)

Старогрчки песник Алкеј (7/6. век пре н.е.) о Сиријусу изјављује следеће:

"Наквасиси своја плућа виноm: звезда Пас Сеириос, долази у околину, сезона је сурова, све је жедно под врелином, са лишћа слатко пева цврчак ... артишока је у цвету; сада су жене најкужније али мушкарци су слаби пошто им Сеириос пржи главе и колена."

(Alcaeus , 1922, 1982, 1993, 1999, *Fragment* PLF 347a,
превод Campbell, vol. Greek Lyric I)

Теогнис (570-480 пре н.е.), значајан песник елегичар из Мегаре, написао је неколико гозбених песама, које се истичу својим достојанством и поштовањем богова. Дао је чак и правило за пијење вина додајући неке информације за период око изласка Сиријуса, називајући га на грчком „астрокион": *"Безумни су и будаласти они људи који не пију вина чак и кад звезда Пас почиње…"* (Wender, *Theognis*, 1984, 1039-1040).

Песник трагичар Есхил (525-456 пре н.е.), у трагедији *Агамемнон*[7] такође помиње Сиријус као «сеириос пас» (стихови 966-968), док га Еурипид (480-406 пре н.е.) у трагедијама *Хекуба*[8] и *Ифигенија на Аулиди*[9] помиње управо по имену Сеириос. Овде су одговарајући стихови:

[7]Aeschylus, 1955.
[8]Euripides, 2008, *Hecuba*.
[9]Euripides, 1999, 2003, 2004, 1A8.

„Јер, док је дебло јако, лишће се пење, ширећи хлад, док звезда Пас (сеириос кинос) сија; А ти се враћаш твоме срцу и кући, вештина је то као блага топлота у зимским часовима."

(*Agamemnon*, 1955, v. 967ff)

"Где Орион и Сиријус расипају из својих очију бљесак као од ватре"
(Euripides, *Hecuba*, v. 1104, превод Edward P. Coleridge, 2004).

"Сиријус који још бије преко зенита на свом путу близу седмоструке стазе Плејада"

(Euripides, *Iphigenia in Aulis*, 1A8,
превод Edward P. Coleridge, 2004)

Песник Ликофрон из Александријске „Плејаде"[10] (3. век пре н.е.), у својој јединој сачуваној песми, писао је о Касандрином пророчанству за пад Троје, у коме се позвао на „Сеиријански зрак", вероватније мислећи на сунчев зрак (Scholia to Lycofron's *Alexandra*, Frag. 397 in Scheer 1958).

Позната грчка астрономска песма *Феномени*, коју је написао Аратус из Солиа на двору Антигона Гоната, краља Македоније (270 пре н.е.), помиње Сиријус називајући га „звезда Пас" „Поикилос" (што вероватно значи мењајућа боју) и „Сеириос":

"Звезда која продорније од свих бљешти спржујућом ватром, и коју људи зову Сеириос. Када излази са Хелиосом (Сунцем), више га не обмањује дрвеће са слабом свежином свога лишћа. Јер његов оштар поглед лако пробија њихове редове, и некима даје снагу а другима потпуно гули кожу. Да ли смо га свесни и при његовом заласку."

(Aratus, *Phaenomena*, 1921, 326-340 ff, превод Mair)

Аратус је такође додао један придев имену, зовући Сиријус μέγας (= велики); према Алену, овим придевом желео је само да карактерише сјај звезде, а не да се она разликује од Малог Пса. У то време Грци нису познавали два Пса, нити се ово поређење појавило до касних дана Витрувија (Allen 1963, стр. 117). Ипак, Ален не помиње употребу тог придева (велики) за Сиријус код Ератостена.

Ератостен (276-194 пре н.е.) у своме раду *Астротесиаи* или *Катастерисмои*[11] пише о Псу, кога зове *Изис* и *Сеириос*, описујући га као „великог и сјајног". Он такође реч сеириос користи као придев пишући на

[10]Плејада је „група од седам звезда" и односи се на седам песника трагичара који су стварали у Александрији за време Птолемеја Филаделфа у трећем веку пре н.е. То су били Александар, Етол, Филиск, Созитеј, Хомер, Еантид, Созифан и Ликофрон.
[11]Eratosthenes, 1997, 2010.

пример: *"Такве звезде астрономи зову „сеириои" због треперавог понашања њихове светлости"*. („Сеириои" је множина од „сеириос").

Аполоније са Родоса (3. век пре н.е.) у *Аргонаутици*, великој епској поеми која преобликује у песничку форму митску експедицију Аргонаута из Тесалије у црноморску Колхиду, такође помиње Сириус у вези са неподношљивом летњом врелином:

> *"Али када са небеса Сиријус пржи Минојска острва, и задуго нема одмора за становнике…"*
>
> (*Argonautics*, 1962, Book II, 517)

Такође и у другом пасажу:

> *"Али убрзо се појавио њеним чежњивим очима, благородно корачајући уздуж, као Сиријус који долази из океанских дубина, излазећи леп и јасан за поглед, али доноси неизрециве недаће стадима…"*
>
> (*Argonautics*, 1962, књига III, 956-958).

Диодор Сикул (око 80-20 пре н.е.), грчки историчар из Агиријума на Сицилији, написао је четрдесет књига о историји света названих *Библиотека историје,* у три дела: митску историју народа (како не-Грка тако и Грка) до Тројанског рата; историју до Александрове смрти (323 пре н.е.); историју до 54 пре н.е. Од његових списа сачуване су у потпуности књиге I-V (Египћани, Асирци, Етиопљани, Грци) и књиге XI-XX (Грчка историја 480-302 пре н.е.; и фрагменти осталог. Био је некритички компилатор, али је користио добре изворе и поуздано их репродуковао. Драгоцен је због детаља који нису забележени на другом месту, и због сведочанства о делима сада изгубљеним, посебно о списима Ефора, Аполодора, Агатархида, Филиста и Тимеја. У *Библиотеци историје*, Диодор Сикул пише:

> *"Куга* [т.ј. кужност која долази у доба суше] *је завладала широм Грчке и жртва коју је принео била је у име свих Грка. И пошто је жртва била учињена у време изласка звезде Сеириос, што је период када обично дувају Етезијски ветрови, кужне болести о којима смо говорили су престале. Сада човек који размишља о овом догађају, може с разлогом да се чуди необичном обрту судбине; као да се завршио утицај на овог човека* [Аристеј], *који је видео свога сина* [Актеј] *на смрт изуједаног од паса, звезде, која међу свим звездама на небу носи исто име* [т.ј. Сеириос, која је позната као звезда Пас] *и сматра се да доноси разарање човечанству и да је тако чинећи, одговорна за спасавање живота осталог."*
>
> (Diodorus Siculus, *Library of History* 1939, IV, 81.1, trans. by Oldfather)

Сатирички аутор Лукијан из Самосата (120-190) помиње Сиријус у својој фантастичној приповетци *Путовања на Месец* (оригинални наслов: *Истинита прича*), где прича о замишљеном рату између земљана и становника Сиријуса који се зову Кинобалани:

"Близу њих било је око пет хиљада Кинобалана [88b], које су послали становници Сиријуса; то су били људи са псећим главама на крилатим жировима: неке од њихових снага нису дошле на време; међу којима су били неки праћкаши из Млечног пута, заједно са Нефелокентаурима; [88c]они су управо дошли када је прва битка била завршена, а желео сам да [88d] никада нису ни дошли: праћкаши се нису појавили, што је кажу разјарило Фаетона тако да је спалио њихов град."

(Lucian, *Trips to the Moon*, 2004, превод Th. Francklin).

Осим у овом делу, које се вероватно може сматрати као прва научно-фантастична прича, Лукијан помиње Сиријус у другим делима, као „Орионовог пса": *Због овог разлога, да би хвалио Орионовог пса, песник га је називао кротитељ лавова"*(Lucian 1911, вол. 6).

Клаудије Птолемеј (2. век) је називао Сиријус *Αστροκύων* (*Астрокион* = Псећа звезда) – пишући у својој *Великој синтези* (*Алмагест*) да је то звезда црвена попут Антареса (Алфа Scorpionis) и Алдебарана (Алфа Tauri) (Ptolemy, 1903, *Almagest*, књиге VII и VIII).

"Птолемеј (2. век) и његови земљаци знали су то из Хомеровог наслова, и често као Αστροκύων, мада се чини необично да претходни није никада употребљавао реч Σείριος"

(Allen 1963, стр. 118).

Птолемеј је користио Астрокион као место централног меридијана небеске сфере.

У истом веку, слично пише Плутарх у своме делу *De Iside et Osiride* да је сазвежђе Пас посвећено богињи Атини-Изиди:

"И брод који су Грци звали „Арго" био је сграђен у облику Озирисовог брода; у знак почасти уврштен је у сазвежђа и креће се не далеко од сазвежђа Орион и Пас, од којих су претходно Египћани посветили Хорусу, а друго је посвећено Изиди."

(Plutarch, 1935, *De Iside et Osiride*, 354c-359f).

Према Алену:

"*Плутарх га је звао Προόπτης, Вођа, што се добро слаже са његовим карактером и готово је тачан превод његовог еуфратског, персијског,*

феничанског, и ведског имена; али Κύων, Κύων σείριος, Κύων αστήρ, Σείριος αστήρ, Σείριον άστρον, или просто το άστρον, била су његова имена у раној грчкој астрономији и поезији."

(Allen 1963, стр. 120).

Према архитекти и аутору Николаосу В. Лицасу:

"Плутарх у своме делу 'De Iside et Osiride' (354c и 366a) пише да је Изида, која се идентификује са Атином, Сиријус, добро позната Псећа звезда. Због тога је Партенон, храм Атине на атинском Акропољу, оријентисан тако, да једном годишње, 2. јула [модерни датум], када Сунце пролази изнад Сиријуса, зраци излазећег Сунца продиру у свети део храма."

(Litsas 2008, стр. 40).

Квинтус Смирнеус је био грчки епски песник, који је стварао у Смирни у касном четвртом веку. Његово једино сачувано дело је еп у четрнаест књига насловљен *Пад Троје* (или *Posthomerica*). Поема покрива период Тројанског рата од краја Хомерове *Илијаде* до коначног разарања Троје. Сматра се да је Квинтус много тога узео из дела песника Епског циклуса, укључујући таква, данас изгубљена дела, као *Aethiopis* и *Мала Илијада*.

"Са руба океана уздиже се Хелиос (Сунце) у слави, бљештећи ватром на далеко преко земље - ватром, када поред запреге његових зрачећих двоколица јури црвена звезда Сеириос, ширитељ најнесрећнијих болести међу људима."

(*Fall of Troy* 1913, 8. 30ff, превео Way).

У истом периоду (4. век) имамо Анонимног, можда Пампрепија из Панополиса, који саопштава о Сиријусу, звезди-псу (*кинос астраиос*):

"*Снежнобели сјај бљештећег Фаетона [Сунце] потиснуле су течне струје кишних облака, и пламен …* [недостајући део - lacuna]... *пасје звезде* [кинос астраиос] *је угашен воденим снежним олујама."*

(Anonymous, *Two Poems Fragments*, 1950, превод D.L. Page,
Vol. Select Papyri III, No. 140,
Greek poetry 4th century AD).

Нонус, грчки епски песник из 5. века пре н.е. из египатског града Панополиса, пише два пута, у делу *Дионизијака*, о Сиријусовим пасјим врућинама:

"Послао је супротни удар ветрова да прекине врелу грозницу Сиријуса."

(Nonnus, *Dionysiaka*, 1940, 5. 275ff, превод Rouse).

"*Он* [Аристеј] *се још није преселио на острво, које се раније звало Меропис* [Кос]*: још није тамо донео живот удахњујући ветар Зевса Бранитеља* [Етезијски ветрови], *и проверио пламена испарења пржећег годишњег доба; није стајао утонуо у мир да прими бљесак* ***Сеириоса****, и да током целе ноћи одолева пламеној врелини звезде — што је и сада ветрови хладе лаким ударима, као да свој пржећи пламен баца кроз ваздух из тињајуће чељусти."*

(ibid. 13. 253 ff).

II. Стара латинска и византијска литература

Према Алену (Allen, 1963), Римљани су прихватили латинизирани назив *Canis* од Грка и задржали за стално ово име, понекад у његовом деминутивном облику *Canicula* (са придевом *candens*, сијајући). Такође су присутна и имена Erigonaeus и Icarius из приче о псу Мера (Maera) – што и само значи Сјајећи – пренесена на небо, његова господарица Еригона (Erigone) која је претворена у Virgo, и господар Icarius у Boötes. Према Алену: Овидије је на то алудирао у *Icarii stella proterva canis* [*Amor*. II.16.4]; и Статије помиње *Icarium astrum*, мада је Хигинус [*Fab*. 130] то приписао Малом Псу (Allen, 1963, стр. 118).

Од латинских аутора и песника, Вергилије у својим *Георгикама*, песник трагичар Сенека (2003) у *Едипу*, епски песник Валерије Флак у *Аргонаутици* (1934) и песник Статије у *Silvae* (2003), помињу Сиријус углавном као „пасју звезду".

Вергилије (1. век пре н.е.) пише:

"*Време када пржећа Звезда Пас* [Canis] *цепа поља зинула од жеђи…"*

(Virgil, 1916, *Georgics* 2. 353 ff, превод Fairclough)

"*А сада је Сиријус (Звезда Пас), који пламено пржи жедне Индусе, горео на небу, и пламено Сунце је захватило пола његовог пута; трава се спарушила и празни токови, у својим спрженим отворима, били су скувани и испечени зрацима који су их претварали у блато"*

(ibid. 2. 425 ff)

Вергилије је о Сиријусу писао и у књигама III и X *Енеиде*:

"*Управо као када тиња комета, крваво црвено и злослутно у јасној ноћи, или када излази пламени* ***Сиријус,*** *који крхким смртницима доноси сушу и кугу, и растужује небо несрећном светлошћу"*

(*Енеида*, 2002, књ. X, v. 271-273)

"*Одрекли су се слатког живота, или су вукли своје болесне удове наоколо: онда је* ***Сиријус*** *забљештао изнад јалових поља:*

Трава је увенула а болесна жетва порекла своје плодове"
(*Енеида*, књ III, v. 140-142, превод A.S. Kline).

Сенека у *Едипу* (1. век пре н.е.) пише:

"[Теба је била окужена сушом] *Нема благог поветарца да својим хладним дахом ублажи наше груди које дахћу од топлоте, не дува ни нежни Зефир; него Титан* [Хелиос, Сунце] *увећава ватре пржеће звезде-Пса* **[Сиријус]**, *блиско притискајући одпозади Немејског Лава* [т.j. Лав, зодијачки знак средине лета]. *Вода је побегла од токова и од травнатог зеленила. Дирке*[12] *је сува, оскудно тече Исменусов [река у Беотији близу Тебе] ток, и својим слабим таласом оскудно влажи голи песак."*
(Сенека, *Едип*, 2004, 37 ff, превод. J.G. Fitch)

Римски епски песник Валерије Флак пише у *Аргонаутици* (1. век пре н.е.):

"Када ***Сиријус*** *у јесен још више изоштри своје ватре, и његово љутито злато светлуца у сјајним плетеницама ноћи, Аркађанин* [планета Меркур] *и велики Јупитер* [планета] *постају слабији; радосна су поља на која неће жестоко да сија са неба, радосне такође и већ загрејане воде у токовима."*
(*Argonautica* 1934, 5. 370 ff, превод Mozley).

Хорације (Quintus Horatius Flaccus) помиње Сиријусs (2003) у *Сатирама* (2004, V). На крају и Статије (Statius) у делу *Silvae* (Римска поезија 1. века) помиње Сиријус:

"То беше годишње доба када небески свод завија највише пржећу врелину према земљи, и ***Сиријус звезда-Пас*** *обузета Хиперионовом* [Сунчевом] *пуном снагом немилосрдно пали дахћућа поља."*
(*Silvae* 3. 1. 5, превод D.R. Shackleton).

Према Алену, Сирион и Сиријус су се повремено јављали код најбољих латинских аутора; и *Алфонсинске Табле* из 1521. имале су Canis Сиријус (Allen 1963, стр. 118).

Арапски астрономи, под утицајем Птолемеја и других грчких астронома, звали су Сиријус Al Shiʿrā, што значи сијајући, због његовог изузетног сјаја (Allen 1963, стр. 121).

[12]У грчкој митологији, Дирке је била жена Ликоса, краља античке Тебе, одана Дионизију, који је на месту где је умрла, код Тебе, учинио да тече поток о коме је овде реч. Tripp, Edward, 1970, *Crowell's Handbook of Classical Mythology*, New York, Thomas Crowell Press, стр. 213.

Учењак и византијска принцеза Ана Комнен, помиње „Пасју звезду“ у своме великом делу *Алексијас* (1148):

> *“…мада је било лето и сунце је прошло кроз Рака и било на прагу уласка у Лава – доба у коме, како кажу, излази* ***Пасја звезда Сиријус****…”*
>
> (*Alexias* 1928, 1969, I, књ. 3, XII.4).

Коначно, Византијски учењак, доктор медицине и астроном Георгије Хризокока (14. век) у свом астрономском делу *Synopsis tabularum persiacarum ex syntaxi Persarum Georgii medici Chrysococcae* (1347) помиње Сиријус као *Siaèr Jamanè*. (Ален помиње ово дело као „Хризококине *Табеле*”. Објавио их је Исмаел Булиалдус 1645. у Паризу).

Као општа опаска, може се напоменути да стари Грци и Римљани генерално нису правили разлику између сазвежђа Canis Major и звезде Сиријуса, и често су их звали једноставно Пас (Ceragioli 1996, стр. 121).

5. МАИРА

У годишњем периоду од свог хелијактичког изласка до 22. августа, Сиријус су такође називали и Маира, од речи која долази од старогрчког глагола *мармаиро*, што значи «сијати» (*Palatine or Greek Anthology*, 1917, 9, 55). С тим именом, Маира (или Мера) је постала звезда-богиња пржење звезде-пса Сеириоса, чији излазак заједно са Сунцем доноси ужасну врелину средине лета. Као и Плејаде и Хијаде, Маира је била звездана кћи Титана Атласа. Удала се за смртног краља Аркадијског Тегеата, оснивача града Тегее, сина краља Ликаона. Њен гроб је показиван како у Тегеи тако и у Мантинеји у Аркадији и Паузанија мисли да је то била Маира коју је Одисеј видео у Хаду (Paus., 1935, VIII. 12. § 4, 48. § 4, 53. § 1): “[Одисеј види духове хероина у Подземном свету:] *Такође сам видео Маиру”* (Хомер, *Одисеј* 11. 326 ff, превод Shewring).

Грчки путник Паузанија (2. век) пише о причи о нимфи Маири и саопштава све митолошке и историографске информације повезане са њом у свом *Опису Грчке*:

> *“Ту* [у Тегеи, Аркадија] *су и гробови Тегеата, сина Ликаона, и Маире, Тегеатове жене. Кажу да је Маира била ћерка Атласа, и Хомер је помиње у пасажу где Одисеј прича Алкиноју о свом боравку у Хаду, и о онима чије је духове тамо срео.”*
>
> (Паузанија, 1935, *Description of Greece*, *Arcadica* 8.48. 6, превод Jones)

"Рушевине села званог Маира, са гробом Маире… Вероватно су Тегејци а не Мантинејци у праву када кажу да је Маира, Атласова ћерка сахрањена на њиховој земљи."

(ibid. 8. 12.7)

"Аполон и Артемида, кажу, по целој земљи су посећивали и кажњавали људе тога времена, који нису обраћали пажњу на Лето са дететом, када је у току својих лутања дошла у њихову земљу [Тегеа у Аркадији]. *Када су божанства дошла у Тегејску земљу, кажу да је Скефрос, син Тегеата дошао Аполону и са њим насамо разговарао. Леимон* [= ливада богата водом], *такође син Тегеата, сумњајући да Скефросов разговор садржи оптужбе против њега, насрнуо је на свога брата и убио га. Леимона је одмах стигла казна за убиство пошто га је Артемида устрелила. У то време Тегеат и Маира су приносили жртве Аполону и Артемиди, али је велика глад завладала земљом, и пророчанство из Делфа је наредило жалост за Скефросом."*

(ibid. 8.53.2).

Маира / Мера (Maera) као пас у грчкој и римској митологији

Мера је био пас Икарија, Атинског краља, следбеника бога вина Дионизија. Био је отац девојке Еригоне.

Према римском митографу Хигину (2. век), Дионизије је научио Икарија како се прави вино. Једнога дана Икарије је био у колима на путу, и срео неке пастире, са којима је поделио мешину вина. Пастири су омамљени заспали и када су се пробудили мислили су да је Икарије покушао да их отрује. Зато су га убили и покопали испод једног дрвета.

Еригона је почела да се брине што се отац не враћа и пошла је са Мером да га нађе а он је одвео до гроба. Пас је урлао од жалости, скочивши са стене у смрт. Еригона, такође очајна због губитка оца, обесила се о дрво изнад његовог гроба.

Сажаливши се на своје следбенике и пса, Дионизије их је поставио на небо. Постали су сазвежђа Boötes (Икарије), Virgo (Еригона), и Мера са Сиријусом. Тако је Маира уско повезивана са Икаријевим псом - *Kyon Ikarion*, који заједно са његовом звездом чини сазвежђе Canis Major. Други кажу да је сазвежђе Canis Major или Canis Minor било Мера.

Дионизије није пустио пастире да избегну казну за убиство Икарија. Проузроковао је лудило у Атини, тако да су све девојке почеле да се вешају. Грађани су сазнали од пророчишта узрок ове појаве. Ухватили су убице и обесили их. Од тада надаље, Атињани имају годишњи фестивал посвећен Икарију и његовој кћери у време бербе грожђа, када се девојке љуљају у љуљашкама које висе на дрвећу. У другој верзији, пастири су нашли уточиште у земљи Кеана (т.ј. на острву Кеи).

Маира као звезда Сеириос

Калимах, хеленистички песник из 3. века пре н.е. пише:

"[Кеански] *Свештеник Зевса Аристеја Икмеја (господара влаге): свештеник чија је дужност да са врхова планине ублажи звезду Маиру* [Сеириос] *када изађе."*

(Callimachus, *Aetia Fragment* 3. 1
Из Оксиринкшког папируса 7, превод C.A. Trypanis, 1958).

Грци су сматрали да сазвежђе Canis Minor и звезда Пас (Сиријус) најављују долазак суше.

Према речима Хигинуса/Псеудо Хигинуса:

"Жалећи њихову несрећу, Јупитер [Зевс], *им је ставио ликове међу звезде… Пса су пак, према његовом сопственом имену и изгледу, назвали Canicula. Грци су га звали Прокион, зато што излази пре већег Пса. Други кажу да их је међу звездама приказао Отац Liber* [Дионизије]. [Сазвежђе] *Canicula излазећи са својом врелином, спржило је земљу Кеана и похарало род са њихових поља, и учинило да становници, пошто су примили убице, буду окужени болешћу, да би Икару платили казну патњом. Њихов краљ Аристеј, син Аполона и Кирене, и отац Актеона, упитао је оца како да ослободи државу од несреће. Бог им је наложио да окају смрт Икара многим жртвама и затражио је од Јупитера да када Canicula изађе пошаље у току од четрдесет дана ветар да смири његову врелину. Аристеј је извршио овај налог и од Јупитер* [Зевса] *добио милост да дувају Етезијски ветрови…"*

(Pseudo-Hyginus, 1960, *Astronomica* 2. 4, превод Grant; и *The Myths of Hyginus*, 1960).

Треба напоменути да се најсјајнија звезда сазвежђа Canis Minor, Alpha Canis Minoris, зове Прокион (од грчких речи *про* = пре и *кион* = пас) пошто излази управо пре Сиријуса, великог Пса.

Епски песник Нонус из Панополиса (такође је Сиријус називао „Маирина звезда" у делу *Дионизијака*, 1940, књ. 5, v. 220-222, Библиотека Аугустана).

6. „ПАСЈЕ ВРУЋИНЕ" И „ПАСЈИ ДАНИ"

Хелијакални излазак Сиријуса, био је у антици повезан са периодом године у коме је било изузетно топло време, *κυνικά καύματα* (пасја врућина). Ово време одговара касном јулу, августу и раном септембру у области Медитерана. Римљани су такође ове дане знали као *dies canicullariae*,

најтоплији дани у целој години, повезане са сазвежђем Велики Пас. Стари Грци су замишљали да је изузетна врелина настајала пошто се зрачење сјајног Сиријуса сабирало са зрачењем Сунца.

У старогрчком фолклору, народ је летње дане после хелијакалног изласка Сиријуса наводио као „пасје врућине". Назив нема везе са звездом Псом или сазвежђем, већ пре са псима уопште, са помишљу да су само пси довољно луди да иду напоље када је толико врело. Ова замисао је опстала кроз векове и може се наћи и у модерном грчком фолклору, као веровање да су, током топлих дана у јулу и августу а нарочито између 24. јула и 6. августа, псећи уједи посебно заразни (Theodossiou, Danezis 1990, стр. 115).

Према старом миту, становници острва Кеа су умирали од глади проузроковане сушом коју су донеле пасје врућине око 1600. пре н.е. Тада је бог Аполон дао пророчанство да позову из Фтије[13] Аристеја, његовог сина, да им помогне. Пошто је дошао на Кеу, Аристеј је извео ритуале, очишћење и принео жртве Зевсу Икмејском, господару киша и неба, и Аполону Псу.

Оба бога су слушали његове молбе и послали су Етезијске ветрове, северне ветрове који од тада дувају преко Егејског мора половином лета, тако да народ може да издржи неподношљиву врућину. После тога, народ Кее, подстакнут од Аристеја, приносио је жртве сазвежђу Canis Major и Сиријусу; у знак сећања на њихово доброчинство, Аристеја су славили као „Аристеја Аполона" и стављали његову главу на на једну страну свог новца, док је на другој био представљен Сиријус крунисан зрацима (*Scholia in Apollonium Rhodium vetera*, у C. Wendel (уредник), Берлин 1935, 168.8-12). Заиста, на старом новцу нађеном на острву –из трећег века пре н.е.- представљени су пас или звезде са зрацима, што подвлачи значај Сиријуса (Holberg, 2005). Од тада па надаље, острвљани са Кее предвиђали су на основу прве појаве Сиријуса (његовог хелијакалног изласка) да ли ће година бити здрава или не: ако је јасно ружичаст, то ће донети добру срећу, ако је магличаст или слаб, то претсказује кужност.

Према Алену: Чак је и „отац медицине" Хипократ, пишући око 460. пре н.е., нагласио у *Епидемијама* и *Афоризмима* утицај Сиријуса на време и на физички аспект људи; што је такође сматрао и за звезду Арктур (Allen 1963, стр. 126). Неки мање познати лекари у антици тврдили су да «звезда пас» има извесну улогу у појави случајева беснила [L. Ideler (уредник), *Physici et medici graeci minores*, Берлин 1841, репринт Амстердам, 1963].

У античкој поезији Сиријус се помиње као звезда са посебно негативним утицајем, а овакво веровање је очигледно у Хомеровом стиху "*најсјајнија не предсказује добро нама сиротим смртницима"* (*Илијада*, XXII 25-31)".

[13]Фтија (грчки Φθία или Φθίη) у старој Грчкој најјужнија област старе Тесалије, са обе стране планине Отрис. Била је домовина Мирмидонског племена које је под Ахилом узело учешће у Тројанском рату - Simon Hornblower, 2004, *Thucydides and Pindar: historical narrative and the world of Epinikian poetry*, Oxford University Press, p. 170.

Сократ се, у *Апологији*, куне Аполоном Псом (а не проклиње, како су неки тврдили): *"…и Пса ми о Атињани – морам да вам кажем истину"* (Plato, 2002: *Apology*, 22a-22b). Слично се Платон (*Platonis opera*, 1900-07) у *Горгији* куне богом Кином (Псом) да су његови списи истинити: *"Пса ми, Горгијо, дуг разговор је потребан о тим стварима, тако да можемо да их анализирамо у детаље"* [461b].

Треба напоменути да је Кинас (Сиријус) једно од бројних имена Аполона, бога сунца, духовног просветљења и музике.

Проф. Перикле Теохарес (1995) пише о миту са острва Кеа:

> "*Овај мит алудира на однос Сиријуса и Земље. Жртве су приношене Зевсу Меилихију,*[14] *богу времена, сунца и кише, и Сиријусу, који узрокује пасје врућине на Земљи; веровали су да није само Сунце одговорно за велику летњу врућину, него и Сиријус када се налази поред Сунца. То су вероватно сматрали градитељи пирамида у Аргосу, који су њихове улазне ходнике оријентисали према азимуту Сиријуса."*
>
> (Theochares, 1995)

Такође је по Манилију (1977) звезда Пас, у ствари, ватрени луди пас. (*Astronomica*, 5.208) који "махнита сопственом ватром".

О утицају Сиријуса на „пасје врућине "Геминус (1898) у *Исагогама* (17.26) пише:

> *"Сви претпостављају да звезда има необичну моћ и да је узрок повећавања летње топлоте, када излази са сунцем."*
>
> (Geminus, *Isagoge* 17.26, у C. Manitius, ур.,
> *Gemini Elementa astronomiae*, 1898).

7. ЦРВЕНА БОЈА СИРИЈУСА

Занимљиво је такође да већина старих аутора, помиње да је звезда црвене боје, док је данас то бела звезда спектралног типа A1 V.

У суштини, постоје многе старе референце о Сиријусу у много различитих цивилизација, у којима се он описује као црвена звезда (Allen 1963, стр. 128). У 4. веку пре н.е., епски песник Квинтус Смирнеус помиње „црвену звезду" Сиријус (*Fall of Troy* 1913, 8. 30ff).

Од личности из римске литературе, Хорације (2004) саопштава о Сиријусу као о црвеној звезди (*rubra*), док Сенека (2004) пише (око 25. године) да: *"када је ваздух чист, Сиријус се појављује црвенији него планета Марс"* (Whittet, 1999).

[14]Милостивом, богу који се може умилостивити, заштитнику оних који су њему у част принели жртве да би га умилостивили.

Си (See, 1927) у своме раду "Историјска истраживања промене Сиријусове боје између времена Птолемеја (138) и Ал Суфија (980)" извештава о литератури о Сиријусовој боји од другог до десетог века.

> *"Многи мајстори класичне литературе – као Цицерон, Хорације и Сенека да набројимо неколико – помињу Сиријус као црвену звезду. Птолемеј иде чак и даље у своме опису и тврди да је Сиријус пламено црвене боје. Са друге стране, арапски астроном Абд-ал Рахман Ал-Суфи им противречи и класификује Сиријус као белу звезду, у свом каталогу датираном око 925, 850 година после Птолемеја. Такође у Carmina Burana, заснованим на пасторалним песмама 13. века, белина Сиријуса је упоређена са оном слоноваче. Џефри Чосер (Geoffrey Chaucer), године 1391, приповеда да су Арапљани звали Сиријус Ал-Хабур, лепа бела звезда. Кинески астроном и историчар Симакјан (91. година), Римски уметници Хигинус, Манилије и Авиенус (360. година),и Надбискуп Свети Исидор од Севиље, сви подржавају мишљење да је Сиријус бела звезда."*
>
> (See, 1927).

Према Холбергу (2007):

> *"Једна од најспорнијих и дуготрајних мистерија о Сиријусу настала је у 2. веку са оним што се јавља као успутни коментар александријског астронома/астролога Клаудија Птолемеја (Глава 3). Књиге VII и VIII Птолемејевог Алмагеста садрже један од најранијих и најчувенијих од старих звезданих каталога, у коме Птолемеј наводи положаје и сјај 1022 звезде. За само шест од њих — Бетелгејз, Алдебаран, Полукс, Арктурус, Антарес и Сиријус — он коментарише боју и свакој од њих додељује црвену. Посебно за Сиријус у сазвежђу Canis Major, утврђује његов положај, на псећој њушци, као и релативан сјај и боју: сјајан и црвен."*
>
> (Holberg, 2007)

Поред горе наведених и Хорације (1. век пре н.е.), Сенека (1. век), и Аратус (3, век пре н.е.) описују да је Сиријус црвене боје пре Птолемеја. Различити рани преводи њихових дела, укључујући оне које су сачинили Цицерон и Германикус, никоме нису скренули пажњу на Сиријусово црвенило. У ствари нико до 1760 (после превода Семјуела Џонсона) није исказао скепсу о томе.

Постоји навођење Хефестиона из Тебе (Ceragioli, 1996), како је боја звезде при изласку била тумачена као знамење. Занимљиво је да он помиње да је звезда „бела" (*лефкос*). То се слаже са Хигинусовим описом Сиријуса да се истиче својом «белином» (candor), што се обично из контекста интерпретира као «сјај», али готово сигурно имплицира белу боју. Овоме

треба додати да Манилије и Авиенус експлицитно описују Сиријус као плаву или можда плаво-белу звезду.

Али како да разумемо заиста недвосмислене референце о Сиријусовој црвеној боји и то не као о његовој „ватреној“ особини или боји сазвежђа Canis. Напоменимо и да је Сенека писао да небеска тела немају својствену боју, него је стичу преко ефеката у атмосфери, а Хорације помиње Сиријус као *rubra* (црвенкаст) у контексту екстремне топлоте.

Можда је Птолемејева карактеризација звезде као „хипокиррос“ мишљење о актуелној боји звезде, пошто не знамо да ли је делио Сенекину претпоставку да небеска тела немају инхерентну боју. Има врло мало повезаности да бисмо извели закључак, премда је неколико астронома (Си (See) пре свега) прихватило овај задатак и сакупило двосмислене цитате који у крајњој линији воде закључку да су у прошлости видели Сиријус као „пламено црвену“ звезду. Стога право питање није у ствари „да ли је Сиријус био црвен у антици“, него пре „да ли се Сиријус у антици понекад јављао или био описиван као црвен (или друге боје), и шта је то могло да значи?“.

Извесно је да данас Сиријус на визуелног посматрача оставља утисак „хладно беле“ звезде (т.ј. са лако плавичастим тоном) када је довољно високо изнад хоризонта, утисак који се слаже са његовом модерном спектралном класификацијом као звезде A1 типа.

Једно од ранијих објашњења је укључивало модерне налазе да је Сиријус део двојног звезданог система. Слабија звезда у пару (пратилац), Сиријус B, је бели патуљак. То значи да је почео са већом масом од друге звезде система и да је еволуирао брже и постао звездани остатак пошто је прво прошао кроз еволуциону фазу црвеног џина. Тада би пламено црвена светлост Сиријуса B доминирала над хладно белим сјајем Сиријуса A, и тако проузроковала све античке описе боје поменуте више. Свакако, ово објашњење је нереално пошто је време потребно да звезда пређе од стадијума сјајног црвеног џина до чисто белог патуљка, према резултатима модерне астрофизике много дуже од неколико хиљада година, тако да ово не може бити разлог за црвену боју Сиријуса у антици.

Један од покушаја да се нађе узрок овој боји био је да су можда извесни међузвездани облаци у простору између Сунчевог система и Сиријуса апсорбовали краће таласне дужине његове светлости, и тако му проузроковали црвени изглед у прошлости. Ово није много реалније с обзиром на релативно мало растојање до Сиријуса од само 2.64 парсека. Много је вероватније да је античка традиција о Сиријусовој боји настала због посматрања веома ниско на небу, близу хоризонта. Тада Сиријус, као и друге звезде, почиње да трепери, да се брзо креће око средњег положаја, да се види нешто увећан и да у десетом делу секунде мења боју, показујући разнолике нијансе много интензивније од његове праве боје. Узрок све три појаве је Земљина атмосфера. Осим тога, Сиријус је само неколико пута слабијег сјаја од Венере а познато је да услед Рејлијевог расејање Венерине

светлости –које је изражена функција таласне дужине– она знатно поцрвени када је ниско изнад хоризонта (ова појава је још познатија и импресивнија код Месеца и Сунца). Као што смо видели раније, Сиријус је у старој Грчкој нарочито често и интензивно посматран када се први пут појављује у свом хелијакалном изласку, ниско изнад хоризонта у последњем часу ноћи. Односно у антици, Сиријус је, за разлику од данашњице, најчешће посматран када је веома ниско изнад хоризонта и то објашњење је највероватније.

8. ЗАКЉУЧАК

У овом раду размотрили смо само грчке, римске као и неке византијске изворе о Сиријусу.

Види се да је име *сеириос*, које значи искричави, пламени, или горући, огњени, пржећа звезда или „пржилац“, врло старо у облику придева, како се јавља у орфичкој *Аргонаутици*, мада се не односи на специфичну звезду. Хомер такође не користи израз *сеириос*, и више воли назив „јесења звезда“ и „Орионов пас“. Хезиод,[15] који ствара у готово истом периоду (око 800 пре н.е.), у два различита дела зове ову, посебно сјајну звезду Сеириос, што је веома важан обрт. Затим, приказана су помињања Сиријуса и његових различитих имена у радовима Аратуса, Ератостена, Теогниса из Мегаре, песника трагичара Есхила и Еурипида, Ликофрона из Александрије, Ератостена/Псеудо-Ератостена, Аполонија са Родоса, Диодора Сикула, и Лукијана из Самосата. Водећи астроном тога доба, Клаудије Птолемеј, следио је старију традицију називајући звезду *Астрокион*. Плутарх је звао *Προόπτης*, Вођа; али *Κύων, Κύων σείριος, Κύων αστήρ, Σείριος αστήρ, Σείριον άστρον*, или просто *το άστρον* („звезда“) била су Сиријусова имена у раној грчкој астрономији и поезији.

Такође су размотрена дела епског песника Квинтуса Смирнеуса и Пампрепија из Панополиса, из 4. века, као и један век млађег епског песника Нонуса из Панополиса.

Латински аутори и песници који су помињали звезду су Сенека и Валерије Флак који је Сиријус звао „Пасја звезда“, као и Статије, Вергилије и Хорације, који су користили сва њена имена: *Сиријус, звезда Пас* и *Icarium astrum*

Половином 12. века, византијска принцеза Ана Комнен такође помиње Сиријус као „Псећу звезду“. На крају, византијски учењак Георгије Хризококка[16] два века касније, у свом астрономском делу *Synopsis tabularum…* (1347), помиње Сиријус као *Siaèr Jamanè*.

[15]Hesiod (1914, 2005)

[16]Bullialdus, I., (ed.), 1645, *Synopsis tabularum persiacarum ex syntaxi Persarum Georgii medici Chrysococcae* (1347), in Paris: Astronomia Philolaica.

Важан додатни елемент је да је Сиријус од свог хелијактичког изласка до 22. августа носио специјални назив Маира, како од грчке речи проистекле од глагола *мармаиро*, што значи „сијати", тако и од имена пса из грчко-римске митолошке приче. Име Маира јавља се за Сиријус у Калимаховим песмама (*Aetia Fragment* 3. 1) у 3. веку пре н.е. и код Нонуса (као Маирина звезда) осам векова (!) касније.

Митологија повезана са звездом и њеним сазвежђем такође је богата, што наглашава њен значај. Према Ератостену, Сиријус је Лелапс, верни пас Ориона Ловца. Друга легенда на његово место ставља Кербера, страшног троглавог пса који чува свет мртвих, или једног од ловачких паса Актеона, славног ловца и хероја из Тебе.

Митови о Сиријусу такође укључују: Ортруса (пса дива Гериона), Маиру (Икаријевог верног пса, кога је, према Овидију и Хигинусу, бог Дионизије ставио на небо) и Хекату, богињу заштитницу паса, ћерку Титана Перза и Астерије.

Према римском миту Canis Major је Custos Europae, пас који је чувао Европу; као и Janitor Lethaeus, пас чувар доњег неба, чувар пакла.

Значај најсјајније звезде на небу је очигледан, како произилази из свих ових навођења. Што се тиче традиционалног описивања Сиријуса у антици као црвеног, то је највероватније настало због обичаја да се посматра у ноћима близу његовог хелијактичког изласка, односно што је могуће ниже на хоризонту.

Литература

Aeschylus: 1955, *Agamemnon*. Ed. G. Murray, *Aeschyli tragoediae*, 2nd edn. Oxford: Clarendon Press, (repr. 1960), Oxford, pp. 207-274.

Alcée: 1999, *Fragments* (Collection des Universités de France publiée sous le patronage de l'Association Guillaume Budé). Ed. & trans. by G. Liberman. Les Belles Lettres. Paris.

Alcaeus: 1982, 1993, *Greek Lyric I, Fragment* 347, trans. D.A. Campbell, The Loeb Classical Library No. 142. Harvard University Press. Heinemann. London.

Alcaeus: 1922, *Lyra Graeca*, Volume I, trans. by J.M. Edmonds. The Loeb Classical Library. Harvard University Press. Heinemann. London.

Allen, R.H., 1963, *Star Names - Their Lore and Meaning*, Constable & Co., Dover edition. London.

Anna Comnena (Komnene): 1928, *The Alexiad*. Ed. and trans. by E.A. Dawes. Routledge, Kegan, Paul. London.

Anna Comnena (Komnene): 1969, *The Alexiad*. Ed. and trans. by E.R.A. Sewter. Harmandsworth. Penguin. London.

Anonymous: 1950, *Two Poems - Fragments*, text, trans. and notes by D.L. Page, Vol. 3, Select Papyri III, Greek poetry 4th century AD. Literary Papyri, Poetry (LCL 1950). The Loeb Classical Library, No. 140. Heinemann. London.

Apollonius Rhodius: 1962, *Argonautica*, trans. by R.C. Seaton, The Loeb Classical Library, Harvard University Press, Heinemann, London.

Aratus: 1921, in *Callimachus: Hymns and Epigrams, Lycophron and Aratus*, trans. by & G.R. Mair, The Loeb Classical Library No. 129. Harvard University Press, Heinemann, London.

Bayer, Johann: 1603, *Uranometria*, Linda Hall Library of Science, Engineering & Technology, (reprint 2005), Leaf 38 Verso.

Bullialdus, I. (ed.): 1645, *Synopsis tabularum persiacarum ex syntaxi Persarum Georgii medici Chrysococcae* (1347), in Paris: Astronomia Philolaica.

Callimachus: 1958, *Aetia, Iambi, Hecale, and other fragments***,** *Fragment* 3.1, from Oxyrhynchus Papyri 7, trans. by C.A. Trypanis. The Loeb Classical Library. Heinemann. London.

Campbell, D. A.: 1991, *Greek Lyric Poetry*, Bristol Classical Press. London.

Ceragioli, R. C.: 1996, "Solving the Puzzle of 'Red' Sirius", *J. Hist. Astron.*, **27**, Part II, 93-128.

Chrysococca, G.: 1645, *Synopsis tabularum persiacarum ex syntaxi Persarum Georgii medici Chrysococcae*, Ismael Bullialdus (ed.): *Astronomia Philolaica*, Paris.

Demetrakos, D.: 1964, *Mega Lexicon of the whole Greek language*. Ed. Tegopoulos, X. and Asimakopoulos, B., Athens [in Greek].

Diodorus, Siculus: 1939, *The Library of History* IV. 81. 1, trans. by C.H. Oldfather, The Loeb Classical Library. Heinemann, London.

Duvent, J.-L., Benest, D.: 1995, "Is Sirius a triple star?" *Astronomy & Astrophysics*, **299**, 221-628B.

Eratosthenes: 2010, *Catasterismorvm Reliqviae*, Latin Edition by Karl Robert. Nabu Press India.

Eratosthenes: 1997, *Catasterismoi*. Trans. By Theony Contos in *Star Myths of the Greeks and Romans: A Sourcebook*. Phanes Press, Grand Rapids.

Euripides: 1999, *Iphigenia at Aulis - Iphigenia at Tauris.* Trans. and supervision by D. Goudis, Papadimas Publications, Athens.

Euripides: 2008, *Hecuba*, Series: Ancient Greek Dramatic Poetry. Zetros publ., Thessaloniki.

Euripides: 2004, *Iphigenia at Aulis*, trans. by E.P. Coleridge, eBooks@Adelaide.

Euripides: 2003, *Bacche, Iphigenia at Aulis, Rhesus*. Ed. and trans. by D. Kovacs. The Loeb Classical Library No. 495. Heinemann. London.

Geminus: 1898, *Isagoge*, in C. Manitius (ed.) *Gemini Elementa astronomiae*, Leipsig.

Hesiod: 1914, *The Homeric Hymns and Homerica (Theogony)*. Trans. by H.G. Evelyn-White, The Loeb Classical Library. Heinemann, London (reprinted 1954).

Hesiod and Apollonius of Rhodes: 2005, *Theogony, Works and Days, Shield of Hercules, Argonautica*. Zetros Publications, Thessaloniki [in Greek].

Holberg, J. B.: 2005, "How Degenerate Stars Came to be Known as White Dwarfs", *Bulletin of the American Astronomical Society*, **37** (2): 1503. (http://adsabs.harvard.edu/abs/2005AAS...20720501H)

Holberg, J. B.: 2007, *Sirius - Brightest Diamond in the Night Sky*. Springer Praxis Books. Springer, New York.

Homer: 1924, *The Iliad*, trans. by A.T. Murray, The Loeb Classical Library, Heinemann. London (reprinted 1954).

Homer: 1919, *The Odyssey*. trans. by A.T. Murray, revised by G.E. Dimock, The Loeb Classical Library. Heinemann. London (reprinted 1995).

Horace: 2004, *The Satires, Epistles and Art of Poetry of Horace*. Trans. by J. Conington, Bibliobazaar Reproduction Series. USA.

Hornblower, Simon: 2004, *Thucydides and Pindar: historical narrative and the world of Epinikian poetry*, Oxford University Press, p. 170.

Hyginus: 1993, *Fabulae. Editio altera*, ed. P.K. Marshall (corrected ed. 2002), K.G. Saur, Munich.

Ideler, L. (ed.): 1841, *Physici e medici graeci minores*, Berlin (reprint. Amsterdam, 1963).

Litsas, N. B. (ed.): 2008, "The Alchemists from the Pre-Socratic Philosophers to Plato", *Archeology and Arts* No. 106, March, Athens, p. 40 [in Greek].

Lucian: 1911, *The Complete Works*, Volume 6. Trans. Ioannis Kondylakis. Fexis, Athens [in Greek].

Lucian: 2004, *Trips to the Moon*. Ed. H. Morley. Trans. by Th. Francklin. Kessinger Publishing, Montana, USA.

Lycofron: 1921, *The Fall of Troy*, in *Callimachus: Hymns and Epigrams, Lycofron and Aratus*, trans. by A.W. Mair. The Loeb Classical Library No. 129. Heinemann. London.

Manilius: 1977, *Astronomica*. Ed. and trans. by G.P. Goold, Cambridge, Mass. and London, 16-319.

Nonnus: 1940, *Dionysiaca*, Volume I, Books 1-15, trans. W.H.D. Rouse. The Loeb Classical Library No. 344. Heinemann. London.

Palatine or Greek Anthology: 1917, Vol. III, Book 9. Trans. W.R. Paton. The Loeb Classical Library No. 84. Harvard University Press. Heinemann. London.

Pausanias: 1935, *Description of Greece*, Vol. IV: *Arcadia, Boeotia, Phocis and Ozolian Locri*, Books 8.22-10, trans. by W.H.S. Jones. The Loeb Classical Library No. 297. Heinemann, London.

Petrides, S.: 2005, *Orpheus' Argonautica – A dissertation on seafaring of the late Pleistocene*. Athens (author's publ.).

Plato: 2002, *The Apology of Socrates*. Introduction, translation and comments by N.E. Tzirakis. Patakis Publ., Athens.

Platonis opera. I-V: 1900-07. Ed. J. Burnet. Clarendon Press. Oxford (republ. 1967-1968).

Plutarch: 1935, *De Iside et Osiride*. Ed. W. Sieveking, *Plutarchi moralia*, Vol. 2.3, Leipzig.

Pseudo-Eratosthenis: 1897, *Catasterismoi*, in *Mythografi graeci* iii., Ed. A. Olivieri, Leipsig.

Pseudo-Hyginus: 1960, *Astronomica* 2. 4, in *The Myths of Hyginus*. Ed. and trans. by Mary Grant. University of Kansas Publications in Humanistic Studies. No. 34. Lawrence: University of Kansas Press.

Ptolemy: 1903, *Claudi Ptolemaei opera quae extant omnia. Syntaxis mathematica*. J.L. Heiberg, Leipsig.

Quintus Smyrnaeus: 1913, *The Fall of Troy*. Trans. by A.S. Way. The Loeb Classical Library Vol. 19. Heinemann, London.

Scheer, E. (ed.): 1958, *Lycofronis Alexandra*, II, scholia. Berlin.

Scholia in Apollonium Rhodium vetera: 1935, in C. Wendel (ed.), Weidmann, Berlin.

See, T. J. J.: 1927, "Historical Researches Indicating a Change in the Color of Sirius Between the Epochs of Ptolemy. 138, and of Al Sûfi, 980, A. D.", *Astronomische Nachrichten*, **229**, 245-272.

Seneca: 2004, *Tragedies* II: *Oedipus, Agamemnon, Thyestes, Hercules on Oeta, Octavia*. Ed. and trans. by J.G. Fitch. The Loeb Classical Library. Cambridge University Press. London.

Statius: 2003, *Silvae*, English and Latin edition, trans. D.R. Shackleton Bailey. The Loeb Classical Library No. 206. Harvard University Press. Heinemann. London.
Theochares, P.: 1995, *The pyramids of Argolis and their dating*, 11th Panhellenic Conference, May 12-13, Nafplio [in Greek]
Theodossiou, E., Danezis, E.: 1990, *The Stars and Their Myths — Introduction to Uranography*, Diavlos Publ., Athens [in Greek].
Theognis: 1997, *Lyrical poems III*. Epikairotita Publ., Athens [in Greek].
Tripp, Edward: 1970, *Crowell's Handbook of Classical Mythology*, New York, Thomas Crowell Press.
Valerius Flaccus: 1934, *Argonautica*. Trans. J.H. Mozley. The Loeb Classical Library No. 286. Harvard University Press. Heinemann. London.
Virgil: 1916, *Eclogues*, *Georgics***,** *Aeneid*, I-vVI. Ed. and trans. by H.R. Fairclough, rev. G.P. Goold. The Loeb Clasical Library No. 63. Harvard University Press. Heinemann. London.
Virgil: 2002, *Aeneid*, Book III & X. rans. Kline, A. S., on line.
(http://www.poetryintranslation.com/index.html)
Wender, D.: 1984, *Hesiod and Theognis*, Penguin Books. New York.
Whittet, D. C. B.: 1999, "A Physical Interpretation of the 'red Sirius' Anomaly", *Monthly Not. Roy. Astron. Soc.*, **310**, 335-359.

SIRIUS IN ANCIENT GREEK AND ROMAN LITERATURE: FROM THE ORPHIC *ARGONAUTICS* TO THE *ASTRONOMICAL TABLES* OF GEORGIOS CHRYSOCOCCA

The brightest star of the night sky, visible from all Greece, especially during clear winter nights is Sirius, Alpha Canis Majoris (α CMa). Due to its intense light, Sirius had one of the dominant positions in mythology, legends and traditions of most ancient people. Greeks were not an exception: The original Greek name 'Seirios' meant sparking, shining, fiery or burning. In this review article the references of the many ancient classic authors and poets, Greeks and Romans, who wrote about Sirius are examined and the problem of its 'red' color arising from these references is discussed.

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КОСМОЛОГИЈЕ АЛКМАНА, ЛЕУКИПА И ДЕМОКРИТА

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Резиме: Дискутовани су и анализирани космолошки погледи пресократовских философа, атомиста и мислилаца Леукипа и Демокрита, који имају сличности са још ранијим гледиштима изнесеним у лирским остварењима Алкмана, који је живео у Спарти током 27. Олимпијаде (672-668. пре н.е.).

1. УВОД

Један од најзначајнијих грчких лирских песника антике, који је током средине 7. века пре н.е. обликовао „хорску" поезију у Спарти у практичном литерарном стилу, био је Алкман, син или Дамаса или Титаруса, коме је због изузетне вештине додељено прво место у „Канону" из Александрије.

Име „Алкман" је изведено због прилагођавања у дорски дијалекат јонског имена Алкмеон и он не треба да се меша са питагорејцем Алкмеоном (око 500 пре н.е.), сином Пеирита из Кротона, грчке колоније на југу Италије. Професор А. Д. Скидас (1981) помиње да је према Suidae Лексикону (одредница о Алкману), песник живео у току 27 Олимпијаде (672-668 пре н.е.), када је владар Лидије био Ардис, док учени човек цркве Еузебије ставља песникове најбоље године у 659. пре н.е. У другом одломку, који долази из Оксириншког папируса 2390, може се наћи да Алкман помиње име „Леотикид", како се звао краљ Спарте. На основу тога Алкман се може ситуирати у каснију половину 7. века пре н.е. Према лексикону Suidae (A. P. 7, 709, одредница Александар Етолијски), Алкман је пореклом јонски Грк, (Сард у Лидији), и одатле је дошао у Спарту. Такав поглед се налази и у белешци у Оксириншком папирусу 29 [P. Oxy. XXIX fr.1, col III, 30 к.ε. (=10 (α), 30 к. ε. P.)] у којој се помиње да: "... *су Лакедемоњани онда поставили*

Алкмана, који је био лидијског порекла, за учитеља (педагога), њиховим ћеркама и синовима…". Овај став пак, доводи се у питање због другог коментара, који се налази у Оксириншком папирусу 2389 [P. Oxy. fr.9 col.1 (=13(a) P.) στ. 11 κ.ε.)] а помиње да порекло великог песника у ствари није лидијско: *"… Јасно је да су Аристотел и други погрешили мислећи да је он (Алкман) био очевидно лидијског порекла..."*. У односу на расправу о Алкмановом месту рођења, Антипатрос из Солуна (Suidae, A. P. 7, 18, 5) напомиње да је у неколико античких градова заједничка пракса била да полажу право да су место рођења великих песника: *"… Постоји спор између два континента (града – области) да ли је или не Алкман био лидијског или лакедемонског порекла. Неколико (градова), се сматрају за место рођења оних који служе поезији..."*.

Алкману дугујемо информацију да су се преци Хелена називали „Греки". То се такође јавља код лексикографа Стефана Византинца (Stephanos Byzantios), који пише: *"Према Алкмановим погледима, мајке Хелена биле су Греке"*. Алкманове лирске песме, како се помиње у Оксириншком папирусу 2390 (Harvey, 1967), садржале су космолошке погледе његовог времена: *"… Јер када је супстанца почела да очвршћује, нека врста пора (пролаза) се обликовала, нешто као почетак. Алкман каже да је супстанца свих ствари била у нереду и нестворена, а тада је рођен неко ко је све довео у ред, и створена је пора, а када је она нестала, следила је граница (завршетак или крај, "текмор"). И пора је почетак, а граница је попут краја. Када је Тетис рођена, то је постало почетак и крај свега, и све ствари имају природу сличну бакру, а Тетис ону мајстора а пора и граница („текмор") ону почетка и краја... а трећа у низу је тама, захваљујући којој ни Сунце ни Месец нису били створени до тада, јер је супстанца била још недовршена. Били су створени они… пора, граница и тама. Дан, месец и као треће тама. Сијање дана није било густо али је потпомогнуто Сунцем (његовим сијањем), јер раније је била само тама, али после овога [тог поступка] то двоје је постало различито једно од другог…"*.

2. АЛКМАНОВА КОСМОЛОГИЈА

На основу изложеног, Алкманов космолошки модел се може сумирати на следећи начин:

1. У почетку, супстанца или материја је била у нереду и недовршена, и тада нису били створени ни Сунце ни Месец, односно може се додати да није ни звездани Космос. Дакле видљиви астрални Универзум био је створен од неперцептибилног, нестворeног и недовршеног материјала који је постојао пре тога.

2. Онда се у оквиру простора, који је био пун овог неперцептибилног материјала (не-материја), родио неко ко је довео све ствари у ред (Тетис, чије је име изведено од грчких глагола *"τιθεμαι, θεσθαι"*, што значи сложити, организовати, уредити), као нека врста мајстора.

3. После тога, у простору не-материје, створена је пора (уски пролаз), која је имала улогу дела почетка. Овај уски прелаз био је излазни канал за неуређену, недовршену и невидљиву супстанцу, из света њеног почетног матерјалног непостојања, до реалног простора перцептибилног Универзума.

4. Стварање границе након тога, односно „текмора“, што је према Весту (West, 1963) био знак за оријентацију унутар поре или према Вернану (Vernant, 1970), међу звездама. Дакле, постаје очигледно да је “текмор” означио крај ситуације која је постојала пре перцептибилног Универзума. Односно када је недовршена и неоформљена материја прошла кроз текмор, аутоматски је постала обликована и перцептибилна, пошто је могла да ствара опсервабилне објекте као што су Сунце и Месец. Према Кирку и др. (Kirk et al.,1983), текмор, као граница, је вероватно истоветан са појмом апеирон Анаксимандра, који је Спарту посетио једну генерацију касније.

5. Пора и текмор су коегзистирали са тамом, као јединствени скуп посебних чињеница. Свакако, пора – текмор – тама систем, био је у целини изван перцептибилног Универзума. Према Пејџу (Page, 1968), пора је вероватно идентична са Хесиодовим Хаосом, заједно са значењем таме, што је концепт који Кирк и др. (Kirk et al., 1983) одбацују. Они истичу поглед да пора као пролаз не може бити идентификована са Хаосом, тамом или непродуховљеном материјом, већ треба да га потискује или му се супротставља.

6. После границе (текмора) створени су дан - вероватно светли део дана, и надаље Сунце - Месец и тама - вероватно ноћ, тамни део дана. После границе (текмора), перцептибилни Универзум почео је да се материјализује.

7. Дневна светлост (зрачење) није била густа, али је била потпомогнута зрачењем Сунца. Занимљива појединост која се може споменути је да нас белешка о Алкману (2. век) обавештава да је светлост (зрачење) била „потпомогнута“ Сунцем, које сходно томе, није било једино одговорно за њен настанак. Ова чињеница наводи нас на закључак да се дан не поистовећује са светлим делом дана, односно са појмом светлости.

Овакав космолошки поглед, који је заступао Алкман половином 7. века пре н.е., свакако описује много старије погледе. Занимљиво је да неки од њих имају понекада сличности са појединим модерним космолошким претпоставкама, које са своје стране описују да је спознајни звездани Универзум био створен преко сингуларне аномалне тачке унутар беле рупе. Ова бела рупа може, услед инверзне временске симетрије Ајнштајнових једначина, да се посматра као црна рупа обрнута у времену. Напоменимо да су још средином шездесетих, изношене сличне претпоставке, према којима беле рупе које могу да постоје, чине области Универзума, које са временским закашњењем пролазе кроз Велики Прасак. Занимљиво је да Алкманове „поре“ концептуално подсећају на Ајнштајн – Розенов мост, тачку сингуларитета са идејом „текмора“, а анти пралелни Универзум у коме мост почиње, асоцира на простор са недовршеном, нестворeном и неперцептибилном супстанцом. Појам беле рупе наводи на помисао да је

„текмор“, као граница „поре“, према Алкману, тачка појављивања перцептибилне материје ‘ex nihilo’, као и израчене енергије, пошто је дан био рођен после тога. На жалост остатак Алкманове космологије није познат, пошто велики део папируса није могао бити прочитан.

Са друге стране, срећа је да можемо да проучавамо наставак оваквих космолошких погледа, у космологији философа атомиста Леукипа и Демокрита. Космологија коју су заступала два велика философа је радикално различита од пресократовских појмова о томе и директно повезана са погледима Алкмана и највероватније се наставља на њих.

3. КОСМОЛОГИЈА ФИЛОСОФА АТОМИСТА ЛЕУКИПА И ДЕМОКРИТА

После проучавања Леукипових и Демокритових текстова не можемо да не поменемо да су извесни њихови интуитивни погледи о природи Универзума и материје, слични онима који су ушли у модерну науку. Као пример наведимо претставу о томе шта је у ствари наша Галаксија. Галилеј је, користећи мали телескоп који је сам направио, открио да се Млечни пут састоји од много звезда које му, због велике удаљености од Земље, магличасти изглед. Још пре много векова пак, Демокрит је писао: *“… Речено је да је наш Млечни пут начињен од веома малих и густих звезда, које нам изгледају сједињене услед велике удаљености неба од Земље, управо као објекат који је посут зрнцима соли…”*.

Друга чињеница је да су Леукип и Демокрит разумели непоузданост људских чула. *Секстус Емпирикус* у своме спису “*Против Математичара”* напомиње о Демокриту: *“У Канону, он помиње да постоје две врсте знања једно које је аутентично и оно које је нечисто. Све што следи припада нечистом; вид, слух, мирис, укус и додир. Други облик знања је стваран и различит од овога.”*

Интересантно је такође, да су они интуитивно претпоставили да је утисак о два објекта који су у контакту један са другим уствари обмана наших чула. У односу на то, *Јоанис Филопонис* у своме делу *‘Тумачење о вечности света противно Аристотелу’* помиње следеће: *“Када је Демокрит рекао да су атоми у међусобном додиру, није мислио на додир у буквалном смислу речи. Уствари он користи појам додир да опише узајамно приближавање атома и мало растојање између њих. Вакуум је оно што их раздваја са свих страна.”*

Демокрит је такође, интуитивно спознао како видимо објекте путем електромагнетног зрачења које они емитују или одбијају. Како *Александар Афродизијски* напомиње у *“Коментарима о Аристотелу, о чулу и чулности”*: *“Демокрит верује, како је Леукип рекао пре њега, а следбеници Епикура после њега, да нешто што личи на објекат, и има истоветан облик, бива истргнуто из њега и пада на очи оних који гледају и тако је произведен осећај виђења”*.

Осим горе наведеног, Демокрит је, претпоставио и оно што је Њутн описао својим законом „акције – реакције“. Аристотел у делу *“Наративај и исквареност”* пише: *“Демокрит је лично развио једну теорију. Верује да су оно што делује и оно на шта се делује заиста једно те исто. Зато што [бића] која се разликују и имају друга својства не могу бити појединачни субјекти акције од других, и чак ако различита бића делују на неки начин индивидуално на друге, то није зато што су различити, него зато што деле нешто слично.”*

Појам тежине објеката је такође привукао Демокритоиву пажњу. *Симплиције*, у делу *“Аристотелово Пери Урану (De Caelo)”* пише: *“Демокрит и касније Епикур, веровали су да су сви атоми исте природе и да зато што имају тежину, они који су лакши, пошто су гурани напоље од оних који су тежи, и који силазе према доле, крећу се на горе, и због тога нам, како кажу, нека тела изгледају лака а друга изгледају тешка.“*

Желели бисмо и да напоменемо Демокритово потпуно разумевање илузије о ономе што се назива људско време. *Секстус Емпирикус* пише: *“… Оваква претстава времена приписивана је природњацима који су били следбеници Епикура и Демокрита. “Време (како га мери човек) је имагинарни појам, сличан оном о дану и ноћи.”* У вези са овим поређењем желимо да поменемо Ајнштајнове погледе о томе. Велики физичар пише: “За нас, заклете физичаре, разлика између прошлости, садашњости и будућности је само илузија, ма како истрајна може да буде.”

3.1. Семантика (терминологија) у Демокритовим текстовима

Велики проблем са којим се суочавају проучаваоци античких текстова када желе да упореде погледе који су у њима изнесени, са модерним научним погледима, је семантички садржај појмова који су употребљени. Ови се појмови семантички разликују у текстовима различитих писаца. Као што је очигледно из одговарајућих текстова, Демокрит описује простор, који ми данас називамо математички простор, речима: “кенон” (вакуум или празнина), “уден” (ништа), или “апеирон” (бесконачно). Вакуум (празнина) за Демокрита се поистовећује са појмом непостојања. Слично томе, он појму „он“ (онај који је, биће), додељује називе “плерес” (пуни, потпун), или “стереон” (масиван, чврст), поистовећује га са појмом атома и каже за то („он“), „настон“ и „ден“.

Као што је постало јасно, појмови бића и не-бића претходе Платону и радикално су друкчији од концептуалног садржаја који им је он доделио.

Биће и не-биће Леукипа и Демокрита осим своје философске димензије, има такође посебан физички садржај, у научном смислу.

3.2. Космологија Демокрита и Леукипа

Мада свако данас сматра Демокрита и Леукипа за оце теорије о атомима, мало их зна да су два философа атомиста такође и претече једног занимљивог космолошког предлога. Размотримо, каже доксограф Диоген Лаертије (IX 30-32) Леукипове погледе, које је заступао такође и Демокрит: *"Леукип је сматрао да су светови створени када су тела пала у неки вакуум (празнину) и била захваћена једна другима, а њиховим кретањем и нагомилавањем је обликована природа звезда… Светови су са друге стране створени на следећи начин: Много тела свих врста облика, било је одвојено од «апеирона» (бесконачног) и доспело у велики вакуум где су начинила вртлог. Због тога, док су се сударала и неправилно спирално кретала, раздвајала су се по врстама. Када су достигла равнотежу због њиховог мноштва и нису могла више да се окрећу, фина (танка) тела су продужила до спољашњег вакуума, као да их је остатак избацио. Она нису остала сједињена и, помешана, приближавају се међусобно и формирају почетни сфероидни систем. Одатле се одвојила опна, која у себи носи неколико тела. Како она ротирају због центрифугалне силе, опна постаје танка, зато што се елементи који су блиско ухваћени у вртлог увек удомљују у њему (у центру). Тако је рођена земља (перцептибилна материја), када су тела која су се нагомилавала у центру сјединила. Тада је опет, ова спољашња опна била увећана нагомилавањем тела, која су дошла споља, зато што како се креће у вртлогу, она захвата тела са којима долази у додир. Од њих, нека бивају захваћена и обликују у почетку систем који је веома влажан и блатњав. После се суше и следе општи вртлог, а касније постају ужарени и сачињавају природу звезда"* (Леукип, A1). На основу претходних одломака, главне етапе космичког стварања према Леукипу и Демокриту биле су следеће:

3.2.1. У почетку био је «плерес» (пун) и вакуум (празнина)

Очито, космологија философа атомиста, управо попут Алкманове космологије, подржава настанак Универзума од неперцептибилног материјала. Овај матерјал сатојао се од две компоненте, "ми он" [не-биће, вакуум (празнина) = апеирон] и "он" (биће, атоми). Ова супстанца пре Универзума (биће и не-биће), била је изван доступа људских чула, пошто су философи атомисти сматрали да су *"Плерес и кенон, односно атоми и простор, постојеће и чињеничне стварност које су изван опсега људских чула."* Користећи терминологију инфлационе космологије, могли бисмо овај почетни и неперцептибилни материјал из кога је Универзум био рођен, назвати „псеудо-вакуум."

3.2.2. Стварање „великих празнина“

У другој фази, у оквиру целокупног почетног простора Универзума (не-биће, празнина = апеирон), настало је неколико појединачних „великих вакуума“, то јест малих субпростора укупног простора Универзума. Користећи модерну научну терминологију, то се може изразити као формирање у свеукупном, неперцептибилном и нееуклидском простору Универзума, раздвојених области са различитим густинама, па према томе и са различитим закривљеностима, чињеница због које се променила геометрија насталих субпростора.

3.2.3. Локални колапс „атома“ у „великим вакуумима“; настанак „вртлога“

У овој фази, неопипљиви комади бића (атоми), пореклом из свеобухватног неперцептибилног универзалног стварања (апеирон+атоми = празнина+плерес = не-биће+биће), теже да заузму “велике празнине” које су створене, формирајући “вртлог” за сваку. Када атоми улазе у субпростор „великих празнина“, створени су перцептибилни „светови“ (универзуми), који су садржани у потпуној неперцептибилној свеукупности „бића+не-бића” (атоми + празнина = Универзум), и који могу бити бесконачни.

Демокрит додељује специфично физичко значење појму „вртлог“, који нам је са космолошког становишта посебно занимљив. Демокритов «вртлог» створен је у оквиру почетног неперцептибилног система, ‘празнина’ + ‘не-вакуум’ (биће+не-биће = атоми+простор = универзални не – Еуклидски, Риманов простор). Ово је друга веза између космологија Алкмана и философа атомиста. У другој фази, «вртлог» еволуира у малој области «великих празнина» (Еуклидски субпростори). Вртлог у почетку заузима мали део велике празнине, пошто треба да се креће ка њеној спољашњости. Враћајући се на појам вртлога, како га описују Леукип и Демокрит, јавља се питање његове еволуције. Где се налази његов врх (око) и дно? У случају Демокритове космологије, материјал мора да се креће од врха (ока) ка доњем крају вртлога, пошто је, као што ћемо убрзо видети, крајњи резултат деловања вртлога коначна по величини сфера. Према томе то је вртлог попут онога код отвора сливника.

У Демокритовој космологији, јавља се, уз физичко објашњење, идеја о постојању мноштва опсервабилних светова као што је наш, унутар створених «великих празнина», светова у којима могу важити друкчији природни закони.

Овакав поглед философа атомиста, потсећа на космолошке претпоставке, као што је инфлаторни космолошки модел, са Мултиверзумом, који је састављен од мноштва «светова универзума»-мехурова, као код пене.

3.2.4. Формирање сфероидалног система од перцептибилне материје и истовремено избацивање материјала у спољашњи вакуум

Према Демокриту, услед вртлога који се обрће, оно што је исте врсте одваја се од онога што је различито. Онда се ротација зауставља и створен је систем „завршених тела“ (не завршених по величини, нити атома), који се креће према спољашњем вакууму (простору), као да су била избачена, док преостала „не-завршена“ (тежа *‘хадра’*), остају заједно, захватају једно друго, међусобно се приближавају и формирају почетни сфероидални систем. Избацивање и ширење „завршеног“ материјала, у схватањима Леукипа и Демокрита, није резултат експлодирајућег сфероидалног система од «незавршеног» (хадра) материјала. Завршени се стварају заједно са сферним кондензацијама од „хадра“ материјала, у резултату догађаја који се одвијају на крајевима „вртлога“, и то тек када се одиграло диференцирање и уравнотежавање оних «исте врсте» од оних «различите», и њихова ротација се зауставила. Леукип и Демокрит сматрају да мешавина „завршеног“ и „незавршеног“ материјала, која се не окреће и достигла је равнотежу, изазива обрнуто кретање – контракцију – „незавршеног“. Ове честице теже да формирају прилично малу по размерама, али такође густу, сфероидалну творевину од материје.

Јасно је из горњег излагања да на завршетку вртлога, када се он јавља из великог вакуума, постоји ограничена у простору, уравнотежена и неротирајућа, сферна кондензација од „незавршеног“ материјала. Сфера заузима веома мали простор у „великој празнини“. Јер ако није тако, не би било начина да се „завршени“ материјал креће (шири) у спољашњи простор, ако је тај простор био заузет почетном сфером. Занимљиво је да се на граници вртлога, првобитни неперцептибилни материјал (атоми + простор) дели на две перцептибилне компоненте, “завршену” и “незавршену” (тешку, густу = “хадра”).

3.2.5. Формирање танке опне – стварање обртног универзалног кретања

Као штто је горе поменуто, избацивање “завршених“ према споља, изазива обратно кретање (сажимање) код „хадра“, које тежи да формира, малу по размерама, сфероидалну кондензацију материје.

Како се данас зна, снажно сажимање почетне сферичне кондензације такве велике количине материјала, сличне оној коју описују Леукип и Демокрит, доводи до јаке експлозије површинског слоја материјала сферичне кондензације. Ова појава може се посматрати у току експлозије супернове. Занимљиво је да је то феномен, веома сличан ономе који је описао Демокрит, пошто у свом казивању, помиње да се после избацивања „завршеног“ према спољашњости, и сажимања сферичне кондензације од материје „хадра“, “*од сферичне кондензације одвојила опна, која се креће према спољашњости, док остатак сфере почиње поново да се обрће и да се*

сажима." Ту нас Леукип и Демокрит још једном изненађују, пошто помињу нешто слично физичком феномену који је био откривен у прошлом веку. Кажу да снажно избацивање танке опне убрзава сажимање преосталог материјала у сфероидалној кондензацији, и такође да га приморава на брзу ротацију. На крају, закључују са описивањем појаве коју су интуитивно осмислили. Помињу да снажно сажимање и ротација ове централне сфероидалне кондензације, доводе до стварања новог џиновског вртлога, који тежи да у њу поново усиса и сакупи сав преостали материјал.

Све ово нас води закључку да су Леукип и Демокрит, у 5. веку пре н.е., интуитивно износили погледе на настанак и еволуцију Универзума, који су били изненађујуће напредни за њихово време.

Ако би користили модерну научну терминологију, могли би да кажемо да интуитивна гледишта два велика философа, асоцирају на Универзум, створен из беле рупе, који после свога настанка, еволуира у оквиру црне рупе, у чијем сингуларитету ће једном нестати.

Литература

Aleksandrov, A. D.: 1976, *Non-Euclidian Geometries*, Hellenic Mathematical Society press, Mathimatiki Epitheorisi, July-August-September.

Apicella, Gabriella R.: 1979, La Cosmogonia di Alcmane. *Quaderni Urbinati di Cultura Classica, Nuova Serie (*QUCC N.S.) 3.32. pp. 7-27).

Aristotle: 1956, *The Metaphysics.* Vol. I-IX, The Loeb Classical Library, Book XVII with an English Translation by H. Rackham. London: William Heinemann Ltd. Cambridge, Massachusetts: Harvard University Press.

Aristotle: 1957, *The Physics.* The Loeb Classical Library, Vol. I, Book III, with an English Translation by Philip H. Wicksteed. London: William Heinemann Ltd. Cambridge, Massachusetts: Harvard University Press.

Balash, M.: 1973, Jodavia sobre la patria de Alcmane, *Emerita*, 41, pp. 309-322.

Danezis, E., Theodossiou E., et al.: 1999, A presocratic Cosmological Proposal, *History and Heritage of Astronomy*, 2(2):125-130.

Danezis, E., Theodossiou E., Dimitrijević, M. S. and Dacanalis A.: 2005, Leucippus – Democritus and modern Cosmology, *Proceedings of Conference: The views of ancient Greek philosophers for Physics Sciences and their relations to the modern thinking*. Xanthi, November, pp. 67-82.

Diogenes Laertius: 1970, *Lives and opinions of eminent philosopher,* volume II, IX 30-32, Loeb classical library, translated by R. D. Hicks. London, William Heinemann LTD, Harvard University press, pp. 441-443.

Drecker, J. D.: 1928, Der Johannes Philoponus Schrift über das Astrolabe, *Isis II*, pp. 15-44.

Harvey, F. D.: 1967, Oxyrhynchus Papyrus 2390 and Early Spartan History. *Journal of Hellenic Studies*, 87, pp. 62-73.

Hase, H.: 1839, *Johannes Philoponus, Περί της του αστρολάβου χρήσεως και κατασκευής*. Rheinisches Museum fur Philologie, 6, pp. 127-171.

Kirk, G. S., Raven, J. E. and Schofield, M.: 1983, *The Presocratic Philosophers. A critical History with a selection of Texts*, Cambridge University press, First printed 1983, p. 428, 2nd edition 1995.

Page, D. L.: 1968, *Lyrica Graeca Selecta, Edidit Brevique Adnotation Critica Instuxit*. Oxford.
Sextus: 1968, *Against the physicists*, vol. III, I 363, Loeb classical library, translated by R. G. Bury. London, William Heinemann LTD, Harvard University press, p. 175.
Simplicius: 1882, *Peri Ouranou* (*De Caelo*) 202, 16, Priores Commentaria, Edit, Hermannus Diels, Berolini, Typis et Impensis G. Reimeri.
Skiadas, A. D.: 1981, *Ancient Lyrics-2*. Kardamitsas Editions, Athens [in Greek].
Sorabji Richard: 1987, *Philoponus and the Rejection of Aristotelian Science*, Duckworth, London.
Suidae Lexicon: 1854, Vol. I and II. Ex Recognition, Imanuelis Bekkeri. Berolini. Typis et impensis Georgii Reimeri. A..
Vernant J.-P.: 1970, *Thetis et le Poeme Cosmogonique d' Alcman. Hommages a Marie Delcourt*. Brussels.
West, M. L.: 1963, Three Presocratic cosmologies. *Classical Quarterly*, New Series 13, pp. 154-176.

COSMOLOGIES OF ALCMAN, LEUCIPPUS AND DEMOCRITUS

Cosmological views of presocratic philosophers, atomists ant thinkers Leucippus and Democritus, which have similarities with more earlier views, presented in lyrical works of Alcman, who lived in Sparta during 27 Olympiad (672-668 BC), are discussed and analyzed.

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КОСМОЛОШКЕ ТЕОРИЈЕ ПРЕСОКРАТОВСКИХ ГРЧКИХ ФИЛОЗОФА И ЊИХОВИ ФИЛОЗОФСКИ ПОГЛЕДИ НА ЧОВЕКОВУ ОКОЛИНУ

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Резиме: Анализирани су погледи на природу, Мајку-Земљу, и животну средину у Старој Грчкој, од *Орфичких химни* и хомеровског света, преко радова Хезиода и Софокла и теорија и радова пресократовских филозофа, Јонске школе, Талеса, Анаксимандра, Анаксимена, Хераклита, Питагоре и Питагорејаца, Емпедокла, Сократа, Платона, Аристотела, Стоика, и Неоплатониста, са посебним нагласком на Плотину. Заједничко у учењу пресократовских јонских филозофа и каснијих античких грчких природних филозофа, било је посматрање животне средине и природе, односа у њој, промена и цикличних периодичних варијација. Истичемо и покушаје Анаксимандра да формулише потребу за очувањем динамичке равнотеже у природи и екосистемима и његове погледе на еволуцију живих бића и људи.

1. УВОД

Погледи старих грчких пресократовских филозофа из Јоније отворили су нови пут за проучавање природе користећи човекову логику. Полазећи од култа Земље као богиње, предузимали су истраживање њеног положаја у космосу, предлажући сферичан облик за нашу планету. Они су били пионири унифицираног прилаза физичком свету, предпостављајући један елемент као основу свега у Универзуму – то је била вода за Талеса, бесконачно за Анаксимандра, ваздух за Анаксимена, ватра за Хераклита. Светови настају и пропадају вечно следећи један другог. Анаксимен је веровао, као и Анаксимандер, да наш свет није једини који је постојао. Хераклит је сматрао да, од великог богатства природног стварања са

непредвидивим променама, ништа не остаје стабилно непокретно. Нема сталности него само бесконачан ток, вечно кретање. То је слично ономе што данас прихватамо у квантној физици; привидна постојаност и непокретност је илузија наших ограничених чула. Према Хераклиту, материја се непрекидно трансформише.

Погледи и теорије античких филозофа указују на однос у старом грчком свету према Мајци-Земљи и природној околини, данас међународно исходиште првог приоритета у односу на неопходност њене неодложне заштите.

У овом раду ћемо анализирати развој претстава о човековој животној средини од *Орфичких химни* и хомеровског света, преко Пресократоваца, Сократа, Платона, Аристотела, Стоика и Неоплатониста са посебним осврtом на Плотина, да бисмо пратили развој идеја као што је потреба за очувањем динамичке равнотеже екосистема и поимања животне средине, природе и Мајке-Земље, што, као нека врста путовања назад, ка првобитним изворима, може много да нам открије у односу на наше модерне бриге.

1.1. Од мита до разложности

Пресократовски филозофи у Јонији пажљиво су у 6. веку пре н.е. посматрали природне појаве и њихов допринос оспоравању митова је био круцијалан. Они су покушавали да изведу све могуће закључке на основу посматрања природе користећи углавном своју логику (Theodossiou, E., 2007, стр. 44)

Антички грчки природни филозофи били су обузети „космичком загонетком“ т.ј. питањем порекла, структуре и грађе нашег Универзума. Истовремено, десио се изненадан и прилично неочекивани помак од мистицизма и религиозног погледа на свет, према промишљајућем разуму, што је величина античке филозофије; преокрет са дубоким последицама за човечанство.

Свакако, већина пресократоваца били су природни „монисти“ филозофи, у смислу да су се интересовали за дефиницију изворне супстанце или принципа, примарног елемента од кога су све ствари у нашем свету потекле. Тако су формулисали филозофске системе помоћу којих би били способни да на рационалан начин објасне однос између човека и природе. То је разлог зашто је њихова филозофска мисао релевантна и данас и што је природна компонента пресократовске филозофије од тако великог значаја.

По први пут у историји света, у пресократовским гледиштима је потпуно одвојен мит од рационалног интелекта. Овде ће бити показано како се од мита појавила физичка мисао о околини и како је била обликована за време прве научне револуције у Јонији у 6. веку пре н.е. Тада су филозофи покушали да одговоре на два основна питања са којима су били обузети: прво о пореклу света и друго о његовој структури и облику. То је разлог што су постали оснивачи филозофске мисли и саме науке.

2. МЕСТО ЗЕМЉЕ У КУЛТУ И УНУТАР КОСМОСА

2.1. Култ Земље

Полазна тачка може бити култ Мајке-Земље. Упоредо са првобитним култом Сунца, истакнуто место у религији заузимао је култ Мајке-Земље, универзалне мајке. Филозофија грчких пресократовских филозофа рефлектовала је погледе који поштују Природу као мајку хранитељку људи и њихов став према њој био је онај који се очекује према живом и поштованом божанству.

У неком смислу, Земља је била највиша богиња, због чега су је Грци звали –реч „земља“ у Грчком је женског рода– *Хипертатан* (Најузвишенија) Земља. Треба напоменути, да Геа (Земља) никада није обожавана као небеско тело или антропоморфно божанство, него пре као *геа-хтон*, као природа са њеним земљиштем, тлом и унутрашњошћу, где људи живе и узимају храну. Песник трагичар Софокле (5. век пре н.е.) “оптужује“ човека као биће које се усуђује да узнемирава најузвишенију богињу, не оклевајући да јој нанесе бол:

“*Орући је плугом, и непрестано ријући је годину за годином*” (Софокле *Антигона*, стих 330).

Претварање земље-природе у свемогућу богињу-мајку највероватније се догодило када су се развила пољопривредна друштва, заједно са њиховим земљорадничким фестивалима-мистеријама, који су се односили на вечни циклус живота (клијање, рађање плодова, сазревање, старење и смрт, семе, сејање и поновно рађање). Почевши од дубоке древности, може се рећи да су примитивни људи од својих првих когнитивних посматрања живота на Земљи схватили, да је попут њих, остатак животињских и биљних животних форми такође везан за тројство рађање-развој-смрт. Човеково преживљавање било је повезано са земљином вегетацијом, пошто је, као остале животиње требао храну, коју је налазио у природи (Eliade, M., 1978).

Наши примитивни преци, пажљиво посматрајући животни циклус биљака, са семеном, његовим сађењем унутар Мајке-Земље и преображајем у нови живот, открили су одговарајући основни циклус животињске сексуалне репродукције. Мужјак је сперму (на грчком реч „сперма“ значи „семе“) убацивао у материцу женке. Аналогно са семеном биљке; и од мајчиног организма настајао је нови живот. Од „безживотног“ семена, Земља је стварала живот, истоветно као женка животиње. Дакле Земља такође треба да је живо биће и да би дала живот треба да дође у додир са мушким елементом. Стога је Земља била персонификарана са женским обликом, док је оплођујући мужјак било Небо са кишом, или нека велика река као што је у Египту био божански Нил.

Земља (*Геа*) и Небо (*Уран*) представљају први божански пар, који сједињује космогонијски орфички Ерос (*Orphic. Fragm*. Kern, 1922, 1); у овој симболици еротичке космогоније Небо (*Уран*) грли и оплођује Земљу кишом. Њихово спајање је према томе представљено као изузетно моћна снага репродукције која је сједињавала и умножавала божанства, аспекат који је поштовао и опевао митски Орфеј као продукт првобитног Хаоса или Ереба и осветљеног дела дана. Ово спајање, такође је симболизовано љубавном афером Семеле, која претставља Земљу, и Зевса (Јупитера), небеског бога који оплођује вољену жену громовима, весницима драгоцене кише. Сличан је начин како Зевс оплођује земаљску Данају, пошто се претворио у златну кишу да би продрео у њену подземну ћелију. Симболично, небески бог је омекшао својом благосиљајућом водом тело Земље суво од суше, да би у њему настао живот.

2.2. Место Земље у Космосу

Земља је у хомеровском Унивезуму посматрана као округли раван диск око кога тече широка кружна „река“ Океан. Овај модел први пут се јавља у *Хомеровској химни*: *“Тамјан Пану - разно”* (*Панос тимиама поикила*): *“И Океан окружује Земљу у својим водама”* (*Homeric Hymns*).

Небо се диже изнад Земље. У *Орфичким химнама* Небо је поменуто као господар Света (Космоса), које обухвата Земљу као сферу (нашу Небеску сферу). Небо је станиште блажених богова и окреће се (*Орфичка химна* 4: *Тамјан Урану*).

Према античкој грчкој традицији Небо је метални свод начињен од бакра или гвожђа, које држе веома високи стубови; а у другим митовима гигант. Хомер комбинује ова два погледа уводећи титана Атласа који придржава стубове (*Одисеја*, 1:53-54). Хезиод пише да му је такву судбину одредио Зевс (*Theogony*, 517). Тако се у античкој Грчкој сматрало да је Небо начињено од чврстог, металног матерјала. Зато се у Хомеровим поемама помиње као *халкис*, односно бакарно (*Илијада*, 17:424) и *полихалкис* т.ј. направљено од много бакра (*Илијада*, 5:504 & *Одисеја*, 2:458, 3:2, 16:364, 19:351), или као *сидерус* – гвоздено (*Одисеја*, 15:329, 17:565).

Простор између Неба и Земље, према веровањима која је забележио Хомер, био је испуњен са (релативно густим) ваздухом у својим деловима према Земљи (*Илијада*, 14:288). Према Небу, овај међупростор био је испуњен чистим и провидним *етром*, неком врстом «лаког ваздуха». Изван етра било је звездано Небо.

Свакако, не треба сматрати да је небо огољена метална купола. Оно је било, како Хомер помиње, пуно живота, живота који је био дарован звездама које га украшавају. Зато је било називано *астероис*, т.ј. пуно звезда (*Илијада*, 6:108, 15:371 & *Одисеја*, 9:527). По овом небеском своду путује Сунце (*Одисеја*, 1:7-9), стога звано *уранодромос* (путујуће по небу).

Хомер у својим еповима, који су датирани на око 900. до 800. пре н.е., описује Земљу као равну и кружну са океаном око ње, модел који се први пут појавио у *Орфичкој химни* "Х. ПАНУ, *Кађење различитим мирисима*, стих 15: "*Стари Океане, такође дубоко поштују твоју врховну наредбу, којом течне руке окружују чврсту земљу*", док Хезиод у *Теогонији* описује Универзум као сферичан, кога на два дела дели равна Земља.

Великом филозофу Питагори (6, век пре н.е.) приписује се да је први подржао идеју о сферној Земљи. Исказао је мишљење, да пошто су Сунце и Месец лоптастог облика, исто треба да буде и са Земљом, која се непокретна налази у центру Уиверзума! Питагора је учио да је Земља сферна, изолована и настањена; треба нагласити да је Анаксимандар такође сматрао да је она изолована, без додира са Небом, док је Емпедокле тврдио да слободно лебди у простору. Питагора и филозофи Питагорејци подржавали су сферичан облик Земље углавном због разлога симетрије, пошто су сферу сматрали као најсавршенији облик који може да има чврсто тело. Исте погледе имао је и Парменид у 5. веку пре н.е., који је са сигурношћу тврдио да је Земља лоптаста.

Под утицајем и вероватно убеђени учењима Питагоре и његове школе, многи други велики грчки филозофи и астрономи усвојили су сличне погледе, као Аристотел, Хипарх, Кратес из Милета и други. Аристотел је знатан део своје књиге *О Небу* посветио подршци и пропагирању таквих погледа, износећи став да *"Земља има сфероидалан облик као што јој је потребно"* (*On the Heavens*, B, 297b, 18-19).

Ипак, као и у случају многих других пионирских погледа, идеје и теорије старих грчких филозофа –нпр. хелиоцентрички систем Аристарха– хипотеза о сферном облику Земље била је заборављена са назадовањем античке Грчке и успоном практичног римског духа за време Римске империје. Стога је било природно да једноставнији поглед освоји византијски Исток и средњовековни Запад, а то је била теорија равне Земље. Против учених људи који су покушавали да поново успоставе стари поглед о облику Земље, снажно су се опирали простији људи, који су у основи тврдили да је немогуће да је Земља округла, пошто би у том случају антиподи, људи који живе на дијаметрално супротној тачки на Земљи, стајали наглавачке и неизбежно пали у амбис!

Свакако треба нагласити да би прихватање лоптастог облика Земље значило не само напуштање „очигледног" равног облика нашег света, него и појма, дубоко усађеног у умове средњовековних људи, да у простору постоји само један, апсолутно дефинисани смер „на горе" и један такав „на доле". То је било доба без физике и нама лако прихватљива идеја да су сва материјална тела привлачена ка центру Земље, у то време била је чак и за учене људе неразумљива!

Од 15. века, када су научници тога доба стекли бољи увид у аристотелијанске текстове, опет је започела расправа о облику Земље. Не

треба заборавити да се, на основу погледа Аристотела (и других грчких филозофа), вођен Птолемејевим списима о географији, Кристофор Колумбо усудио да крене на запад да би открио нови пут за Индију.

3. ПРЕСОКРАТОВСКИ ПРИЛАЗИ ПИТАЊИМА ОКОЛИНЕ

У 6. веку пре н.е., са филозофима из Милета и остатка Јоније, у филозофији и науци дошло је до праве револуције. Рођена је научна филозофија, њена теорија, појмови и задатак физичко-математичке науке, велико остварење грчког духа (Theodossiou, E., 2007, стр. 40).

Најпре је Талес из Милета, оснивач монизма, предложио да је основа свега вода. Онда је Анаксимандар претпоставио да је то бесконачност, Анаксимен ваздух, а Хераклит из Ефеса, сматрао је да је примарни елемент ватра. Њихову филозофију карактерише разноликост одговора на питање о примарном елементу.

Заједничко у учењима свих пресократовских грчких филозофа-природњака било је посматрање околине, односа и промене природних елемената, и цикличких, периодично променљивих природних процеса.

Талес, оснивач Јонске школе и први теоретичар геометрије и астрономије, био је први који је изразио мишљење да полиморфан свет природних појава има јединствену основу, и да потиче из само једног стваралачког, заједничког, природног ентитета, што је према њему била вода.

За Талеса, вода је била основна компонента свих ствари, изван сваке божанске интервенције; сви ентитети у природи биле су мутације овог првобитног материјала. За њега, вода је била примарна суштина, из које настају сви облици материје и у коју се поново враћају. Према Талесу, жива бића имају заједничко природно порекло и разлог, воду, и сви физички објекти су настали трансформацијом овог примарног елемента „кондензацијом“ и разређивањем. Вода (*хидор*) је елемент који, ширећи се помоћу испаравања, ствара ваздух, док сажимањем и кондензацијом ствара земљу; Талес је сматрао да то може потврдити појава алувијалних наслага у рекама.

Према Талесу је не само наша планета, него и цео Универзум заснован на води и има облик полусфере. Његова унутрашњост је пуна ваздуха, а површина му је небо, небески свод. У равни његове основице је непокретна Земља, која, како је сматрао, плива на води: *“пливајући као парче дрвета или нешто слично”* (Aristotle, *On the Heavens*, B, 297b, 28).

Анаксимандар је веровао да у Универзуму влада нека врста природног закона, космичке „правде“, која одржава равнотежу између четири основна елемента, који су увек у стању антагонизма услед различите суштине и састава. Њихов природни однос, према Анаксимандру, треба да буде очуван у вечности, тако да ниједан од четири основна елемента не може да преовлада над осталима. Анаксимандар је одбијао идеју свога учитеља Талеса да је основни елемент вода, јер ако би то било тако, природна

равнотежа „правде“ између четири елемента би била нарушена. Ако би један од елемената био у предности над другима, он би апсорбовао остале, и Универзум не само да би би потпуно друкчији, већ би се кретао ка свом коначном уништењу.

Нео-платонистички филозоф Симплиције (6. век) Анаксимандру приписује следећи исказ):

“Анаксимандар је рекао да је порекло свих бића бесконачност, од које су створена сва небеса и цео свет који постоји унутар њих; и да је њихово рођење дошло из бесконачности и у бесконачности ће завршити кроз своје трошење. На тај начин они надокнађују један другоме неправде које су се дешавале са протоком времена“ (*Симплиције у Physicorum*, 24, 13).

Овај пасаж указује на веровање да супротности, кроз сукцесивно преовлађивање једне над другом, стварају еволуцију и промену. „Пролазак“ времена означава највероватније универзални закон који проверава рокове за долазак „правде“, која ће исправити „неправде“.

Овај принцип се може доказати применом на равнотежу екосистема. У њему нема једностраних и монополистичких процеса; све је у стању динамичке равнотеже. Деструкција, декомпозиција, креација и дегенерација су непрекидни процеси који се периодично смењују. Нови организми се рађају тек када стари облици умру, зато што материјал за стварање нових бића долази од разграђивања старих. Ово стање динамичке равнотеже (чији су велики значај еколози схватили тек у другој половини 20. века), је према Анаксимандру основа за „проток времена“, односно за периоде времена. Овакво посматрање примењује се на биоритмове, и биолошке циклусе екосистема, пошто се унутар сваког отвореног биолошког система налазе периоди пораста и опадања популације коју садржи. Проширујући овај принцип можемо сматрати да је вероватно непознавање његове снаге одвело цивилизацију Запада да улаже енергију и време у једностран избор, као што је избор фосилних горива за главни извор енергије, пренебрегавајући чињеницу да је циклус њихове обнове, реда много милиона година. Сходно томе, потреба за динамичком равнотежом у природи је неопходна, чињеница која се може извући као закључак на основу горњег Анаксимандровог предлога.

Анаксимандер је био први картограф који се усудио да нацрта познати свет. Такође је предложио веома интригантно порекло људске врсте; према њему први људи настали су од рибама сличних бића. Други пресократовски јонски филозофи, као Емпедокле, формулисали су такве претпоставке у односу на порекло од неживе материје, кроз различите трансформације првих животних облика; који су, према Емпедоклу, нестали због помањкања способности прилагођавања. Ови први покушаји да се формулише теорија историје природе и разумско објашњење феномена живота заступали су

идеју о „спонтаној креацији“, а не о настанку живота посредством неког Бога Створитеља, што је касније подржавао Платон у *Тимеју*.

Као што се из горњег може извести, идеја да ниједан животни облик није вечно непроменљив, него да еволуира у покушају да се прилагоди околини која се такође мења, није потекла од Чарлса Дарвина (Charles Darwin, *The origin of species*, 1998) него од Анаксимандра.

Анаксимен је такође прихватао (као и остали јонски филозофи) основне принципе монизма, заједничког у Јонској школи, да све потиче од једног основног елемента и на крају му се враћа. Према његовим погледима, порекло свега је ваздух, који је за Анаксимена бесконачан, односно неодређен и вечан. Ваздух је огромна материјална маса на коју се све може свести.

Анаксименов ваздух се непрекидно креће, исто као Анаксимандрова бесконачност. Из овог непрекидног кретања ваздуха на крају је била створена сва разноликост ствари и појава. Ватра је настала истањивањем ваздуха а његовом кондензацијом воде и Земља.

Настанак и пропадање светова вечно се смењује. Анаксимен је веровао, као и Анаксимандар, да наш свет није једини који је постојао; такође је подржавао идеју да је огромна маса ваздуха садржала небројене светове који су се цело време стварали и нестајали, излазећи и враћајући се у почетну бесконачност.

Хераклит је сматрао ватру као почетну суштину нашег света. Веровао је да међу огромним богатством природних и небеско/Универзалних креација са непредвидљивим променама, ништа не остаје непроменљиво, непокретно и стално. Нема постојаности, него само вечни ток, непрекидно кретање.

То је управо оно што прихватамо данас за свет квантне физике; привидна стабилност и непокретност је илузија и последица је наших ограничених чула. Према Хераклиту, материја се непрестано преображава, док су у нашем коначном Универзуму елементи „ватра“, „ваздух“ и „земља“ само различита стања једног јединог материјала.

Сви стари природни филозофи у Јонији раздвајали су Бога стваоца од природе и историје, имајући увек дубоко поштовање према веровањима свога народа; вероватно су такође у својим умовима и душама чували неку форму Бога у његовој духовној и моралној димензији.

После природних филозофа Јоније, код Сократа видимо одбацивање разликовања људско-животињског царства, док код Платона налазимо филозофски третман Земље и небеских тела. Платон такође помиње и неке проблеме животне средине у старој Атици. У Платоновим *Дијалозима*, посебно у *Горгији*, налазимо следећи филозофски став: *“Друштво држи заједно небо и земљу, и богове и људе…”* (508A), док у космолошком *Тимеју* (77a) Сократ додирује, као што смо напоменули, наш однос са животињским и биљним царствима:

"Мешајући се са другим облицима и свестима створили су супстанцу сличну људској, тако да чине друкчијег живог створа: такви су култивисано дрвеће и биљке и семење које је било оплемењено на газдинству и сада су одомаћени међу нама; док су раније постојале само дивље врсте" (*Тимеј*, 77a).

Сократ закључује да нема суштинске разлике између три широке категорије живих бића (људи-животиње-биљке): *"… Дакле и тада и сада, жива бића прелазе једно у друго на све такве начине, када трпе преобликовање губитком или добитком разума и неразума."* (*Тимеј*, 92b-c), и: *"било је две врсте живих бића, људска раса и друга, јединствена класа која обухвата све животиње"* (*Statesman*, 1925, 263c).

Може се додати, да је из проучавања Аристотелових дела очигледно, да су у његовом учењу наука, филозофија и свет који нас окружује корелисани и међузависни. Исходећи из описа ове своје концепције, велики филозоф ствара темин «енергија» (Aristotle, *Metaphysics*, I, 982b, 7 & 1072a - 8, 1073a).

4. СТОИЦИЗАМ И НЕОПЛАТОНИЗАМ

У вековима који следе сведоци смо наставка платонистичке традиције код Стоика. Професор П. Дамаскос, полазећи од погледа неколико учених људи (нпр. Sambursky, S., 1959, Long, A.A., 1986, Brennan, T., 2005), пише:

"Стоицизам уздиже на положај основног принципа одлуку да се живи у складу са Природом и коегзистирајућим Логосом. Ови појмови нису објашњени; узети су као познати. Поред тога, Стоицизам није познат по размишљању о теоријским облицима и менталним анализама о космолошким и метафизичким питањима. Ипак, чак и у његовим моралним учењима морамо издвојити поштовање за Свеукупност, братску коегзистенцију свих бића и за природу сваке врсте." (*The problem of ecology in the Stoics*, 27 Март 2009).

У низу филозофских школа следећи је Неоплатонизам; Неоплатонисти се враћају теоријској, прилично догматској платонској традицији и представља их значајан филозоф Плотин. Класична грчка филозофија много дугује Плотиновој обнављајућој мисли и продорном уму, његовом знању, као и дијалектичком покушају да развије платонски догматски поглед и истовремено га комбинује са теоријама Стоика и Перипатетичке школе, као и са погледима Аристотела.

Клаус Елер (Klaus Oehler) напомиње да:

"Неоплатонизам, без сумње подвиг систематског размишљања, је последњи продукт методичког и систематског карактера, који је био инхерентан филозофским школама још од почетка хеленистичке епохе до тога доба." (2000, стр. 6).

Према теологу др Јоанису Лилису (2006, стр. 583), Плотин такође користи термин «енергија» да опише свој властити космички поглед. Специфичније, Плотин назначује да се целокупна реалност састоји од Ен (Један – Бог), Нус (Ум) и Психе (Душа Света), природе и материје. Универзум потиче од Бога не слободном вољом и жељеним стварањем него непрестаном *еманацијом.* Преко ове еманације «Бог-супстанца» постаје заједнички свим степенима реалности (пантеизам). Бог превазилази Свет пошто је супстанца света божја. Еманације су Нус, Психе, природа и материја. Прва еманација је Нус,односно Ум, а друга Психе – Душа Света. Она произилази из Нуса као што Нус произилази из Ена па је према томе нижа од њега. Трећа еманација која произилази из Нуса и Психе формира природу и материју; материја је крајњи корак и нема форму, а има је природа, која је спознајна преко наших чула. Плотин, наглашавајући да Нус произилази из Ен, и да је Психе у сједињеној реалности (пошто има две врсте активности, контемплативну (изван материје и времена) и пластичну, у формирању појединих ствари у Универзуму према идејама које су осмишљене у Нусу), зове Нус и Психе: "*из енергије, не потенцијално*". Указује такође да је све створено од Есенције или Квантитета и: «*Ако је чињеницом његове непрекидности подржано да је непрекидно један Квантитет, онда дискретно неће бити Квантитет. Ако насупрот томе непрекидно поседује Квантитет као случајност, шта је онда заједничко непрекидном и дискретном да би их чинило квантитетима*?" (Plotinus, *Enneades* 6, 4, 4).

Осим тога, *Енеаде* садрже лепи пасаж о персонификираној Природи: *"Ако се пита: Зашто она ствара? И ако би Природа чула питање и желела да одговори, сигурно би рекла: Не треба да ме питате већ да сами схватите, у тишини попут мене, пошто не говорим често. Дакле шта треба да разумете? Да је моје стварање видљиви објекат који сам начинила, у тишини, објекат који је резултат природе и коме сам дала особину да буде видљив (Ја сам такође била резултат такве видљивости) И моја видљивост ствара видљиве објекте, управо као што их математичари могу нацртати само када их могу видети. И мада не цртам већ само гледам, граничне линије тела резултују у нечему сличном воденом талогу. Са мном се не догађаа ништа друго него оно што се дешавало са мојим родитељима; они су такође произашли из такве видљивости."* (*The Enneads*, 3, 8,4).

Другим речима, природа, коју је Плотин персонификирао у овом пасажу, представља себе, своје порекло и рад.

ЗАКЉУЧАК

Овде смо размотрили погледе који се односе на природу, Мајку-Земљу, и животну средину у Старој Грчкој, од *Орфичких химни* и хомеровског света, преко радова Хезиода и Софокла и теорија и радова пресократовских филозофа, Јонске школе, Талеса, Анаксимандра, Анаксимена, Хераклита, Питагоре и Питагорејаца, Емпедокла, Сократа, Платона, Аристотела, Стоика, и Неоплатониста, са посебним нагласком на Плотину. Анализирано је како су од митолошке тачке, овакви погледи еволуирали до физичког проучавања, размишљања и теорија током прве научне револуције у Јонији у 6. веку пре н.е., развој таквих теорија и неке од њихових могућих импликација у каснијим вековима, као што је идеја Питагорејаца о округлој Земљи и Колумбова идеја о тражењу новог пута за Индију.

Можемо закључити да је заједничко у учењу пресократовских јонских филозофа и каснијих античких грчких природних филозофа, било посматрање животне средине и природе, односа у њој, промена и цикличних периодичних варијација.

Такође бисмо истакли покушаје Анаксимандра да формулише потребу за очувањем динамичке равнотеже у природи и екосистемима и његове погледе на еволуцију живих бића и људи, што све сведочи колико се у делима из античке Грчке може наћи интересантних погледа и размишљања о проблемима који нас и данас брину.

Захвалност

Ова студија је део истраживања на Универзитету у Атини, на Катедри за Астрофизику, Астрономију и Механику, и захвални смо Универзитету у Атини за финансијску подршку преко Специјалног рачуна за истраживачке пројекте. Рад је такође помогло Министарство за науку и технолошки развој Републике Србије у оквиру пројекта 1460022 *Историја и епистемологија природних наука.*

Литература

Aristotle: 1933, *Metaphysics*, Books I-IX, transl. by Hugh Tredennick. The Loeb Classical Library (reprinted 1936, 1947, 1956, 1961, 1968, 1975, 1980, 1989, 1996). Heinemann, London.

Aristotle: 1956, *On the Heavens* (*De Caelo*), transl. by W. K. C. Guthrie. The Loeb Classical Library (reprinted 1936, 1947, 1953, 1956). Heinemann, London.

Bible: *The Holy Bible*: 1979, The Gideons International. National Publishing Company, USA & The King James version.

Brennan, T.: 2005, *The Stoic Life*, Oxford: Oxford University Press.

Damaskos, P.: March 27, 2009, *The problem of Ecology in the Stoics*, Symposium Hellenic Physicist Society, Rethymno, Creta [in Greek].

Darwin C. R.: 1998, *The Origin of Species*, Oxford World's Classics. Oxford University Press, Oxford, New York.

Eliade, M.: 1978, *A History of Religious Ideas*, vol. I, *From the Stone Age to the Eleusinian Mysteries*, transl. by W. Trask, IL: University of Chicago Press, Chicago.

Kern, O.: 1922, *Orphicorum Fragmenta*, Weidmann. Berlin.

Long, A. A.: 1986, *Hellenistic Philosophy: Stoics, Epicureans, Skeptics*, 2nd edition, Duckworth, London.

Lilis Ioannis: 2006, The presence of ancient Hellenic philosophy during the first Byzantine centuries, *Orthodoxy*, period 2, year 13, IJuly-September, pp. 577-596. Ecumenical Patriarchate, Constantinople [in Greek].

Orphic Hymns (*The Hymns of Orpheus*): 1981, transl. from the original Greek text by Thomas Taylor, Introduction preface by Manly Hall, The Philosophical Research Society INC., Los Angeles, California.

Oehler Klaus: 2000, The continuation of Hellenic Philosophy from the end of Ancient Times to the fall of Byzantine Empire. Linos Benakis (edit.), Medieval Philosophy. Modern research and Anticipations, *Parousia*, Athens, p. 6. [in Greek].

Plato: 1929, *Timaeus, Critias, Cleitophon, Menexenus, Epistles*, transl. by R. G. Bury (reprinted 1942, 1952, 1961, 1966, 1975, 1981, 1989, 1999). The Loeb Classical Library No. 234 (v. 9). Harvard University Press. Heinemann, London.

Plato: 1925, *Lysis. Symposium. Gorgias*, transl. by W. R. M. Lamb (reprinted 1932, 1939, 1946, 1953, 1961, 1967, 1975, 1983, 1991, 1996). The Loeb Classical Library No. 166. Harvard University Press. Heinemann, London.

Plato, 1925, *Statesman, Philebus, Ion*, transl. by H.N. Foweler & W. R. M. Lamb. The Loeb Classical Library No. 164. Harvard University Press. Heinemann, London.

Plotinus: 1991, *The Enneads*, transl. by Stephen MacKenna and John Dillon. Penguin, London & *The Six Enneads*, transl. by S. Mackenna and B. S. Page. The Internet Classics Archive at MIT. classics.mit.edu/Plotinus/enneads.html

Sambursky, S.: 1959, *The Physics of the Stoics*, Routledge, London.

Simplicius: 1882, *Peri Ouranou (De Caelo).* Priores Commentaria, Editit Hermannus Diels, Typis et Impensis G. Reimeri. Berolini.

Simplicius in Physicorum: 1895, *Libros VVIII*, in *Commentaria* in *Aristolelem Graeco*, Editit Hermannus Diels, Typis et Impensis G. Reimeri. Vol. X. Berolini.

Sophocles: 1994, Vol. II. *Antigone. The women of Trachis. Philoctetes. Oedipus at Colonus.* Edit. & trans. by W. H. S. Jones, The Loeb Classical Library No. 21. Harvard University Press. Heinemann, London.

Theodossiou, E.: 2007, *The dethronement of the Earth – The dispute between geocentric and heliocentric systems*, Diavlos Publ., Athens [in Greek].

Hesiod: 2006, volume I, *Theogony*. *Works and Days*. *Testimonia*. Ed. & transl. by Glenn W. Most. The Loeb Classical Library, No. 57N, Heinemann, London.

Homer: 1924, *The Iliad*, transl. by A. T. Murray (reprinted 1954), The Loeb Classical Library, Heinemann, London.

Homer: 1919, *The Odyssey*, transl. by A. T. Murray, revised by G. E. Dimock (reprinted 1954 and 1995). The Loeb Classical Library, Heinemann, London.

Homeric Hymns: 1914, transl. by Hugh G. Evelyn-White, Cambridge, M. A., Harvard University Press. Heinemann. London

THE COSMOLOGICAL THEORIES OF THE PRE-SOCRATIC GREEK PHILOSOPHERS AND THEIR PHILOSOPHICAL VIEWS FOR ENVIRONMENT

Here are analyzed the views related to nature, Mother-Earth and natural environment in the ancient Greek world from *Orphic Hymns* and Homeric world, through works of Hesiod and Sophocles and theories and works of pre-Socratic philosophers, Ionian School, Tales Anaximander, Anaximenes, Heraclites, Pythagoras and Pythagoreans, Empedocles, Socrates, Plato, Aristotle, Stoics and Neo-Platonists, with a particular accent on Plotinus. The common in the teaching of pre-Socratic Ionian philosophers and latter ancient Greek natural philosophers was the observation of leaving environment and nature, the corresponding relations, changes and cyclic periodic variations. We note the attempts of Anaximander to formulate the need for the conservation of a dynamical equilibrium in nature and in ecosystems and his views on evolution of the leaving creatures and the humans.

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ДОПРИНОС ВИЗАНТИЈЕ ПРИРОДНИМ НАУКАМА ВИЗАНТИЈСКИ АСТРОНОМИ И НАУЧНИЦИ

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Резиме: Византијска филозофија, чија је главна карактеристика било њено теолошко усмерење, наставила је традицију старе грчке филозофије чувајући много информација о њој и велики број античких филозофских текстова, који су уз то били коментарисани и објашњавани. Византијска хришћанска теологија не може се сматрати науком, зато што је логички метод довођен у питање или чак напуштан. Само у току последњег периода Византијске империје чињени су покушаји да се уведе дијалектички метод у теолошким разматрањима, али то је пре био утицај западног сколастицизма. Са друге стране, у Византији није недостајало оригиналних идеја и доприноса математичким и астрономским методама, или практичним применама научног знања у свакодневном животу у царству. У овом прилогу, размотрени су: природне науке у Византији и допринос водећих учених људи.

1. УВОД

Велики период грчке историје заузима хиљадугодишње Византијско царство. Оно је било Источна средњовековна хришћанска империја, коју Хелена Гликаци-Арвајлер (Hélène Glykatzi-Ahrweiler) назива *Империја хришћанског истока* или *Грчка средњовековна империја* (Glykatzi-Ahrweiler, 2009, стр. 10).

Византијски период представља везу између грчке антике и модерног доба и у њему могу бити нађени корени модене грчке нације и Православља. Томе се обично прилази преко теологије, религиозне уметности и религиозне литературе; ипак, Византија је била империја чији су учени људи такође дали допринос и природним наукама и математици. У следећим

радовима ћемо се детаљније позабавити доприносом и делима појединих научника. Овде ћемо поменути изабране али у нашој средини недовољно познате учене људе, који су неговали и развијали науку а посебно астрономију.

Према историчару Ани Лазару:

"Допринос Византије није толико у увећавању корпуса које нам је оставила грчка антика, него пре свега у очувању многих од њених достигнућа, преписивањем и чувањем старих текстова, као и њиховим сакупљањем, писањем коментара и интерпретацијом."

(Лазару 2010, стр. 60)

Истина да је у периоду од 2. века пре н.е. (доба Клаудија Птолемеја) до 16. века (доба Коперника) општи прогрес науке, укључујући астрономију, пре стагнирао него напредовао. За такву ситуацију, постоје у основи следећа три разлога:

1. Огромни ауторитет, готово са статусом религиозне догме, два велика научника: Аристотела, у свим наукама, и Птолемеја у астрономији. Њихови резултати, теорије и неспорна научна присутност, били су и на истоку и на западу квинтесенција науке више од 15 векова. Когод се усудио да доведе у питање ова два научна ауторитета, ризиковао је да буде окарактерисан као незналица или неписмен, или да се суочи са ругањем и отвореним непријатељством целе научне јавности, а касније и Хришћанске цркве.

2. Осуда нове религије свих који су упражњавали астрологију и обожавање звезда, чије границе са научном астрономијом често није било лако раздвојити. Због тога ова наука није могла да достигне критичну масу следбеника да би цветала.

3. Опште усмерење Византије на теолошке студије пре него на научне. Византијски научници више су волели да се баве хришћанским учењима и да покушавају да раде на усклађивању људског живота са божанским примером Исусовог живота.

Без обзира на то, веома је занимљиво да се истражи и проучи живот византијских научника, нарочито астронома, који су упркос различитим тешкоћама нашли начин да негују математику, физику и астрономију, живећи у царству које није фаворизовало овакву врсту студија.

Математика и астрономија су се нарочито развијале за време последњег периода Царства, у време Палеолога (1261-1453); многи учени људи, чија имена овде можемо да поменемо само селективно, посветили су део свога времена науци, сакупљајући матерјале из чувених дела старих грчких математичара и астронома, која су била обезбеђена и сачувана у манастирским библиотекама. Истовремено, они су уводили и усвајали знање других народа проучавајући индијске, персијске и арапске књиге, од којих су многе такође засноване на старим грчким изворима.

Византијски учени људи су били успешни у чувању и преносу позитивног знања и то је њихов велики и занемарени допринос науци и посебно астрономији. Они су мукотрпно проучавали, писали, коментарисали и преписивали рукописе у манастирима и обезбедили и сачували драгоцено наслеђе старих грчких филозофа и научника. Само због тог разлога њихов допринос науци је вредан сваког поштовања. Византијски научници су сачували на добро целог човечанства ремек дела старе грчке мудрости и науке.

Свакако, ту је и контра аргумент да је Источна Православна Црква ометала истраживања у астрономији. Овај аргумент произилази из списа Отаца Цркве; они су ипак углавном изражавали своје противљење астролозима а не самим посматрањима небеских тела. У ствари Православна црква је зависила од астрономије и од александријских астронома због прорачуна датума Ускрса, док је велики број византијских учених људи, чланова свештенства и калуђера трошио много времена на различите уметности и науке, од филозофије-теологије до математике и астрономије (Theodossiou, Danezis 1996, стр. 160).

За време последња два века империје, астрономија је у великој мери негована како у Константинопољу тако и у Трапезунту; одјеци изврсности трапезунтске школе дошли су и до наших дана (Plakides 1946, стр. 318).

Вероватно је да су се неки византијски монаси и свештеници бавили науком са даљим циљем да саставе и класификирају знање у хармоничну слику, да би оно служило духовном култивирању и уздизању човека према Богу, што је такође и задатак теологије. Ипак, ако пажљивије проучавамо рад већине учених људи, запазићемо да је знање, узето из античких грчких списа са додацима и коментарима византијских научника, било управљено према обликовању обједињене науке која се састојала од «септета курсева»: граматике, реторике и дијалектике са једне стране и квадривијума са друге: аритметике, геометрије, астрономије и музике. Све то у основи је требало да служи теологији (Koukoules 1948, вол. I, стр. 129-130).

Занимање за природне науке и математику у Византији треба ставити у овај оквир. Коментари су писани о многим делима античких математичара, астронома и природних филозофа, као што су Ариостотелове *Метеорологија*, *De Caelo* и *Physica Minores*, Еуклидови *Елементи* или *Велика математичка синтакса* Клаудија Птолемеја. Веома је вероватно да то објашњава појаву бројних природно-научних термина у (углавном) историјским радовима, али такође чак и у теолошким расправама. Ови термини се односе на природу и природне узроке појава као што су грмљавина, муње, земљотреси и друго (Koukoules 1948, вол. I, стр. 219).

2. ФИЛОЗОФСКЕ ШКОЛЕ И ЊИХОВИ ПРЕДСТАВНИЦИ

Александријска школа истицала се у наукама као што су медицина, ботаника, фармакологија, зоологија и наука о пољопривреди. Географија је и даље била важна за Хришћане, пошто је њено познавање било потребно за одређивање путева на света места и граница између црквених области јурисдикције. Дакле, користећи као полазну основу рад античког картографа и географа Мариноса из Тира (60-130), и чувене Птолемејеве *Geographike Hyphegesis* (2. век), византијски учени људи писали су своје властите расправе. Географске студије су биле извођене практично само у манастирима и перцепције византијских географа о Земљи (посебно оне Козме Индикопловца у 6. веку) биле су имагинарне, или копиране из Библије и религиозних идеја, док су географске књиге биле са једне стране ограничене на листе имена места и водиче по градовима за школску употребу, а са друге на путописе; што јасно указује на разлику између античке грчке географије и онога што су Византинци подразумевали под „географијом“.

Као први византијски географ јавља се путник, трговац, калуђер и писац Козма Индикопловац. Као калуђер, написао је 547. 12-томну књигу *Хришћанска топографија*, у којој је покушао да створи нови географски систем који би био у сагласности са учењима *Библије*.

У Константинопољу је непосредно после оснивања града основан и Универзитет. Ова институција је у различитим вековима била позната под различитим именима, као што су Мега или Екуменикал Дидаскалион, Школа Капитолијума, Царски Аудиторијум и Пандидактерион (Theodossiou и Danezis, 2010, стр. 130). У 5. веку, услед потребе за новим црквеним грађевинама, дошло је до развоја архитектуре и грађевинског инжењерства, што је довело до појаве добрих математичара, геометара и инжењера, као што су Артемије из Тралеса, Исидор и Исидор млађи из Милета, који су пројектовали и саградили чувену Свету Софију (Света мудрост Господња) у Константинопољу, док је Евтокије (6. век) из Аскалона у Палестини, ученик Исидора из Милета, познавао прву књигу Херонове *Механике*, која је данас изгубљена (Theodossiou и Danezis, 2010, стр. 175).

Из Школе у Константинопољу потекао је познати калуђер монофизита Јован Филопонус (490-570), религиозни писац, филозоф, граматичар, математичар, физичар, астроном и један од најистакнутијих научника шестог века. Филопонус, који је предавао у првој половини шестог века, развио је оригиналне идеје у физици, као што је појам момента, што је било у супротности са тада доминирајућим аристотелијанским позицијама; детаљно ћемо истражити његов допринос физици у једном од следећих чланака.

3. ЦРКВЕНИ ОЦИ И МУДРЕ ВЛАДИКЕ

Од 4. до 8. века црквеном мисли су доминирали велики кападокијски Оци који су обликовали хришћанску догму: Св. Василије Велики, Грегорије Назианзос, Грегорије из Нисе, Св. Јован Златоусти; а потом Епифаније са Кипра, Астерије из Амасије, Кирил I из Александрије, Цезарије, Немезије (владика из Емесе у Сирији) и Дионизије Кратки (Exiguus), који су дали оригиналне доприносе науци, док су се истовремено борили против астрологије и прорицања будућности.

Селективно помињући само Грегорија из Нисе, можемо рећи да је сматран за експерта у математици и астрономији свога доба, као и за великог космолога; добро је познато да је написао да је почетак Универзума у *„семену-сличној снази, датој (од Господа) ка стварању свега”* (Gregorius of Nyssa, P.G. 44, 77D). Ова *‘семену-слична снага’* одговарала би у модерној терминологији ултра густој почетној маси у Теорији Великог праска, а исказ*‘ка стварању свега’* наглашава динамику космичке експлозије и кретање од ‘могућности’ до ‘оснажености’ (Metallinos 2006, стр. 5).

Осим тога, професор Филозофије и писац Г. Зографидес каже:

“Многе хришћанске црквене вође тражиле су сагласност између грчке и хришћанске мисли. У том циљу пронашле су велики број пасажа у античким текстовима који су сагласни са хришћанским учењем и формулисале су теорију ‘семена Речи’ т.ј. присуства семена хришћанске истине у грчкој филозофији”

(Zographides 2000, стр. 347)

4. НАУКА У АЛЕКСАНДРИЈСКОЈ ШКОЛИ

У првим вековима Византијске империје, Александријска школа је још увек доминирала као ранија „светска престоница науке“ у хеленистичком и римском периоду. Ту су успешно стварали научници, као Серенус из Антиноополиса (Египат), или математичар Теон из Александрије (330-395), астроном који је забележио сва помрачења Сунца и Месеца од 365. до 372, и писао коментаре о томе шта је Аратос писао о месечевим и сунчевим халоима, као и коментар Птолемејеве *Математичке синтаксе*. Теон је био отац математичарке, астронома и филозофа Хипатије, чији је ученик, потоњи владика Кирене, Синезије направио астролаб следећи њена упутства.

У Академији, филозофској школи у Атини, у раном шестом веку, управо пре него што је затворио цар Јустинијан, стварао је Симплиције, чувени коментатор Аристотелових дела (види Simplicius, 1882, 1882-1895). Симплиције је такође написао коментаре и белешке о списима Еуклида, а сачувао је део дела Парменида, Емпедокла и Анаксагоре. У приближно исти период смештају се и дела Стефана из Александрије (Papathanassiou 1977, стр. 107).

5. СРЕДЊЕВИЗАНТИЈСКИ ПЕРИОД (610-1204)

У средњевизантијском периоду стварао је Јован Дамаскин или Хрисороас (676-754), који је добро познавао Аристотелова дела и сматрао да је филозофија знање које служи теологији. Из ове идеје проистекла је доминантна перцепција у западној средњовековној мисли да је филозофија слушкиња теологије.

Према бившем професору Астрономије на Универзитету у Атини, Д. Коцакису, Јован Дамаскин се и сам бавио астрономијом и другим природним наукама:

"Јован Дамаскин (1. половина VIII века) сам се бавио Астрономијом и општије Природом, док се са великом ревношћу борио против астрологије и пророка."

(Kotsakis 1958, стр. 8-9)

Јован Дамаскин, у свом делу –како је похрањено у *Patrologia Greca* (том 94)– пружа изванредне описе различитих природних и небеских појава, као што су помрачења Сунца и Месеца, која детаљно описује (P.G. 94, 896). У исто време бори се против астрологије (P.G. 94, 892-903), док такође описује природне појаве као што је грмљавина, за коју нуди објашњење: *"грмљавина је увојити дух који се креће као ватра, путује надоле пламтећим огњем и са мућама свуда наоколо"* (P.G. 94, 1601). Ипак приступ проучавању природних појава и њиховом објашњавању био је немогућ. У основи, у Византији је доминантан начин мишљења био теолошки, који је од субјекта проучавања био управљен ка трансцендентном свету. Сам Јован Дамаскин пише:

"Ствари природе изгледају безчулне, јер све што се односи на Бога је изван природе, рационалног мишљења и аргумената. Знање ових ствари је знање душе и сличног демонском."

(Ioannes of Damascus, P.G. 94, 895)

У суштини, овај учени црквени поглавар са оваквим својим погледима, правио је разлику између теолошке мисли и апокрифног знања, које (неоплатонско у основи) је засновано на кореспонденцији између снага „космичке душе" (у којој учествује и човекова) и снага природе и материјалних бића (Lazarou 2010, стр. 64).

Свакако, овакви погледи су били засновани на „поново рођеном" Платонизму, који је као Неоплатонизам, после 4. века, нудио веровање да живот није у реалности и да је Бог део овог земаљског света.

Леон Филозоф или Математичар, стварао је као научник око 820-869 и касније је постао владика Солуна. Леон је био човек вишестраног знања, који је познавао филозофију, аритметику, геометрију, астрономију и музику; предавао је у Константинопољу, а његова слава досегла је калифа Ал

Мамуна у Багдаду, па га је позвао да поучава у његовој престоници (Lemerle, P., 1971, стр. 130). Леон је био изванредан наставник у више дисциплина, тако да су му савременици давали надимке „Филозоф“, „Математичар“, „Геометричар“ и „Астроном“,које је алтернативно користио. Такође су га звали човек „миријадног“ знања међу филозофима’.

Конструисао је оптички телеграф или „хорономиум“, који је знатно увећао његов углед. То је био оптички механички систем за пренос информација, који су екстензивно користиле византијске војне снаге као метод за брзо упозоравање на арапску инвазију. Хорономијум, који би се данас могао назвати ‘оптички војни телеграф’, био је заснован на синхронизованим часовним механизмима и систему погодно смештених постаја за сигнализацију ватром. Леон је такође конструисао неколико аутомата који су украшавали царску палату. У будућем чланку ћемо детаљно истражити његов допринос астрономији.

За време Македонске династије, око 890, радио је Фотије, Патријарх. То је било време када се проучавање хришћанских светих књига на својствени начин комбиновало са вечним текстовима грчке антике. Савремени учени људи откривали су у манастирима класичне рукописе и проучавали их, коментарисали, преписивали и класификовали у кодексе. Тада се одиграло прво официјелно буђење науке, са Фотијем, човеком широких знања, аутором књиге *Мириобиблос*, као њеним главним представником: када је постао Васељенски Патријарх уз помоћ свог заштитника Цезара Вардаса (†865), поново је у Константинопољу успоставио проучавање античких филозофа.

“Припрема за метафизику били су списи Платона, Плотина, и Прокла. У завршном делу, филозофско учење метафизике било је сведено на теологију, прву филозофију.”

(Tatakis 1949, стр. 164)

Калуђер и научник Михајло Псел (1018-1078/1096) био је *логотет* (министар) императора, док је због непревазиђених предавања на Универзитету окарактерисан као ‘врхунски филозоф’. Његови радови су многобројни и различитог садржаја: филозофски, математички, географски, медицински, теолошки и чак о фолклору. Написао је такође и историјско дело, *Хронографију*, у коме описује догађаје од 976. до 1077, како су испреплетани око живота царева тога доба.

Михајло Псел је написао коментар на Аристотелову *Физику* и значење које је дао појму ‘физис’ (природа) усвојили су многи каснији филозофи. Ипак, рестаурација рационалистичког духа у испитивању природних појава, није се слагала са доминантним религиозним погледом, у коме су метеоролошке или друге природне појаве означавале Божју интервенцију у свету. Свакако, овде је филозофска мисао била више него потребна. Према Ани Лазару:

"Потреба за рационалним објашњењем води ка потрази за научним методом, који је могла да понуди једино грчка филозофска традиција. Према Пселу, нема другог начина да се објасне појаве осим тражења њихових природних узрока."

(Lazarou 2010, стр. 66)

Овај поглед произилазио је код Псела из аристотелијанске праксе, која је утврђивала да је свако биће управљано законима његове сопствене природе. У овој тачки, хтео је да усклади два различита погледа на свет: није желео да напусти аристотелијанску позицију истраживања природних појава, али ни да доведе у питање Божју свемоћ над бићима и природним феноменима. Свакако, то га је водило ка Неоплатонистичким ставовима, према којима је природа последња веза у непрекидном каузалном ланцу, који је почео са трансценденталним првим узроком.

Како Михајло Псел, тако и Јосиф Бријениј (1350-1431), сматрају се за прве грчке фолклористе, који су покушали да забележе народна сујеверја, да их објасне и покажу њихову неоснованост. У основи, трудили су да свет ослободе од њих.

У географији се истицао владика Солуна Ефстатије Катафлорос (1125-1194) са својим делом *Проширења (Parekvolai) Дионизија Путника* (1170) и калуђер Јован Фока са својом *Маршрутом* (1177).

Професор Хелиас Понтикос пише да:

"Предуслов који је знатно погодовао проучавању природних појава, астрономије, метеорологије, географије и медицине, био је што су византијска традиција и црквени Оци прихватали диференцијацију људске мудрости на три посебна дела: i) Практичну, чији је циљ морално усавршавање појединца, ii) Природну, са циљем проучавања природе као Божје креације, и iii) Теолошку, чији је циљ просветљење и спајање индивидуалног са божанским."

(Pontikos 1992, стр. 83)

У 11. веку, стварали су астрономи Симеон Сет (2 половина 11. века) и Елефтерије Зевеленос (рођен 1040), док је после њих, плодан писац Ефстратије из Никеје (1092-1120) написао неколико филозофских дела, углавном коментара и бележака о Аристотеловој *Аналитици*, и *Филозофским дефиницијама*. У потоњим радовима, усмерио је свој интерес на природне науке, посебно на метеорологију и астрономију; ови радови укључују расправу о природним наукама под насловом *Метеорологија*. Ова расправа и његови коментари две Аристотелове књиге *Никомахова Етика* (1968) и две књиге *Потоња Аналитика* (1960) преведене су на Западу и биле познате Алберту Великом (1193. или 1206-1280) и Томи Аквинском (1225-1274), док је у 19. веку чувени теолог и класични филолог Фридрих Ернст Данијел Шлајермахер (Friedrich Ernst Daniel Schleiermacher, 1768-1834) сматрао да су то изванредни радови (Georgoulis D. K., 2007, стр. 771).

Ефстратије из Никеје (1050-1120) и Михајло из Ефеса (11-12. век) –који је писао о природној историји и зоологији– претстављају рационалистички покрет теолога-коментатора аристотелијанских дела, који су користили аристотелијанско резоновање у теолошким проблемима. Овај покрет утицао је много на усмеравање Запада према аристотелијанској мисли.

За њима следи велики број образованих калуђера и свештеника, који су писали о науци, од Константина Манасеса (1130-1187), који у својим радовима описује „хорономијум“, проналазак Леона Математичара о коме смо већ писали, до Продрома Монаха (12. век).

Продром Монах је поучавао математику и астрономију у Константинопољу. Онда је прешао у Битинију у Малој Азији, где је постао калуђер. Био је изузетан наставник и основао је школу у Скамандеру. Међу његовим ученицима –нешто после 1222– налазимо великог теолога, астронома, математичара, географа и лекар Нићифора Влемида (1197-1272) са пионирским радом о природним наукама и аутором књига као што су *Епитоме Физике* (P.G. 142, 1023-1302). Луј Бреје (Louis Bréhier) га помиње као *„најчувенијег научника свога времена”* (Bréhier 1950, стр. 479).

Затим долази Георгије Акрополит и његов ученик Георгије са Кипра (*око*. 1241-1290), који је касније постао Патријарх под именом Георгије II, и Георгије Пахимерес (1242-1310), наставник и филозоф који је писао реторичка дела, писма и изнад свега чувену *Синтагму четири курса, аритметике, музике, геометрије и астрономије* или *Тетрабиблос* (Quadrivium). Бивши професор астрономије Д. Коцакис пише о овом делу и његовом аутору:

“Ово дело је довољно да уздигне Пахимереса у први ред математичара свога времена како на Истоку тако и на Западу, пошто је писано у највишем научном духу. Пахимерес лако употребљава старе и касније ауторе, али њихове погледе подвргава критици и наглашава своја сопствена гледишта, у која убеђује читаоца.”

(Kotsakis 1956, стр. 8)

6. „НОВО“ ВИЗАНТИЈСКО ЦАРСТВО (1261-1453)

Насупрот неповољној политичкој ситуацији, уметност и књижевност су цветале у току трећег и последњег византијског периода, у таквој мери да историчари говоре о „Палеолошкој ренесанси“ у територијално веома ограниченом Царству. После репатријације 1261, цар Михајло VIII Палеолог наредио је рестаурацију свих школа и поставио Георгија Акрополита за директора реорганизованог јавног Универзитета у цркви Свете Софије.

У овом периоду стварају многи научници, као што је учени филолог, математичар и астроном Манојло Планудис (1260-1310), који је рођен у Никомедији Битинијској (данас Изник) и био образован у Константинопољу.

Планудис је сматран за једног од највећих филозофа свога времена и један од византијских учених људи који су најавили ренесансу проучавања класике на Западу. Године 1285, када је постао калуђер, променио је име у Максим и постао познат под овим другим именом. Планудис је поучавао са 20 година од 1280, у две манастирске школе у Константинопољу. Његов латински био је изврстан и са латинског на грчки је преводио Боетија (Boethius Anicius Manlius Torquatus Severinus), Катона Старијег, Овидија, Цицерона, Јулија Цезара, псеудо-Августина, Тому Аквинског, итд., почевши са *De consolatione philosophiae* Боетија, припремајући тако везу између Византијске цивилизације и Запада.

У то време астрономији је служио и Теодор Метохит (1260/61-1331), *"један од најзначајнијих свестраних учених људи у последњим столећима Византијске империје"* према Карлу Крумбахеру (1897, вол. II, стр. 288). Наследио га је његов ученик Нићифор Григора (1295-1360), ван сваке сумње највећи астроном у историји Византије (Theodossiou et al. 2006). За најзначајнијег експерта за Птолемејеву астрономију сматра се Исак Аргирос (1310-1375), Григорин ученик. Како Григора тако и Аргирос су инсистирали на потреби реформе Јулијанског календара. Савремени астроном Теодор Мелитиниотес (1310-1388) је вероватно други највећи византијски астроном после Григоре. Са делом *Три књиге о Астрономији* или *Астрономски Трибиблос* (*Tribiblos Astronomique*, Leurquin, R., 1990, 1993) што је најсвеобухватније и најбоље уређено византијско астрономско дело.

7. НАУЧНЕ АКТИВНОСТИ У ТРАПЕЗУНТУ

У Трапезусу (Трапезунту), малу астрономску традицију створили су Грегорије Хиониадес (1240/50-1320), који је познавао арапску и персијску астрономију и основао „Трапезус Академију", Георгије Хризокок, Константин Лукит или Ликит, Андреас Ливаденос и калуђер Манојло.

Бивши професор Историје и Филозофије природних наука на Универзитету у Атини Михаел Стефанидес помиње (Stefanides, 1938) Грегорија Хиониадеса као познаваоца персијске астрономије заједно са Константином Лукитом (1938, 217). Учени човек Константин Лукит (13-14. век) био је професор на Академији у Трапезусу. Ценећи његове вредности и способности, краљ Алексије II Мега Комнен (1297-1330) указао му је почаст државним звањима.

Учени човек Андреас Ливаденос (14. век) био је почаствован звањима *прототабуларијуса* и *хартофилакса* Цркве Трапезуса. Његов рад био је углавном географски, а такође је писао писма и песме. Како Ливаденос тако и Лукит имали су преписку са Хиониадесом и Нићифором Григором.

Према Херберту Хунгеру (Herbert Hunger): *Калуђер и црквени човек Манојло, који је знао Фарси, је забележен као човек који је Георгију Хризококи предавао астрономију* (Hunger Herbert, 1978, стр. 57-58). Постао је астроном проучавајући све књиге из физике, математике, астрономије и

медицине, које је Хиониадес донео у Трапезус из Табриза, града у северозападном Ирану, који је тада био научни центар.

Истовремено, калуђер Манојло поучавао је у школама у манастирима Св. Евгенија и Свете Софије у Трапезусу. Ове «школе» вероватно су биле Академија Трапезуса, која је у почетку била смештена у манастиру Св. Евгенија, који је био светац заштитник града; овај манастир био је изван градских зидина и пошто је уништен у пожару (1340) Академија је премештена у манастир Свете Софије, око пола сата пешке изван града (Plakides 1946, стр. 365).

Коначно, византијски учени човек, лекар и астроном Георгије Хризокока (14. век), ученик калуђера Манојла, објавио је чувени астрономски рад са насловом *Synopsis tabularum persiacarum ex syntaxi Persarum Georgii medici Chrysococcae* (1347). Њега је публиковао и Исмаел Булиалдус (Ishmael Bullialdus) у Паризу 1645. Р. Х. Ален (1963) помиње овај рад као *Хризококине Таблице.*

8. ПОСЛЕДЊЕ ГОДИНЕ ЦАРСТВА

У последњим деценијама Царства, Георгије Јемистос или Плетон (1355-1452) исказао је поглед да је Земља округла и такође предложио увођење потпуног лунисоларног календара.

Опсада Константинопоља од Отоманских Турака и његов пад, означили су почетак таласа емиграције учених људи и научника на Запад. Аристотелијанци Теодор Газис (1400-1476), Андроник Калист (1400-1486), Георгије из Трапезуса (1396-1486), Теофан из Медеје (†1480), као и Платониста Михајло Апостолиос (1420-1480), Јован Аргиропулос (1415-1487) и кардинал Бесарион (1403-1472) утицали су у позитивном смислу на Италијанску мисао и на ренесансу наука. Већ је Манојло Хризолора (1350-1415) имао каталитичку улогу оснивајући на Универзитету у Фиренци Катедру грчке литературе (1397-1400), прву такву у просветној историји Европе. Манојло Хризолора се сматра за првог значајног пионира Ренесансе. Године 1434, са успоном Куће Медичи, почиње ново доба у интелектуалном животу Фиренце. У томе граду се настанио Георгије Јемистос и почео да поучава о Платону, а следили су га Јован Аргиропулос, Деметрије Халкокондил (1423-1511), италијански песник и хуманиста Анђело Политано (1454-1494), Јанус Ласкарис (1445-1534) и Михајло Марулос из Тарханије (1499), што су најпознатији учени људи који су пренели у Италију не само спор између филозофа аристотелијанаца и платониста, него и живу интелектуалну активност, доприносећи тако Ренесанси у уметности и књижевности у Италији, а оданде у целој Западној Европи.

Сви горе наведени филозофи и научници такође су одлучујуће допринели такозваном «буђењу науке» на Западу; што додатно указује на значајну улогу, коју су византијски учени људи имали у «иницирању» Ренесансе у

Европи. Срећом за европску цивилизацију, интелектуална активност Византије продужила се на Западу и није нестала са падом њене престонице. На тај начин, преко Византијске цивилизације, цео период Ренесансе засновао је своју суштину на наслеђу античке Грчке. И следећи векови у Европи, чак и 18. и 19, били су натопљени античким грчким духом.

Истовремено, у Грчкој коју су поробили Турци, живот нације био је у рукама Цркве. Генадије Схолариос, први Васељенски Патријарх после пада, православни „аристотелијански" мислилац који се дивио западњачком схоластицизму, добио је од освајача, султана Мехмеда II црквене привилегије које ће спасити идентитет нације.

Кроз све тешке векове који су следили, Православна Црква ће све до грчке независности остати чврсти ослонац који је покривао не само религиозне потребе поробљеног народа, него и обезбеђивао и његову културу и образовање. Независност ће, четири столећа касније, такође доћи уз њену помоћ.

Литература

Allen, R. H.: 1963, *Star Names - Their Lore and Meaning*, Constable & Co., Dover edition. London.

Aristotle: 1960, *Posterior Analytics, Topica*, The Loeb Classical Library, with an English Translation by H. Tredenick & E. S. Forster. William Heinemann Ltd. Harvard University Press. London.

Aristotle: 1968, *The Nicomachean Ethics*, The Loeb Classical Library, with an English Translation by H. Tredenick. William Heinemann Ltd. Harvard University Press. London.

Bréhier, L.: 1950, *La civilization Byzantine*, Editions Albin Michel, Paris.

Bullialdus, I. (ed.): 1645, *Synopsis tabularum persiacarum ex syntaxi Persarum Georgii medici Chrysococcae* (1347), Astronomia Philolaica, Paris.

Cosmas, Indicopleustes: 1897, Ed. J. W. McCrindle. *The Christian Topography of Cosmas Indicopleustes*. Hakluyt Society. (Reissued by Cambridge University Press, 2010).

Georgoulis, D. K.: 2007, *History of Hellenic Philosophy*. Papademas Publ., Athens [in Greek].

Glykatzi-Ahrweiler, H.: 2009, *Why Byzantium?*, Ellinika Grammata Publ., Athens [in Greek].

Gregorius of Nyssa, *Apologetic speech about the Six-day Creation*, P.G. (Patrologia Greca) vol. 44 and *On the creation of man*, P.G. 44 [Migne J.-P., 1857-1866].

Hunger, Herbert: 1978, *Die hochsprachliche profane Literatur der Byzantiner*. Pp. xxvi + 542. Beck, Munich.

Ioannes of Damascus, in P.G. vol. 94, 892-903 & 1601.

Kotsakis, D.: 1956, "Four scientific figures of the Paleologian period", *Deltion Geographikis Ipiresias Stratou* (trimesters III and IV), pp. 111-136, Athens [in Greek].

Kotsakis, D.: 1958, "The positive sciences in Byzantium: Astronomy and mathematics during the Byzantine period", *Deltion Geographikis Ipiresias Stratou* (trimesters III and IV), Athens [in Greek].

Koukoules, F.: 1948, *The life and civilization of the Byzantines*, in 6 vols. + Appendix, Papademas Publ., Athens [in Greek].

Krumbacher, Karl: 1891 und 1897, *Geschichte der Byzantinischen Litteratur von Justinian bis zum Ende des oströmischen Reiches (527-1453)*, München (in Nabu Press. Bookseller Inventory)

Lazarou, A.: 2010, "The ancient Greek thought and Byzantium", *Istorika Themata*, No. 91, January [in Greek].

Lemerle, Paul: 1971, *Le premier Humanisme byzantin, Notes et remarques sur enseignement et culture a Byzance des origines au Xe ciècle*, Presses Universitaires de France, Paris.

Leurquin, R.: 1990, *Théodore Méliténiote Tribiblos Astronomique*, Livre I (Corpus des Astronomes Byzantins 4), Gieben.Amsterdam.

Leurquin, R.: 1993, *Théodore Méliténiote Tribiblos Astronomique*, Livre II (Corpus des Astronomes Byzantins 5-6), Hakkert. Amsterdam.

Metallinos, G.: 2006, "Faith and Science as a theological problem" (announcement in the Meeting of the Hellenic Physicists Society "Science and God", Athens, 22 Jan. 2006), reprinted in the *Christianiki* newspaper, February 9, Athens [in Greek].

Michael, Psellus: 1953, *Chronographia*, transl. by E. R. A Sewter, New Haven: Yale University Press, U.S.A. (on line: http://www.fordham.edu/halsall/basis/psellus-chrono00.html).

Papathanassiou, M.: 1977, "The *Apotelesmatiki Pragmateia* or *Islamic Horoscope* of Stephanus of Alexandria", in *The Sciences in the Greek area*, Center for Modern Greek Studies of EIE. Trochalia Publ., Athens [in Greek].

Patrologia, Greca (P.G.): 1857-1866, J.-P. Migne (ed.) *Patrologiae cursus completus, series graeca*. Turnholti, Belgium. Typographi Brepols Editores Pontificii.

Plakides, S.: 1946, "Astronomy and Byzantium", *Aktines*, vol. 53, Athens [in Greek]

Pontikos, He.: 1992, *The revival of Aristotle as a physicist in the 11th century in Byzantium*, Dodone Publ., Athens [in Greek].

Ptolemy: 1883, *Klaudiu Ptolemaiou Geographike Hyphegesis*, trans. Karl Müller, Edit. Alfredo Didot, Paris.

Simplicius: 1882, *On Aristotle's Physics* (In Aristotelis Physicorum, Libros IV) 24, 13 (Z. 3-8 aus Theophrastus Phys. Opin. Fr. 2 Dox. 476), Priores Commentaria, Edit. Hermannus Diels, Typis et Impensis G. Reimeri, Berolini.

Simplicius: 1882-1895, *On the Heavens (De Caelo).* Priores Commentaria, Edit, Hermannus Diels, Typis et Impensis G. Reimeri, Berolini.

Stefanides, M.: 1938, *An Introduction to history of Natural Sciences*, Publications of the University of Athens, Athens [in Greek].

Tatakis, B. N.: 1949, *La Philosophie byzantine*, Presses Universitaires de France (PUF), Paris (rendered into English as *Byzantine Philosophy*, 2003, trans. N.J. Moutafakis, Hackett, Indianapolis).

Theodossiou, E. and Danezis, E.: 1996, *The Odyssey of the calendars – Vol. II: Astronomy and tradition*, Diavlos Publ., Athens [in Greek].

Theodossiou, E. and Danezis, E.: 2010, *At the years of Byzantium*, Diavlos Publ., Athens [in Greek].

Theodossiou, E., Manimanis, V. N., Dimitrijevic, M., Danezis, E.: 2006, "Nicephoros Gregoras – The greatest Byzantine astronomer", *Astronomical and Astrophysical Transactions*, vol. **25**, No. 1, February.

Vlemmydes, Nicephoros, *Epitome of Physics*, P.G. 142, 1023-1302 [*Patrologia Greca*, Migne J.-P., 1857-1866].

Zographides, G.: 2000, *Byzantine Philosophy*, in S. Virvidakis *et al.* (ed): *Greek Philosophy and Science: From the Antiquity to the 20th century*, vol. I, pp. 343-380. Ed. E. A. P., Patra.

THE CONTRIBUTIONS OF BYZANTIUM TO THE NATURAL SCIENCES - BYZANTINE ASTRONOMERS AND SCIENTISTS

Byzantine philosophy, whose main characteristic was its theological orientation, continued the tradition of ancient Greek philosophy by preserving a lot of information about it and many ancient philosophical texts, which in addition were commented and explained. Byzantine Christian theology cannot be considered as a science, since the logical method was questioned or even abandoned. Only during the last period of the Byzantine Empire attempts were made to introduce the dialectic method to theological inquiry, but this was rather the result of influences from the Western scholasticism. On the other hand, in Byzantium there was no lack of original ideas, contributions in mathematical and astronomical methods, or practical applications of scientific knowledge to the daily life in the empire. In this paper, the natural sciences in Byzantium and the contribution of distinguished scholars are considered.

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ШЕСТ КАЛЕНДАРСКИХ СИСТЕМА У ЕВРОПСКОЈ ИСТОРИЈИ ОД 18. ДО 20. ВЕКА

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Резиме: Размотрени су и анализирани следећи календарски системи, које је дуже или краће време користила већа или мања заједница у Европи а увођени су у периоду од краја 18. до половине 20. века: француски Револуционарни календар, Теозебијски календар који је формулисао Т. Каирис, Револуционарни календар Совјетског Савеза (или Бољшевички календар), Фашистички календар у Италији и Календар Метаксасове диктатуре у Грчкој пре Другог светског рата. Осим њих, размотрен је и Миланковићев Новојулијански календар Православне цркве, који је једини од поменутих опстао до данас. На крају су дискутоване и тешкоће увођења новог календарског система.

1. УВОД

У историји календарских реформи, Јулијански календар, који је преовладавао најмање 16 векова, постепено је замењен Грегоријанским, од 1582. на даље. Грегоријански календар је био потребан, пошто је исправио Јулијански и вратио пролећну равнодневицу на њен прави астрономски датум, ипак он није променио месеце, или дане у недељи (њихов број и имена): само је променио начин рачунања преступних година. После ова два календара, пет других политичких календарских система, од којих ни један није надживео своју ограничену (у простору и времену) политичку околину, и један црквени били су уведени у Европи. У овом раду су размотрени следећи такви неуспешни календари: француски Револуционарни календар, Теозебијски календар који је формулисао Т. Каирис, Револуционарни календар Совјетског Савеза (или Бољшевички календар), Фашистички

календар у Италији и Календар Метаксасове диктатуре у Грчкој пре Другог светског рата. Осим њих, размотрен је и Миланковићев Новојулијански календар Православне цркве, који је једини опстао.

У основи, са изузетком француског Револуционарног календара (*Le Calendrier Républicain*), који је добро познат и проучаван у међународној литератури, и Миланковићевог, о коме се доста писало код нас[1] а приказиван

[1]Младен Берић, „О реформи календара“, 1924, *Хришћански живот*, год. 3, бр. 4, Сремски Карловци, 157-164.
Младен Берић, 1924, „О реформи календара (Свршетак)“, *Хришћански живот*, год. 3, бр. 7 и 8, Сремски Карловци, 289-296.
Јован Живковић, 1927, *Свети архијерејски саборе!*, Сремски Карловци, Српска манастирска штампарија, 1-3.
Јован Живковић, 1927, „Реформа календара“, *Гласник Православне Патријаршије*, вол. 2, 19.
Јован Живковић, 1929, „С. П. Црква и манифест Њ. В. Краља“, *Гласник Православне Патријаршије*, вол. 3, 39-41.
П. Л. Вукићевић, 1932, „Календарско питање“- студија (прештампано из *Весника Српске Цркве*, св. 1)
Војислав В. Мишковић, 1966, „Прилог уједначењу грађанског календара“, Глас Српске Академије Наука и Уметности, CCLXIII, Одељење природно-математичких наука, н. с. Књ. 28, Београд, 94-147.
Бранко А. Цисарж, 1970, „Календар и његова реформа“, *Православна мисао*, год. 13, бр. 1-2, 52-78
Ненад Јанковић, «Срби и реформа Јулијанског календара», Зборник радова VII националне конференције, *Публикације Астрономског друштва «Руђер Бошковић»*, бр. 4, Београд, 1984, стр. 103.
Јован Л. Симовљевић, 1996, «Миланковићева реформа Јулијанског календара», *Глас Одељења природно-математичких наука*, књ. 58, 1-9
Јован Д. Кечкић: 2001, «О питању календара и његовој историји», *Флогистон*, **11**, 47-75.
Бранислав Скробоња, 2000, *О рачунању времена и православном календару*, Епархија Рашко – призренска, Призрен (Грачаница), 1-176.
Мирјана Петровић, 2002, „Зашто није примењен календар Милутина Миланковића?“, *Флогистон*, **12**, 257-267.
Veselka Trajkovska, 2003, „Reform of calendar: Maksim Trpković and Milutin Milanković“, *Publications of Astronomical Observatory of Belgrade*, vol. 75, 301-306.
Милан С. Димитријевић, 2005, „Да ли је Новојулијански календар усвојен у Константинопољу 1923. године Миланковићев, Миланковић-Трпковићев или Трпковић-Миланковићев?“, Зборник радова конференције «Развој астрономије код Срба III», Београд, 25 – 28. април 2004, Уредник Милан С. Димитријевић, *Публикације Астрономског друштва «Руђер Бошковић»*, св. 6, Београд, 347-350.
Веселка Трајковска, 2005, „Из архивске грађе: један документ о реформи календара“, Зборник радова конференције «Развој астрономије код Срба III», Београд, 25 – 28. април 2004, Уредник Милан С. Димитријевић, *Публикације Астрономског друштва «Руђер Бошковић»*, св. 6, Београд, 335-340.

је и у међународним изворима[2] наш напор је усмерен на четири друга календарска система, која су много мање позната, нарочито Теозебијски и календар Метаксасаове диктатуре (1936-1940) у Грчкој, и фашистички у Италији. На крају су размотрене и тешкоће увођења новог календарског система.

2. ФРАНЦУСКИ РЕВОЛУЦИОНАРНИ КАЛЕНДАР

После Грегоријанског календара, следећи корак за календарску реформу предузет је у Француској, после револуције 1789, чији је резултат био укидање монархије и проглашење Демократије. Француски револуционари, после раскидања окова монархије хтели су да прекину такође и везе са религиозно-папским (како су га доживљавали) календаром, уводећи његову првобитну основу, древни Египатски календар. Стога су желели да створе календар сличан ономе који би водио потпуном одвајању цркве и Државе. Први напади против Грегоријанског календара, праћени одговарајућим

Видојко Јовић, 2008, "Милутин Миланковић и његово мерење времена", *Даница*, год. 15, 201-208.

Veselka Trajkovska, 2008, "An evaluation of the contributions of Maksim Trpković and Milutin Milanković to the calendar reform", *Publications of Astronomical Observatory of Belgrade*,vol. 85, 195-196.

Радомир Ђорђевић, Милан С. Димитријевић, 2009, „Став Младена Берића према календару", Зборник радова конференције «Развој астрономије код Срба V», Београд, 18 – 22. април 2008, Уредник Милан С. Димитријевић, *Публикације Астрономског друштва «Руђер Бошковић»*, св. 8, Београд, 501-508.

[2]M. Mijatović, V. Trajkovska: 2001, „Maksim Trpković and the reform of the Julian calendar", Balkan meeting of young astronomers, 25-29 september 2000, Belogradchik, Bulgaria, Proceedings, eds. A. Antov, R. Konstantinova-Antova, R. Bogdanovski, M. Tsvetkov, Belogradchik, 43-52.

M. S. Dimitrijević, E. Theodossiou, 2002, „The calendar of the Greek Orthodox Church", *Astronomical and Astrophysical Transactions*, vol. 21, 145-147.

Veselka Trajkovska, 2005, „On the fundamental contribution of the Maxim Trpković 's project to the pan-Orthodox solution of the calendar reform in Constantinople in 1923", Balkan Astronomical Meeting, 14-18 June 2004, Rozhen, Bulgaria, BAM 2004, *Aerospace Research in Bulgaria*, No. 20, 335-340.

Veselka Trajkovska, 2005, "On a document concerning the calendar reform", Balkan Astronomical Meeting, 14-18 June 2004, Rozhen, Bulgaria, BAM 2004, *Aerospace Research in Bulgaria*, No. 20, 328-334.

M. S. Dimitrijević, E. Theodossiou, 2005, "Reforma calendarului Iulian la sinodul de la Constantinopol din 1923", *Noua Reprezentare a Lumi* 5, Bucuresti, 81-86.

M. S. Dimitrijević, E. Th. Theodossiou, P. Z. Mantarakis, "Milutin Milanković and the reform of the Julian Calendar in 1923", *Journal of Astronomical History and Heritage*, 2008, vol. 11, 50-54.

календарским предлозима за његову реформу одиграли су се од 1785 до 1788.

После пада Бастиље, 14. јула 1789. године, времена су била погодна да француски револуционари траже са одговарајућим ауторитетом, нови календар, који за почетак узима прву годину владавине народа. Тако је 1793 Народна скупштина поверила Шарлу Жилберу Рому (Charles Gilbert Romme), председнику Комитета јавног образовања, календарску реформу. Он је пак, доделио славним математичарима Жозефу-Лују Лагранжу (Joseph-Louis Lagrange) и Гаспару Монжу (Gaspar Monge) да технички остваре задатак. Резултати студије два математичара поднети су Народној скупштини септембра 1793, и одмах су били прихваћени. Истовремено је одлучено да ускоро буде примењен овај нови календарски систем. Заиста, *Calendrier Républicain de la Rèvolution de 1789*, како је назван, Народна скупштина је прихватила 5. октобра 1793, и изгласала 4. децембра 1793. Почетни датум ове хронологије био је из блиске прошлости, наиме 22. септембар 1792, познат у новом календару као 1 Вандемиер (Vendèmiaire), датум укидања монархије и проглашења демократије, који се случајно поклапао са астрономском јесењом равнодневицом. Тако је Нова година „револуционарне“ грађанске године била јесења равнодневица сваке тропске године, са почетком хронологије 22. септембра 1792, или 1. Вандемиера године I.

Година овог „демократског“ календара имала је 12 месеци од по 30 дана, са 5 или 6 додатних дана (*jours complèmentaires*), који су, додати на крају 12. месеца, т.ј. између 17 и 22 септембра, употпуњавали укупан број дана у години. Дакле, укупан број дана опет је био 365 или 366 за преступне године, чувајући традицију Јулијанског календара и његове усавршене варијанте Грегоријанског.

Временски интервал дана и ноћи, од поноћи до следеће, био је подељен на 10 часова, а 1/100 таквог сата била је „децимална минута“. Т.ј. француске демократе су укинуле хексадецимални систем у рачунању времена и установиле простији децимални (свака минута имала је такође 100 секунди). Недеље су биле напуштене, пошто су биле повезане са јеврејским календаром па према томе и са религијом, и сваки месец је подељен на три декаде (*decades)*. Имена дана у недељи су такође напуштена и десет дана сваког 10-дневног интервала били су називани управо по њиховом редоследу: први, други, трећи,…, десети дан (*primidi, duodi, tridi, quartidi, quintidi, sextidi, septidi, octidi, nonidi, dècadi*). Последњи дан сваке *décade, dècadi*, био је дан одмора, посвећен култу Врховног Бића. Имена месеци имала су исте завршетке у свакој групи од три месеца и била су инспирисана природом. Дао им их је члан Народне скупштине, песник Филип Фабр Д'Еглантин (Philippe Fabre d'Eglantine 1750-1794). Овај песник и драмски писац добио је 1783 (за дело *Студија природе - Étude de la nature*, 1783) прву награду на тулузком Фестивалу цвећа; награда је била златна дивља ружа, која се зове *еглантина* (*eglantine)* па је ову реч изабрао за надимак, под којим

је познат у историји. Филип Фабр је био члан Дантонове групе, и када је његов пријатељ изгубио политичку моћ, био је оптужен за корупцију јер је био уплетен у скандалозно распуштање Индијског друштва. Гиљотиниран је са Дантоном и његовим следбеницима 5. априла 1794.

Демократски календар је био прожет антихришћанским, рационалистичким духом испуњеним љубављу према природи. Поетична имена месеци, заједно са њиховим значењима и корелацијом са нашим месецима су следећа (Flammarion, 1955, p. 28):



Слика 1: *Обојени цртеж из 19. века. Особа десно је обучена у свечане панталоне до испод колена (culottes), које је носила аристократија.*

Табела I: Француски револуционарни календар

ГОДИШЊЕ ДОБА	МЕСЕЦ	Значење	Корелација
Јесен	Vendèmiaire (Вандемиер)	Бербански	септ. 22 – окт. 21
	Brumaire (Бример)	Магловити	окт. 22 – нов. 20
	Frimaire (Фример)	Хладни	нов. 21 – дец. 20
Зима	Nivôse (Нивоз)	Снежни	дец. 21 – јан. 19
	Pluviôse (Пливиоз)	Кишни	јан. 20 – феб. 18
	Ventôse (Вентоз)	Ветровити	феб. 19 – март 20
Пролеће	Germinal (Жерминал)	Од клица	март 21 – април 19
	Floréal (Флореал)	Цветни	април 20 – мај 19
	Prairial (Прериал)	Ливадски	мај 20 – јун 18
Лето	Messidor (Месидор)	Жетвени	јун 19 – јул 18
	Thermidor (Термидор)	Даровалац топлоте	јул 19 – авг. 17
	Fructidor (Фруктидор)	Даровалац воћа	авг. 18 – септ. 16*
Jour de la Vertu	Дан Врлине		Септ. 17
Jour du Génie	Дан Градитељства		Септ. 18
Jour du Travail	Дан Рада		Септ. 19
Jour de l' Opinion	Дан Мишљења		Септ. 20
Jour des Récompenses	Дан Награда		Септ. 21
Jour de la Révolution (само у преступним годинама)	Дан Револуције		Септ. 22

*Грегоријански датуми мало варирају због преступних година и због некомпатибилности члана III (Свака година почиње у поноћ на дан јесење равнодневице за Париску опсерваторију) и X (... Четврта година Франциаде је пресупна) декрета о његовом увођењу (*Décret de la Convention nationale sur l'ère, le commencement et l'organisation de l'année, et sur les noms des jours et des mois)*, календар је неприменљив после године XVIII, пошто додатни „преступни“ дан ради усклађивања са тропском годином није потребан за годину XIX (четврту годину Франциаде) него XX (*nemy* годину Франциаде).

Постоје различити системи за конверзију после године XVIII и одговарајући датуми се мало разликују у зависности од употребљеног система.

Пет или шест додатних дана су у почетку називани санкилотиди (*Sans Culottides),* да би славили револуционаре који нису носили скупе панталоне до испод колена (culottes) аристократије него дугачке од чупавог грубог материјала. Французи који су користили календар говорили су: први санкилотид, други санкилотид, итд. (*la première sans culottide, la seconde sans culottide....*). Заједничко име „додатни дани“ (*jours complémentaires*) дато је санкилотидима 7. фруктидора године III, т,ј. 24. августа 1795.

Имена светаца придружена сваком датуму у хришћанским календарима, замењена су именима дрвећа, биљака, цвећа воћа и житарица, пошто је календар требао да буде ослобођен од хришћанске номенклатуре (Renouard, A.A., 1822).

Додатни дани, између 17. и 22. септембра Грегоријанског календара, били су посвећени Врлини (*la Fête de la Vertu*) Градитељству (*la Fête du Génie*), Раду (*la Fête du Travail*), Мисли (*la Fête de l' Opinion*) и Наградама (*la Fête de Génie*)

Дан Мисли је био посебно важан због свог јединственог карактера: тога дана, сваки грађанин имао је право да слободно изнесе своје ставове. На заједничком нивоу, грађани су процењивали, мада фигуративно, дела свих јавних службеника. Током овог дана дозвољена је била свака врста сатире, заједно са цртежима, сатиричним песмама и много других лукавих шала, које су слободно циљале према онима на власти. Тада је било на њима да својом врлином оборе ове шаљиве оптужбе. Стога је разматрано да овај дан буде посвећен и Делима и Врлини. Шести додатни дана у преступној години био је посвећен прослави Револуције (*la Fête de la Rèvolution*). Прва преступна година новог календара требала је да буде година III. Четворогодишњи период између два сукцесивна Дана Револуције назван је Франсиада (*Franciade).*

Диван француски изум да месеце Револуционарног календара именују у складу са климом у Француској, исмејали су Енглези следећом пародијом:

Јесен : *Wheezy, Sneezy, Freezy (звиждави, кијави, промрзли)*

Зима: *Slippy, Drippy, Nippy (клизавко, капавко, штипкавко као што“ штипа“ мраз]*

Пролеће : *Showery, Flowery, Bowery (пљусковити, цвећко, од англизиране старе холандске речи bowerij – фарма)*

Лето: *Hoppy, Croppy, Poppy (скочко, остријжени - са кратко ошишаном косом што је била и мода француских револуционара, црвени мак)*

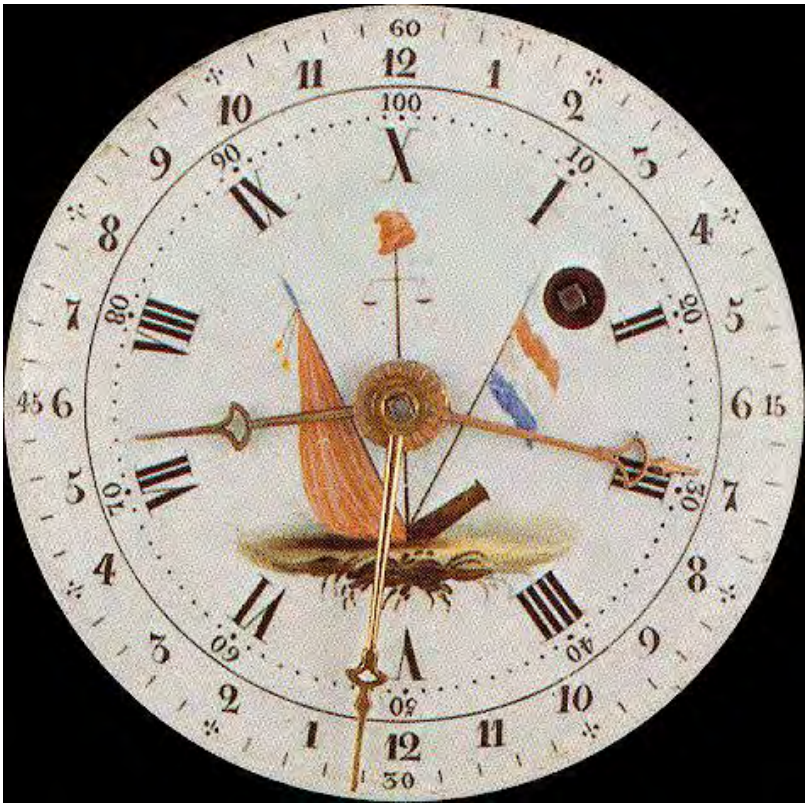
(Wilson P.W., 1937, p. 154).

За лето неки дају и: *Wheatty, Heaty, Sweety (пшенични, врући, слатки)*

(The Historical Maritime Society, Nelson and His Navy - Revolutionary Calendar, http://www.hms.org.uk/nelsonsnavyrevcalend.htm,



Слика 2: *Француски Револуционарни календар. Нацртао Луј Филибер Дебукур (Louis-Philibert Debucourt 1755-1832).*



Слика 3: *Француски републикански сат са комбинованим, децималним (унутра) и традиционалним (споља) бројчаником.*

Овај у приличној мери поетски календар био је функционалан и ефикасан у Француској; ипак био је неповољан за радничку класу, пошто је садржао само један дан одмора у десет дана а не у седам као што је било. Друга велика слабост му је била ограниченост употребе, пошто је коришћен само у Француској, те водио изолованости од осталих европских земаља у календарским, административним, економским и међународним питањима и релацијама.

Због тога али и углавном због политичких разлога, Наполеон се 1801. сагласио са папом да се у календар врати недеља и велики хришћански празници Божић и Ускрс. Коначно, 1806, Револуционарни календар је укинут Наполеоновим декретом од 22 фруктидора (9. септембра) године XIII којим је Француска опет прешла на Грегоријански календар од 11. нивоза XIV односно 1. јануара 1806. Револуционарни календар имао је кратак живот, мање од 13.5 година. Ипак, неколико деценија касније учињен је покушај његове рестаурације.

Године 1870, цар Наполеон III (1808-1873) изгубио је рат са Прусима. Резултат овог пораза била је његова абдикација 4 септембра 1870, и проглашење Друге републике. Али Пруси су напредовали и заузели део Париза. Крај рата дошао је 1. марта 1871, када је Тјерова влада потписала капитулацију.

Пораз и понижавајући услови уговора изазвали су нову револуцију 18. марта 1871. Народ Париза сместио се у Градску кућу, комуналну администрацију, која је ушла у историју под именом „Париска Комуна“. Формирана револуционарна комисија организовала је одбрану града. А један од њених првих потеза био је да оживи Револуционарни календар - *Calendrier Républicain de la Rèvolution*. 10. маја 1871, коме је одговарао 18. Floréal године 79, «Влада националног спаса» како је била позната Тјерова влада, нашла је уточиште у Версају. Успела је да окупи 100,000 људи и да са таквом војском нападне Париз. После неколико недеља борби, у којима је умрло више од 20,000 људи, владина армија је, уз помоћ Пруса, поразила револуционаре крајем маја 1871.

Брзи крај овог народног устанка опет је довео до укидања Револуционарног календара, овога пута заувек, 28. маја 1871. Тако је Париска Комуна успоставила Револуционарни календар само на кратко (Wilson, P.W., 1937, стр. 155 & стр. 334).

Ипак, чак и данас, француски астрономски алманаси, као почаст Првој републици, заједно са другим календарима (Грегоријански, Јулијански, Исламски, Јеврејски и Коптски) дају и корелацију датума са Револуционарним календаром, који је у 2010. у својој 218. години (1. јануар 2010, одговара 12 Нивозу 218).

3. ТЕОЗЕБИЈСКИ КАЛЕНДАР

Укидање француског Револуционарног календара обесхрабрило је друге режиме да усвајају нове календарске системе. Француски календар инспирисао је грчког свештеника и учењака Теофила Каириса да начини свој сопствени «Теозебијски календар» чија је судбина такође била да не опстане. То је била варијанта француског Револуционарног календара, али под верском капом.

Монах и свештеник Теофил Каирис (1784-1853), мислилац и учењак са острва Андрос, учесник Рата за независност 1821, који се сматра као један од великих „Учитеља нације“ а студирао је на универзитетима у Пизи и Паризу. Створио је култ „Теозебизам“, због чега је прогањан и умро у затвору.

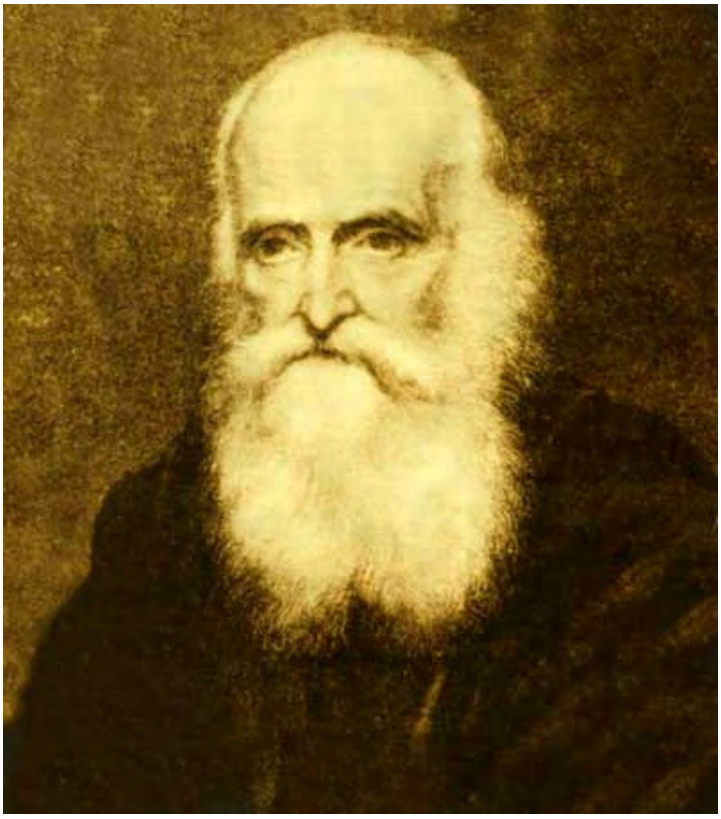
Теофил Каирис, је под утицајем западно хришћанске социјалне филозофије тражио „златну аналогију“ између религијске вере, научног знања и социјалне правде. Није прихватао хришћанску хронологију, и инспирисан француским Револуционарним календаром (Calendrier Républicain de la Rèvolution de 1789), предложио је напуштање недеље и поделу сваког месеца на тридесет дана: “Дванаест „30-дневних’ месеци са

три групе од десет дана свака“ (Theophilos Kairis, Code 53). Такође је променио имена месеца (нова имена дата су у Табели II према Theodossiou, E., & Danezis, E., 2000, стр. 337-338): Пет или шест дана додатих ради употпуњавања тропске године имали су датуме од 18 до 22 септембра Грегоријанског календара.

Табела II: Имена месеци у Теозебијском календару, њихово значење и еквиваленција

А/А	**Име**	**Значење**	**Корелација**
1	Теозебијус	Побожни (који поштује Бога)	11/23 Септ.- 10/22 Окт.
2	Софаретус	Мудри и непорочни (од Мудрост и Врлина)	11/23 Окт.- 10/22 Нов.
3	Дикеос	Праведни (Правда)	11/23 Нов.- 9/21 Дец.
4	Хагиос	Свети	10/22 Дец.- 8/20 Јан.
5	Агатијус	Добар (Доброжелатељни)	9/21 Јан.- 7/19 Феб.
6	Стенијус	Храбри (од Снага)	8/20 Феб.- 9/21 Март
7	Агапијус	Вољени (од Љубав)	10/22 Март- 8/20 Април
8	Харизијус	Милосни (од Милост)	9/21 Април- 8/20 Мај
9	Макротимус	Кротак	9/21 Мај- 7/19 Јун
10	Еониус	Вечни	8/20 Јун- 7/19 Јул
11	Ентеус	Божански (‘Бог-у-њему’)	8/20 Јул- 6/18 Авг.
12	Сосиус	Спаситељ (или Спас)	7/19 Авг.- 5/17 Септ.

* Први датум је према Јулијанском календару а други по Грегоријанском, са разликом од 12 дана како је то било у 19. веку. За конверзију датума од почетка 20. века треба узети у обзир да је разлика нарасла на 13 дана . Као и у случају француског Револуционарног календара датуми мало варирају због преступне године. (Напомињемо да су у Portaz (1935, стр. 220) Грегоријански датуми погрешно увећани за један дан зато што су за прерачунавање узети Јулијански датуми из 20. века, односно разлика од 13 дана).



Слика 4: *Теофилос Каирис.*

Теофил Каирис је знао да са астрономске тачке гледишта нема посебног значаја стављање почетка године 1. јануара и да су сви стари календари почињали своју годину у једној од четири карактеристичне тачке на привидној Сунчевој путањи, а то су:

a) Две равнодневице – пролећна 21. марта и јесења 23. септембра

b) Солстицији – летњи 22. јуна и зимски 22. децембра.

Календарски систем Каириса, познат као „Теозебијски календар“ имао је такође као своју Нову годину дан јесење равнодневице. Прва година Теозебијске хронологије почела је 23. септембра 1800 (Грегоријански календар). Уствари, као почетак свог календарског система он је узео јесењу равнодневицу, која је била 11/23 септембра (први датум се односи на Јулијански а други на Грегоријански календар, који су тада имали разлику од 12 дана), као стари грчки календар Дораца и Македонаца. Дорски (Спартански) календар почињао је првог новог месеца после јесење равнодневице на планини Панамос, а македонски на светој планини Диос. Његов календарски модел, француски Револуционарни календар, почињао је

на јесењу равнодневицу (22. септембар или 1. Вандемиер 1792 (Theodossiou & Danezis 2000, p. 338).

На одговарајући начин, прва година Теозебијске хронологије почињала је 11/23 септембра – када је те године била јесења равнодневица, 1800. и завршавала се 10/22 септембра 1801. Као што смо већ напоменули, Теозебијска година имала је 12 месеци по 30 дана сваки (12 × 30 = 360), тако да је остајало 5 дана (или 6 за преступне године) за употпуњавање соларне године од 365 (или 366) дана. Ови прекобројни дани, су као и у античким грчким календарима називани "изведени дани" и били су уметани на крају теозебијске године, т.ј. пре 11/23. септембра „хришћанских" календара (Јулијанског и Грегоријанског).

Слично, као у древногрчким календарима, сваки месец је био подељен на десетодневне периоде (декане); први декан називан је "полазни декан месеца", други „средњи декан месеца" и трећи „декан одлазећег, или месеца који се завршава", или "декан после двадесет" (Theodossiou & Danezis 1996, вол. I, стр. 360-364).

Стручњак за Каириса, Деметрије И. Полемис, директор Каириске библиотеке на Андросу, уредио је преписку Теофила Каириса, и објавио је у три тома. Он дели ове три књиге писама у три периода. Први том садржи садржи писма до затварања Сиротишта (1839), у другом су писма из периода прогона и прогонства до повратка у Грчку (1844) а трећи садржи писма која је са Андроса упућивао на различите адресе до своје смрти 1853 (D. Polemis, вол. I, стр. 22). У уводу другог тома, Полемис извештава да је детаљан опис Теозебијског календара дат у Каирисовом делу *Epitome of the Theosebic teaching and ethics* (London 1852, стр. 102-104). Полемис што се тиче декана пише следеће:

"Декан је подељен на десет дана, а дан на десет часова, час на 100 минута а минут на 100 секунди. Дани декана се зову Први, Други,… …, Десети или Свети".

Како Каирис пише, "ера Теозебиста" почиње "од прве године Деветнаестог века Хришћана и и подељена је у петогодишње ***ентеаде****". Дакле прва година теозебијске хронологије почела је 11/23, септембра 1800* [Прва година 19. века није 1800, него 1801 – Прим. аутора]*, и завршила се 10/22, септембра 1801. Дани од 6. до 10. септембра 1801, били су* ***Епакта*** *(изведени дани).*

Потпуна теозебијска хронологија је изложена у писму бр. 220: "33, или 9. од ентеаде 9, до 3, 1. од средњег [декана] Софаретус". Година 33 почиње 11/23 септембра 1842, док се 8. Ентеада завршава 10/22, септембра 1840. и следећег дана почиње девета ентеада, чија је трећа година била 1842-1843. Софаретус је други месец Теозебијског календара (11/23, октобра до 9/21, новембра). Дакле Први од средњег декана овог месеца је 21. октобар/2. новембар 1842.

Каирис и следбеници његове секте користили су табеле одговарајућих датума у два календара (Теозебијском и Хришћанском), од којих су неке сачуване." (Polemis, Увод, том II, стр. 12-13).

Каирис је сматрао годину 1801 'као годину 1' Теозебијског календара, у основи имплицитне варијанте француског Револуционарног календара огрнутог у религију. Овај Каирисов календар, „последњи трзај" календара који није опстао, био је такође „мртворођенче".

Деветнаести век је први век каиријанског мерења времена. У свом календару он користи старогрчко означавање бројева; тако је у години μλ каиријанске хронологије (која одговара 1852) објављен у Лондону "Compendium of Theosebian Doctrine and Ethics". У овој књизи су детаљно описани доктринарна позадина Теозебизма и Каиријански календар. Према свом еклезијастичком календару, Каирис је поделио 'ноћ и дан' на пет «Времена» од по два «часа» (укупно 10 часова подељених на по 100 минута а сваки минут на 100 секунди - Portaz, 1935, p. 220, Theodossiou et al., 2004, p. 788 and Theodossiou et al. 2006, p. 116).

Табела III: "Времена" дана у Теозебијском календару

Каиријанска "Времена"	
Јутрење	Време молитве
Часови	Време учења и читања
Вечерње	Време рада у својој професији
Ноћна молитва	Време добротворног рада
Поноћ	Време неопозивог одмора

У свом календару, Каирис укида све хришћанске празнике (везане за Исуса Христа, Богородицу, свеце итд.). Такође замењује недељу –дан Господњи– са 'Титхе' (десети дан), т.ј. пошто не прихвата божанску природу Исуса Христа, укида и дан посвећен њему.

Према принципима Теозебизма, верници, побожни људи, сакупљали су се у средини сваког од четири годишња доба године, почевши са одговарајућом средином јесени и славили следеће: Ентеогона, Ентеагона, Ентеобиа и Ентеодиа.

Све ове –непреведиве– називе измислио је Каирис. Њихово значење је тешко растумачиво и на грчком а сваки укључује реч Бог (Теос на грчком).

Закључујемо да је Каирис свој календар са новом хронологијом створио да би га користио у религији секте коју је створио, у чије је ритуале увео нове молитве, химне и култ и тако направио свој посебни теоријски и култни ритуал, написан на старом дорском дијалекту.

Заиста, Каирис који је поред осталог, био поштовалац старог грчког духа, написао је на старом дорском дијалекту потпуно оперативну књигу химни. Одговарајуће службенике називао је «Божји свештеници" (Теаги). Теаги или Хиераги (Свети свештеници) класификовани су у пет редова: Декани, Предавачи, Химноди, Проповедници и Свештеници.

Свакако, овај календар, колико нам је познато непознат у међународној литератури и српској јавности, никад није изишао из његовог најужег круга и нестао је са смрћу свога изумитеља, заједно са култом Теозебизма (Theodossiou et al., 2007, стр. 117).

4. РЕВОЛУЦИОНАРНИ КАЛЕНДАР СОВЈЕТСКОГ САВЕЗА („БОЉШЕВИЧКИ КАЛЕНДАР“)

Последњи велики покушај календарске реформе предузела је 1929. влада Совјетског Савеза (СССР), која је усвојила Револуционарни календар (или Бољшевички).

Да би започела са реформом влада формирана 1918, после Октобарске револуције, заменила је Јулијански календар Грегоријанским, усклађујући тако Русију са Западном Европом са календарске тачке гледишта; због тога се у Совјетском Савезу годишњица „Октобарске револуције“ славила 7. новембра. Руска православна црква никада није прихватила Грегоријански календар.

ТАБЕЛЬ-КАЛЕНДАРЬ НА 1931 ГОД.

	ЯНВАРЬ							ФЕВРАЛЬ							МАРТ							АПРЕЛЬ						
I день	1	6	11	16	21	27		1	6	11	16	21	26			3	8	13	18	23	28		2	7	12	17	22	27
II день	2	7	12	17	23	28		2	7	12	17	22	27			4	9	14	19	24	29		3	8	13	18	23	28
III день	3	8	13	18	24	29		3	8	13	18	23	28			5	10	15	20	25	30		4	9	14	19	24	29
IV день	4	9	14	19	25	30		4	9	14	19	24			1	6	11	16	21	26	31		5	10	15	20	25	30
V день	5	10	15	20	26	31		5	10	15	20	25			2	7	12	17	22	27		1	6	11	16	21	26	

	МАЙ							ИЮНЬ							ИЮЛЬ							АВГУСТ						
I день		4	9	14	19	24	29		3	8	13	18	23	28		3	8	13	18	23	28		2	7	12	17	22	27
II день		5	10	15	20	25	30		4	9	14	19	24	29		4	9	14	19	24	29		3	8	13	18	23	28
III день		6	11	16	21	26	31		5	10	15	20	25	30		5	10	15	20	25	30		4	9	14	19	24	29
IV день		7	12	17	22	27		1	6	11	16	21	26		1	6	11	16	21	26	31		5	10	15	20	25	30
V день	3	8	13	18	23	28		2	7	12	17	22	27		2	7	12	17	22	27		1	6	11	16	21	26	31

	СЕНТЯБРЬ							ОКТЯБРЬ							НОЯБРЬ							ДЕКАБРЬ						
I день	1	6	11	16	21	26		1	6	11	16	21	26	31		5	12	17	22	27			2	7	12	17	22	27
II день	2	7	12	17	22	27		2	7	12	17	22	27		1	6	13	18	23	28			3	8	13	18	23	28
III день	3	8	13	18	23	28		3	8	13	18	23	28		2	9	14	19	24	29			4	9	14	19	24	29
IV день	4	9	14	19	24	29		4	9	14	19	24	29		3	10	15	20	25	30			5	10	15	20	25	30
V день	5	10	15	20	25	30		5	10	15	20	25	30		4	11	16	21	26			1	6	11	16	21	26	31

ЯНВАРЬ. 22 — день 9 янв. 1905 г. и памяти вождя пролетар. В. И. Ленина.
МАЙ. 1-2 дни Интернац. **НОЯБРЬ 7-8** — дни праздн. Пролетарск. революции.

Слика 5: *Шема совјетског цепног календара за 1931. На Грегоријанском календару су означени дани петодневне непрекидне радне недеље. Пет празничних, нерадних дана, 22. јануар, Дан успомене на 9. јануар 1905, и на Леђина, 1-2. мај, Дан Интернационале и 7-8. новембар, Дан пролетерске револуције су искључени*
(http://ru.wikipedia.org/wiki/Файл:Soviet_calendar_1931_pocket_2.jpg).

Друга, много радикалнија промена десила се 1929.

Идеја је била да се укине недеља као дан одмора и да се уведе непрекидна производна недеља (неперерывка). Тако је у производњи, од јесени 1929 до близу краја 1931, паралелно са Грегоријанским, уведен календар подељен у 72 петодневне недеље (=360 дана), од којих су три биле подељене у два дела са пет дана три национална празника, али празници се нису рачунали као део недеље, тако да су и оне подељене имале пет дана. Сваки дан петодневне недеље (пятидневка) био је означен или једном од пет различитих боја, или римским бројем од I доV, или именима: первый, второй, третий, четвертый, пятый. Сваком раднику била је додељена, једна боја или број да би идентификовао свој дан одмора, тако да је сваког дана 80% радника неке фабрике радило а 20% се одмарало.



Слика 6: *Лист из совјетског календара за 1937 Написано је: Двадесет прва година Социјалистичке револуције / 1937 ДЕЦЕМБАР 1937 / 12 / шести дан шестидневке / Дан избора за Врховни Савет СССР (http://ru.wikipedia.org/wiki/ Файл::Revolution_kalendar.jpg).*

Године 1930, предложен је Совјетски револуционарни календар са 12 месеци са по 30 дана и пет националних празника, који не припадају ни једном месецу. Предлог је био одбијен и такав календар никада није уведен али је у многим западним изворима погрешно наведено да су 72 петодневне недеље биле организоване у 12 месеци са по 30 дана, на пример у раду Алберта Парија (Parry, 1940).

Ипак, покушај да се промени недеља био је неуспешан, и 21. новембра 1931, Савет народних комесара СССР (Совнарком) заменио је „петодневку“ „шестодневком“, тако да се година од 360 дана састојала од 60 таквих интервала. Ова недеља није била са непрекидном производњом, него су 6, 12, 18, 24 и 30 дан сваког месеца били дани одмора. На крају фебруара, последњи дан је био нерадни или је то био први март. У месецима са 31 дан, рад тога дана се сматрао додатним и плаћао посебно. Али ни један од ових система није пустио корене у свести народа. Тако је 1940, Совјетска влада вратила у употребу Грегоријански календар и стару седмодневну недељу у фабрике и предузећа.

Такође је занимљиво да је уз грегоријанску годину, у неким случајевима додаван додатни датум као на сл. 6: *Двадесет прва година Социјалистичке револуције*, при чему су године бројане од 7. Новембра 1917. То је било присутно до распада Совјетског Савеза 1991 (види нпр. Щербинин 2008, стр. 58).

Револуционарни календар Совјетског Савеза (Бољшевички календар), детаљно је описан у Theodossiou, Manimanis, Danezis (2002).

5. МУСОЛИНИЈЕВ ФАШИСТИЧКИ КАЛЕНДАР

Такозвани „Фашистички календар“ појавио се (и нестао) у фашистичкој Италији. Ипак, то није био заиста различити календар, већ уствари почетак нове хронологије, после превратничког фашистичког «Марша на Рим» 28. октобра 1922, који је довео Мусолинија на власт.

Уствари, према Марли Стоун (Marla Stone): *Користећи француски пример, фашизам је ретроактивно рестартовао календар 1927, узимајући 28. октобар 1922, као први дан, прве године новог календара I.I.I. Фашизам је објавио да ће то променити старе поданичке обавезе и колективну историју. На тај начин «фашизација» је била нераскидиво повезана са «национализацијом»* (Stone, 1993, стр. 230).

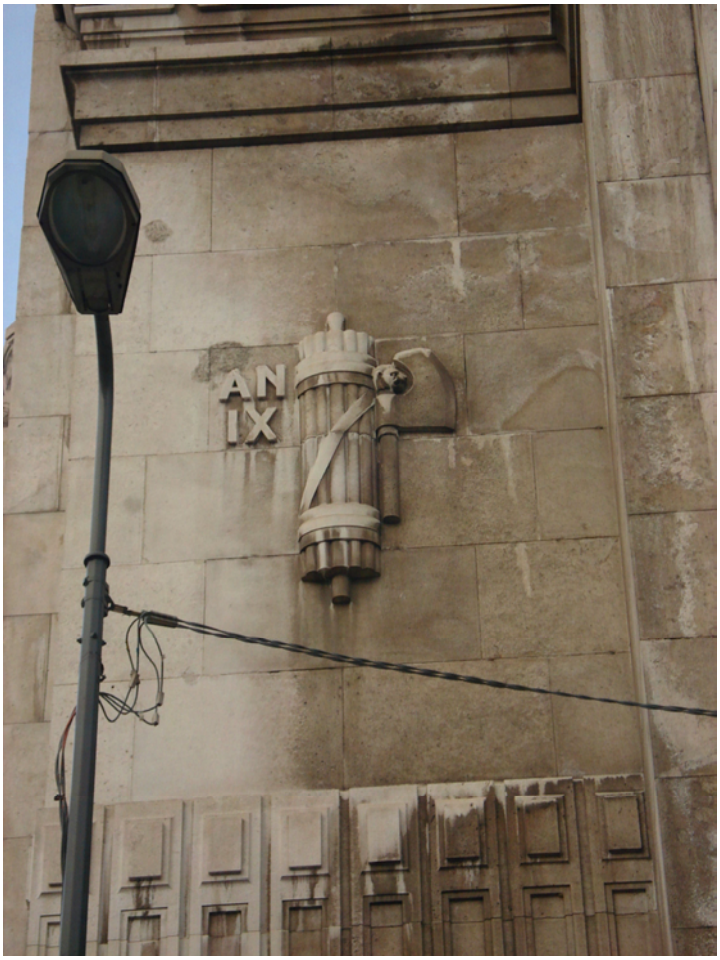
Тако је Фашистички календар почео 28. Октобра 1922. Датуми су у Фашистичкој ери писани римским бројева. Период од 28. октобра 1922. до 27. октобра 1923, узет је као фашистичка година I (или година I *“di era fascista”* – фашистичког доба). У италијанским календарима ова година је писана *заједно* са уобичајеном годином: до Грегоријанске године био је римски број који је означавао одговарајућу фашистичку годину. На пример датум када је Италија објавила рат Грчкој писан је као: 28 октобар 1940 – XIX (римски број 19 означавао је 19. годину фашистичке ере).



Слика 7: *Плоча на Берзи у Милану са датумом према фашистичком календару. Фото Ђовани Дал'Орто.*

Према Марку Антлифу: *Најдраматичнији пример таквог социјалног инжењерства био је 'уметање преко Грегоријанског календара' оквира фашистичког времена, у коме 1922 постаје „година I" фашистичке ере, сигнализирајући регенеративни прекид са плутократском декаденцијом непосредне прошлости. Нови календар је онда допуњен са појединим данима националног празновања,а сваки је имао „двоструко митско значење". Тако је 23. март, Дан младости, био у знак сећања на оснивање фашизма; 21. април, Дан рада, на датум оснивања Рима; 24 мај, Дан империје, одговарао је уласку Италије у Први светски рат; 20. септембар, Дан уједињења Италије, поводом укључивања Рима у Краљевину Италију; 28. октобар, фашистички превратт, Марш на Рим… На тај начин, обични Италијани били су охрабривани да искусе проток времена као феномен са трансценденталним језгром упоредо са метафизичком реалношћу прожетом Хришћанством* (Antliff, 2004, стр. 149-150).

Година од 1922 (октобар) до 1923, сматрала се као фашистичка година 1 — са римским бројем: I. То је био део датума који је функционисао упоредо са Грегоријанским календаром у свим фашистичким документима и другим штампаним материјалима. На пример, први мај 1934, био је праћен фашистичком годином XII, док је уз 25. децембар 1938, стављана година XVII, пошто је децембар после октобра, па је година фашистичке ере промењена. Као што се могло очекивати, слом фашистичког режима у Италији, донео је и укидање ове тривијалне календарске промене.



Слика 8: *Година IX фашистичке ере на згради Миланске централне железничке станице. Фото Ђовани Дал'Орто.*

6. КАЛЕНДАР МЕТАКСАСОВЕ ДИКТАТУРЕ У ГРЧКОЈ

Занимљиво је да је Мусолинијеву хронологију у Грчкој имитирала диктатура Јоаниса Метаксаса (1936-1940), узимајући 1936, као годину почетка, „годину А΄" писану грчким обележавањем бројева. На свим званичним папирима грчке диктатуре биле су две хронологије: Хришћанска година и одговарајућа година диктатуре. На пример датум када је Италија објавила рат Грчкој писан је као: 28. октобар 1940 – година Е΄.


ΠΡΩΤΗ ΔΙΑΣΚΕΨΙΣ

ΠΡΑΚΤΙΚΑ ΣΥΝΕΔΡΙΑΣΕΩΝ

Слика 9: *Зборник Прве конференције регионалних администратора Националне омладинске организације из 1939, где се јавља година делта (Δ') Метаксасове диктатуре.*

Нема потребе да се каже да је крај оваквих начина обележавања дошао заједно са крајем одговарајућих режима. Штавише, ова акција диктатуре је практично непозната у модерном грчком друштву. Није поменута ни забележена било где, осим у извесним званичним документима из тога периода и у државним архивима, на пример у зборнику са Прве конференције регионалних администратора Националне омладинске организације из 1939, године делта (Δ'), из кога смо сазнали о овоме.

7. МИЛАНКОВИЋЕВ НОВИ ИСПРАВЉЕНИ ЈУЛИЈАНСКИ КАЛЕНДАР ПРАВОСЛАВНИХ ЦРКАВА

Васељенски Патријарх Мелетије IV (1922-1923), сазвао је Конгрес Православних цркава у Константинопољу у мају 1923, на коме је једна од основних тема била реформа Јулијанског календара. У српској делегацији били су Гаврило Дожић и Милутин Миланковић. У то време, Дожић је био владика Црне Горе и Приморја, а касније је постао Патријарх Српске православне цркве. Милутин Миланковић (Даљ, 28. мај 1879 – Београд, 12. децембар 1958) у свету је познат због установљавања веза између сунчевог загревања Земљине површине и појаве ледених доба у Европи за време квартара.. Он је развио астрономску теорију еволуције климе на планетама и објаснио настајање ледених доба и померање северног пола.

Милутин Миланковић је био два пута потпредседник Српске академије наука и уметности и директор београдске Астрономске опсерваторије (1948-1951). У част његових научних достигнућа на пољу астрономије, на XIV конгресу Међународне астрономске уније у Брајтону, један кратер на невидљивој страни Месеца (са координатама $+170^{o}$ $+77^{o}$) добио је његово име. На XV конгресу ове организације у Сиднеју његово име добио је и један кратер на Марсу (са координатама $+147^{o}$, $+55^{o}$), а 1982. је мала планета са привременомн ознаком 1936GA, коју су 1936. открили Миодраг Протић и Перо Ћурковић, добила име 1605 Миланковић (Димитријевић, 2002).

На Конгресу Православних цркава представници Српске и Румунске су поднели два предлога (детаљни опис реформе календара и Конгреса у Константинопољу дат је у делима Миланковић 1923, 1995, 1997, види такође Dimitrijević 2002, Dimitrijević, Theodossiou 2002, Dimitrijević, Theodossiou, Mantarakis, 2008). Предлог Српске делегације, који је формулисао Максим Трпковић, био је да се уведе интеркалационо правило да секуларне године (године са две нуле којима се завршавају векови) које подељене са 9 имају као остатак 0 или 4 буду преступне. На тај начин, у 9 векова биће испуштено 7 дана и календар ће бити ближе тропској години од Грегоријанског, где је интеркалационо правило да су преступне секуларне године код којих је број векова дељив са четири. Осим тога, пролећна равнодневица ће увек бити 21. марта или близу њега.

У Румунској делегацији су били архимандрит Јулијан Скрибан и сенатор Драгићи. Они су дошли са следећим предлогом за реформу календара (Миланковић 1923, 1997, Трајковска, Нинковић 2008): Свака година има 364 дана (тачно 52 недеље) тако да сваки датум има сталан дан у недељи. Март, јун, септембар и децембар имају 31 дан, а други месеци 30 дана. Сваких пет година, додаје се једна недеља између 31. јуна и 1. јула, што уклања разлику са тропском годином. Први дан Ускрса је фиксиран на 29. април, и сви други покретни празници постају фиксирани. Овај предлог Конгресу је представио сенатор Драгићи, који је Миланковићу рекао да је његов аутор уствари барон Густав Бедеус из Сибиуа, који није Православне вере, тако да није згодно да ту буде његово име. Ипак, према истраживањима Трајковске и Нинковића (2008), "Концепт резолуције за конференцију о календару Православних цркава 23. маја 1923 у Константинопољу", који је Бедеус на немачком објавио у *Siebenbuergisch-Deutschen Tagesblatt* (Дневник Немаца Седмограђа – односно Трансилваније на румунском) разликује се од предлога сенатора Драгићија.

Конгрес је одбио оба предлога. Српски, чији је аутор био Трпковић, пошто према њему 2000. година не би била преступна као у Грегоријанском календару, тако да би се после само 77 година између њих појавила разлика од једног дана. Конгрес је закључио да је боље решење да се из Јулијанског календара избаци тринаест дана тако да између њега и Грегоријанског не би било разлике до 2100, када би она износила један дан.

Милутин Миланковић је од Конгреса добио задатак да разради нови предлог. Закључио је да је жеља већине учесника да календар Источне Православне цркве не треба да буде идентичан са Грегоријанским, али треба да буду паралелни што је могуће дуже. Сходно томе, уместо да се труди да фиксира датум пролећне равнодневице на 21. март, као што је било у Трпковићевом предлогу, покушао је да добије најдуже могуће слагање два календара. Разрадио је ново интеркалационо правило, да су секуларне године преступне само под условом да када број векова који садрже поделимо са 9 остатак буде 2 или 6. На тај начин, нови календар је тачнији од Грегоријанског, али они се не разликују до 2800, т.ј. током 877 година после Конгреса у Константинопољу. Друга предност је да је Нови поправљени Јулијански календар, како Миланковићев календар називају у свету, у бољем слагању са природом него Грегоријански. Разлика од једног дана са тропском годином настаће после готово 30000 година!

Миланковић је представио Конгресу нови предлог Српске Православне цркве, који су потписали он и Гаврило Дожић, на седници од 23. маја 1923. У свом историјском обраћању Конгресу, рекао је делегатима да ће, ако само усвоје брисање 13 дана из Јулијанског календара, Православна црква бити у подређеном положају у свакој будућој дискусији о календарском питању. Усвајајући предлог Српске делегације, Православна црква ће моћи са поуздањем да уђе у преговоре о овом питању са западним црквама, с обзиром да ће имати најтачнији и најнаучније заснован календар у целокупном Хришћанском свету. Подвукао је такође, да са таквом одлуком, Православна црква неће прихватити календар Католичке, него ће добити бољи.

Визијски митрополит Антим, такође је предложио Конгресу, да се тачан датум Ускрса одређује астрономским методама уз помоћ опсерваторија и универзитета у Атини, Београду, Букурешту и Пулкову.

Милутин Миланковић је уобличио коначну верзију реформе календара, коју је Конгрес усвојио, 8. јуна 1923, а потписали су је Патријарх Мелетије IV, Владика кизички Калиникос, Надбискуп Северне Америке Александар, Владика црногорско-приморски Гаврило Дожић, Владика никејски Василије, Владика драчки Јакуб, архимандрит Јулијан Скрибан и професори Е. Антонијадис и Милутин Миланковић.

Као датум официјелног увођења Новојулијанског календара узет је 1. октобар 1923, који ће постати 14. октобар, да би било избачено 13 дана разлике између Јулијанског календара и тропске године. Тога дана, нови календар је требао да буде уведен у Васељенској Патријаршији и у Грчким Црквама, али без дела који се односи на одређивање Ускрса, где се стари Јулијански календар задржава док све Православне цркве не изврше реформу. Данас, „Нови“, „Ревидирани“ или „Поправљени“ Јулијански календар Милутина Миланковића користе Патријаршије у Константинопољу, Александрији и Антиохији, Цркве Грчке, Кипра, Румуније, Пољске, Финске, Бугарске (од 1968) и Православна црква у

Америци (Од 1. септембра 1983, види нпр. http://www.holy-trinity.org/modern/calen2.html). Са друге стране, Патријаршија у Јерусалиму и Српска и Руска Православна црква, као и светогорски манастири, и даље користе стари Јулијански календар (види нпр. http://www.yalchicago.org/ paschacalculati on.html).

8. ЗАКЉУЧАК

Од шест представљених календарских система, који су били осмишљени од краја 18. до средине 20. века, до данас је опстао само Новојулијански календар Милутина Миланковића. Историја је показала да људи, који не желе да мењају друштвене и религијске навике повезане са календаром који користе, веома тешко прихватају његову промену. Чак и у случају Миланковићевог календара, који је у овом тренутку по датумима идентичан као Грегоријански, у употреби као грађански и у државама у којима доминира Православље, и мења само датуме црквених празника, наилази на велике отпоре и у Православним црквама које су га прихватиле настале су секте старокалендараца који не желе његову употребу.

Од ових шест календарских система, насталих вековима после Грегоријанског календара, највише је у међународној литератури разматран француски Револуционарни календар (*Le Calendrier Républicain*), с обзиром да је повезан са чувеном Француском револуцијом из 1789, која још увек покреће и утиче на европску мисао.

О Миланковићевом календару такође се писало, нарочито много код нас. Ту је и совјетски Револуционарни календар, испреплетан са посебним периодом историје СССР, док је Теозебијски календар Теофила Каириса, потпуно непознат међународној јавности, пошто о њему зна само мали број научника и астронома у Грчкој

Мусолинијев фашистички календар се помиње у међународној литератури, али он, као и практично потпуно непознат у међународној јавности календар Метаксасове диктатуре у Грчкој, уствари нису посебни календарски системи; него паралелно писање година после датума Грегоријанског календара, који су означавали дужину ових диктатура, а у случају Мусолинијевог календара такође смо поменули и важне празнике. То су, како професор са Универзитета у Атини Стериос Фасулакис пише (Fassoulakis, 2001), календарски системи политичке идеологије.

Размотрени случајеви подупиру закључак да је тешко да нека календарска реформа преовлада или се одржи дуго, ако је не прихвати више различитих држава, Црква или нека организација присутна у више различитих заједница. У разматраним примерима, крај режима који их је увео био је и крај оваквих календарских система.

Литература

Antliff, Mark: 2004, *Fascism, modernism and modernity* in R. Griffin & M. Feldman (Ed.), *Fascism: Critical concepts in Political Science*. Routledge, New York, pp. 149-150.

Dimitrijević, M. S.: 2002, Milutin Milanković (1879-1958) and his contribution to European astronomy, *Astronomische Nachrichten*, **323**, 570-573.

Dimitrijević, M. S., Theodossiou, E.: 2002, The calendar of the Greek Orthodox Church, *Astronomical and Astrophysical Transactions*, **21**, 145-148.

Dimitrijević, M. S., Theodossiou, E. Th., Mantarakis, P. Z.: 2008, Milutin Milanković and the reform of the Julian Calendar in 1923, *J. Astron. History and Heritage,* **11,** 50-54.

Fassoulakis, Sterios: 2001, "Calendars of political ideology", *Istorika*, vol. **64**, January 4, 2001, pp. 48-49.

Flammarion Camille: 1955, *Astronomie Populaire*, Édition Entièrement Refaite, G. C. Flammarion, Paris.

Le Calendrier Républicain: 1994, *Bureau des Longitudes*, Paris, p. 19.

Milanković, M.: 1923, *The reform of the Julian Calendar,* Serbian Royal Academy of Sciences and Arts, Special editions No 47, Natural and Mathematical Sciences No 11 [in Serbian].

Milanković, M.: 1997, *Memories, experiences, cognition*, Selected works of Milutin Milanković, No 7, Завод за уџбенике и наставна средства, Београд [in Serbian].

Milanković, V.: 1995, *Milutin Milanković 1879-1958*, European Geophysical Society, Katlenburg – Lindau.

Parry, Albert: 1940, "The Soviet calendar", *Journal of Calendar Reform*, **10**, p. 68.

Polemis, D. P.: 1994-1996, *Allilografia Theofilou Kairi*, 3 volumes, Kairios Vivliothiki Publ., Andros [in Greek].

Portaz, Maximine: 1935, *Essai critique sur Theóphilos Kaíris.*, Paquet, Lyon, p. 220.

Renouard, Antoine Augustin: 1822, *Manuel pour la concordance des calendriers républicain et grégorien: ou, Recueil complet de tous les annuaires depuis la première année républicaine* (2 ed.).

Щербинин, А. И.: 2008, «Красный день календаря»: Формирование матрицы восприятия политического времени в России, стр. 58, *Вестник Томского Государственного Университета*, *Философия*, *Социология*, *Политология*, Но. 2(3), стр. 52-69.

Stone, Marla: 1993, Staging Fascism: The Exbition of the Fascist Revolution. *Journal of Contemporary History*, vol. **28**, No. 2. April, by Sage Publications, Ltd.

Theodossiou, E. & Danezis, E.: 1996, *The Odyssey of the Calendars.* Diavlos Publications, Athens [на грчком].

Theodossiou, E. and Danezis, E.: 2000, *In the traces of ICHTYS: Astronomy, History and Philosophy.* Diavlos Publications, Athens [на грчком].

Theodossiou, E., Manimanis, V. N. and Danezis, E.: 2002, The Russian Calendars after the Christianization of the country, *Journal of the Astronomical and Astrophysical Transactions*, vol. **21**, No. 1-3, June 2002, pp. 149-153.

Theodossiou, E., Grammenos, Th. and Manimanis, V. N.: 2004, Theophilos Kairis: The Creator and Initiator of Theosebism in Greece, *The European Legacy*, vol. **9**, no. 6, pp. 783-797.

Theodossiou, E. and Danezis, E.: 2006. Theophilos Kairis: The Initiator of a new religion in Greece, *Istorika Themata*, February, vol. **48**, pp. 104-117 [на грчком].

Theodossiou, E., Danezis, E, Katsiotis, M. and Mantarakis, P.: 2007, Theophilos Kairis: The Initiator of Theosevism in Greece, *Aeropos*, February, September-October, vol. **75**, pp. 104-117 [in Greek].

Theophilos, Kairis, Code 53, Library of the Historical and Theological Society, as in Issue **65** the text 'Correspondence of months'" [s.d.].

Trajkovska, V., Ninković, S.: 2008, On a resolution concept concerning the calendar reform submitted to Pan-Orthodox Congress in Constantinople in 1923, *Publ. Astron.Obs. Belgrade*, 85, 189-194.

Wilson P. W.: 1937, The Romance of the calendars, W.W. Norton, New York.

On line референце

http://www.hms.org.uk/nelsonsnavyrevcalend.htm: The Historical Maritime Society, Nelson and His Navy - Revolutionary Calendar.

http://en.wikipedia.org/wiki/French_Republican_Calendar

http://www.yalchicago.org/paschacalculation.html

http://www.holy-trinity.org/modern/calen2.html

SIX CALENDRICAL SYSTEMS IN THE EUROPEAN HISTORY FROM 18TH TO 20TH CENTURY

The following calendrical systems, introduced in Europe from 18th to 20th century, which were in use in Europe for a shorter or longer period by a larger or smaller community, were reviewed and discussed: The French Revolutionary Calendar, the Theosebic calendar invented by Th. Kairis, the Revolutionary Calendar of the Soviet Union (or 'Bolshevik calendar'), the fascist calendar in Italy and the calendar of the Metaxas dictatorship in Greece before World War II. Also the unique of them which is still in use, the New Rectified Julian calendar of the Orthodox Church is presented and discussed. At the end, difficulties to introduce a new calendar are discussed as well.

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ФИЛАТЕЛИЈА И АСТРОНОМИЈА

МИЛАН С. ДИМИТРИЈЕВИЋ

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Резиме: Размотрени су астрономски садржаји у филателији са посебним осврtом на астрофилателију, пригодне жигови и пригодне коверте са астрономском тематиком, балонску и ракетну пошту код нас, и космичку пошту. Укратко је представљена активност филателистичког друштва «Космос» из Земуна и збирка марака «Освајање космоса» Сергија Димитријевића.

1. УВОД

Филателија је једно од подручја где су астрономски садржаји веома присутни те свакако треба посветити одговарајућу пажњу и овом аспекту утицаја науке о звездама на различите области људске активности. Када су у питању пригодне марке, жигови и специјални коверти поводом различитих догађаја и јубилеја можемо на њима наћи доста космичких и астрономских мотива. Распрострањени филателистички тематски правац је постала Астрофилателија. Она је популарна због своје лепоте и перспективности а приступачна је пошто обично не обухвата недостижно скупе и ретке марке. Неки је условно деле на три групе:[1] *Космонаутику са геофизиком*, *Астрономију са метеорологијом* и *Атомистику*. Ове групе могу се даље делити, тако да Игоров Космонаутику са геофизиком дели на претече космонаутике (нпр. Циолковски); филателистичке вредности у част манифестација као што су Геофизичка година или Година астрономије; марке издате поводом догађаја који немају везе са овом тематиком али садрже као мотив и спутњик, ракету и слично и филателистичке вредности емитоване после лансирања првог спутњика које су и тематски и мотивски посвећене освајању космоса.[2]

[1]Борис Игоров, 1963, «Астрофилателија», *Филателиста* , бр. 6, стр. 55.
[2]Занимање за ово тематског подручје може додатно да илуструје вест да је 1959. у Бриселу на четрнаест месеци затвора осуђен Роберт Хампис, који је наивнима

2. ПРИГОДНИ ЖИГОВИ

Пригодни жигови употребљавани у нашој земљи, повремено су регистровани и описивани у часопису *Филателиста*, па смо у њему пронашли оне које се односе на космичко-астрономску тематику и овде је, као пример овакве праксе, понуђен њихов преглед из периода 1959-1982.



Слика 1: *Пригодни жиг поводом слета селенита Југославије, 22-27.06.1958.*[3]

ПРИМЕРИ ПРИГОДНИХ ЖИГОВА У ЈУГОСЛАВИЈИ СА АСТРОНОМСКОМ ТЕМАТИКОМ, КОЈИ СУ ПОВРЕМЕНО ОПИСИВАНИ У ЧАСОПИСУ ФИЛАТЕЛИСТА 1959-1982

1. Београд, аеродром: 22-27. VI 1958, за слет селенита Југославије на београдском аеродрому. Текст - "SLET SELENTA JUGOSLAVIJE / BEOGRAD - AEROPORT" (сл. 1).[4]

2. Дубровник: За прославу 250-годишњице рођења Руђера Бошковића, на пошти у Дубровнику 18. маја 1961. у употреби пригодни жиг са непокретним датумом. Облик жига елипсаст, величине 35-29 мм, са двојним оквиром, око кога је текст: са горње стране „RUĐER BOŠKOVIĆ" а са доње

продавао марке са „Марса" које је сам израдио („Марке са Марса", *Филателиста*, 1959, бр. 5-6, стр. 74).

[3]Ал. Ј. Петровић, 1959, „Пригодни жигови употребљавани на територије ФНРЈ", *Филателиста*, бр. 1-2, стр. 3.

[4]Исто, стр. 5

„DUBROVNIK“; у оквиру су датум Руђеровог рођења „18. 5. 1711“ горе, а доле датум прославе односно употребе жига „18. 5. 1961“; у средини је пригодан цртеж. Цртеж жига је израдио др П. Гавранић, академски сликар из Загреба (сл. 6).[5]



Слика 2: *Поштански жигови првог дана поводом прославе стогодишњице Астрономске и Метеоролошке опсерваторије 7. септембра 1987.*

3. Сарајево 1: Прослава јубиларне године Академског астрономско-астронаутичког клуба, 25. мај 1968.[6]
4. Београд 7. јун 1974, Земаљска сателитска станица у Ивањици.
5. Исто, Загреб, 7. јун 1974.
6. Исто, Прилике (код Ивањице) 7. јун 1974.[7]
7. Загреб, 12. мај 1975, Лансирање поштанске ракете у част тридесетогодишњице ослобођења.[8]
8. Запрешић, 17. мај 1975. Лансирање поштанске ракете у част тридесетогодишњице ослобођења.[9]
9. Загреб 15. јул 1975. Лансирање „Сојуза“.[10]
10. Загреб, пошта 41101, 21. децембар 1977. Поводом годишњице првог облетања Месеца космичким бродом са посадом.[11]
11. Загреб пошта 41106, 31. децембар 1979. Петнаест година постојања Савеза астронаутичких и ракетних организација Хрватске.[12]
12. Загреб пошта 41150, 31. децембар 1979. Десет година од првог спуштања човека на Месец.[13]

[5]«Пригодни жигови», *Филателиста*, 1961, бр. 5-6, стр. 81.
[6]„Пригодни жигови“, *Филателиста*, 1968, бр. 124, децембар, стр. 19.
[7]„Наши нови пригодни жигови“, *Филателиста*, 1974, бр. 152, јул-август, стр. 29.
[8]Исто, *Филателиста*, 1975, бр. 158, јул-август, стр. 34.
[9]Исто.
[10]Исто, стр. 36.
[11]„Пригодни поштански жигови“, *Филателиста*, 1978, бр. 173, фебруар, стр. 18.
[12]Исто, *Филателиста*, 1980, бр. 186-187, стр. 26.
[13]Исто.



Слика 3: *Пригодан коверат поводом потпуног помрачења Сунца 15. Фебруара 1961. године.*

13. Пошта 41150 Загреб-Аеропорт, 28. април 1980. Изложба Астронаутичког и ракетног клуба „Загреб“ о достигнућима у свемиру – Дан аерофилателије.[14]

14. Пошта 41150 Загреб-Аеропорт, 29. април 1980. Изложба Астронаутичког и ракетног клуба „Загреб“ о достигнућима у свемиру – Дан астронаутике.[15]

15. Пошта 41150 Загреб-Аеропорт, 29. април 1980. Изложба Астронаутичког и ракетног клуба „Загреб“ о достигнућима у свемиру – Десетогодишњица срећног повратка на Земљу космичког брода „Аполо 13“.[16]

16. Пошта 41150 Загреб-Аеропорт, 19. јул 1980. Пет година заједничког орбиталног лета и сарадње у космичком програму „Аполо – Сојуз“.[17]

17. Пошта 50101 Дубровник, 9. септембар 1980. Четрдесет и пет година од одржавања 35. Конференције Међународне астронаутичке федерације.[18]

18. Пошта 71230 Калиновик, 20. март 1981. Прва међународна аеро и астро изложба „ЛУРАБА 81“ у Луцерну.[19]

[14] „Нови пригодни жигови“, *Филателиста*, 1980, бр. 188-189, стр. 34.
[15] Исто.
[16] Исто.
[17] Исто, стр. 36.
[18] „Пригодни поштански жигови“, *Филателиста*, 1980, бр. 190-191, стр. 38.
[19] Исто, стр. 39.

19. Пошта 71230 Калиновик, 21. март 1981. Изложба поводом 20-год. првог лета човека у космос.[20]

20. Пошта 41101 Загреб, 12. април 1981. 20-год. лета J. A. Гагарина - првог човека у свемиру.[21]

21. Пошта 41421 Хрватски Лесковац, 12. април 1981. Дан астронаутике и први лет свемирског транспортера „Спејс шатл“.[22]

22. Пошта 41150 Загреб-Аеропорт, 12. април 1981. 20-год. лета првог човека у свемир и Дан астронаутике.[23]

23. Пошта 11080 Земун, 12. април 1981. 20-год. првог лета човека у космос.[24]

24. Пошта 11080 Земун, 17. јун 1981. Боравак у СФРЈ двојице америчких космонаута из првог орбиталног лета по програму „Спејс шатл“ 81.[25]

25. Пошта 42000 Вараждин, 20. новембар 1981. Сусрет астронома и астрономске вечери у оквиру акције САРОХ 81, у поводу 40-год. устанка и револуције и 800-год. града Вараждина.[26]

26. Пошта 42000 Вараждин, 21. новембар 1981. „Балони над градом“ – у оквиру прославе 800 год. града Вараждина и акције САРОХ 81.[27]

3. ПРИГОДНЕ КОВЕРТЕ

Пригодне коверте, такође могу да обележавају поједине астрономске догађаје и јубилеје. Добар пример је она коју је Филателистичко друштво Хрватске издало поводом потпуног помрачења Сунца 1961. године (сл. 3). Том приликом је на Видовој гори на Брачу, одакле је један део европских научника, који нису били са нашим астрономима на Хвару, посматрао ову појаву, отворена привремена пошта Нережишће, на којој су марке поништаване пригодним поштанским жигом (сл. 3).[28]

Занимљива је и пригодна коверта коју је 18. маја 1961, поводом 250-те годишњице од рођења Руђера Бошковића, издао Филателистички савез Хрватске, са мотивом који приказује Бошковићев споменик Ивана Мештровића.[29]

[20]Исто, *Филателиста*, 1982, бр. 194-195, стр. 41.
[21]Исто.
[22]Исто.
[23]Исто
[24]Исто.
[25]Исто, стр. 43.
[26]Исто, стр. 45.
[27]Исто.
[28]„Помрачење Сунца на Брачу“, *Филателиста*, 1961, бр. 5-6, стр. 46.
[29]„250-годишњица рођења Руђера Бошковића“, *Филателиста*, 1961, бр. 9-10, стр. 144.



Слика 4: *Пригодна коверта поводом 250-годишњице рођења Руђера Бошковића*.

И 200 година од смрти Руђера Бошковића филателистички је обележено 1987. године. Тим поводом изашла је пригодна марка где су укомпоновани уметнички портрет, помрачење Сунца и детаљ астрономске опсерваторије у Брери коју је основао.[30] Поред ове марке од 60 динара издати су и коверти првог дана у Београду и Дубровнику (сл. 5) и пригодни жигови у Београду, Загребу и Дубровнику. Осим тога издата је и максимум карта[31] на којој је представљена Народна опсерваторија нашег астрономског друштва „Руђер Бошковић“ (сл. 5).[32]

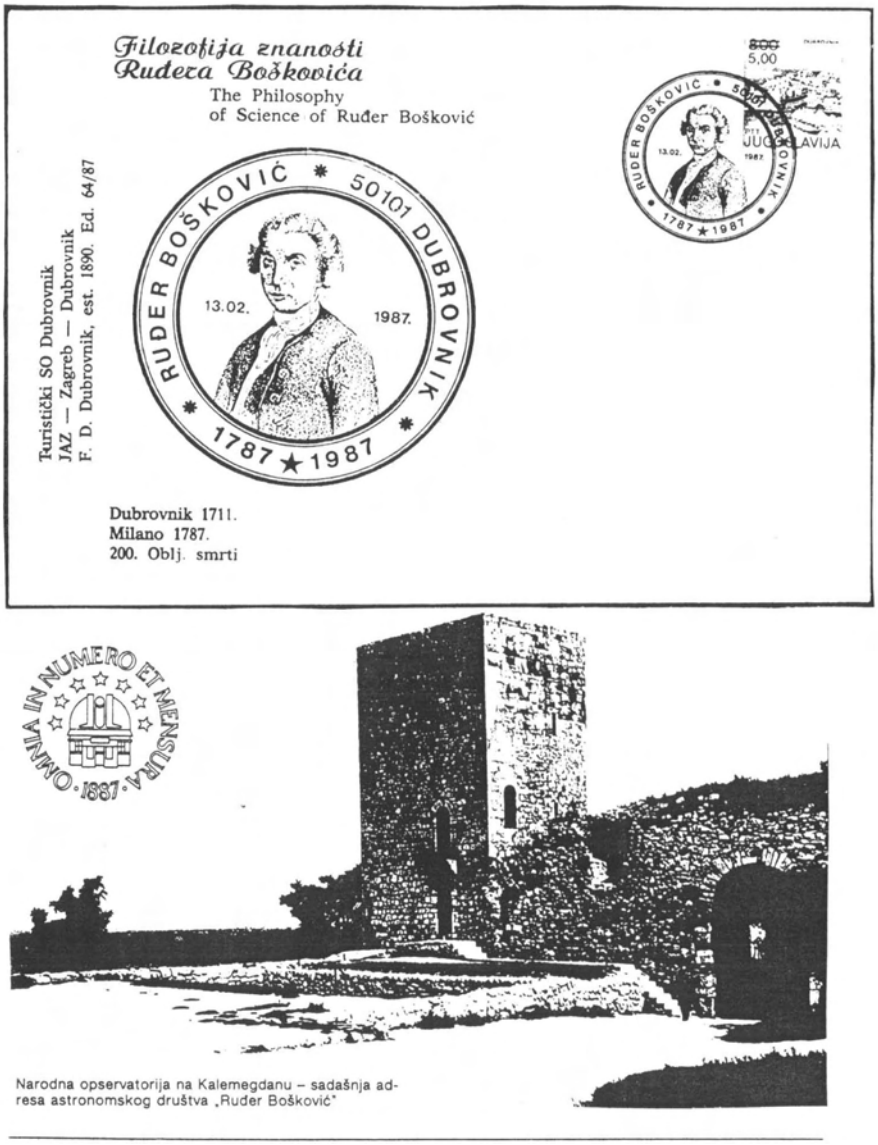
Исте 1987. године, пригодним жиговима (сл. 2) филателистички је обележена и прослава стогодишњег јубилеја Астрономске и метеоролошке опсерваторије, о чему је у часопису *Филателиста* објављен и мали чланак .[33]

[30] *Филателиста*, 1987, бр. 204, стр. 24.

[31] Максимум карта је илустрована поштанска карта величине 9x14 см или 10,5x15 см. Илустрација мора да захвата бар 75% површине карте и мора бити у вези са мотивом на поштанској марки на другој страни, али слика не може бити идентична. Марка се мора поништити жигом првог или последњег дана важења дотичне марке. Сакупљањем максимум карата бави се максимафилија.

[32] В. Прикић, 1987, «Руђер Бошковић (1711-1787)», *Филателиста*, бр. 205, стр. 14.

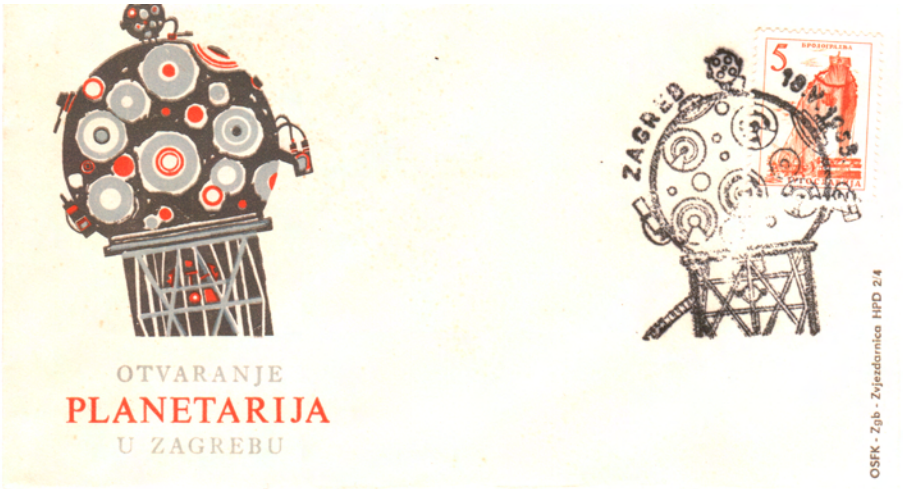
[33] В. Прикић, 1987, «Сто година Метеоролошке и Астрономске опсерваторије у Београду», *Филателиста*, бр. 205, стр. 16.



Слика 5: *Пригодни коверат и жиг издати у Дубровнику 13. Фебруара 1987, поводом 200 година од смрти Руђера Бошковића и максимум карта са Народном опсерваторијом издата тим поводом у Београду („Филателиста", 1987, бр. 205, стр. 15).*



Слика 6: *Пет година Туристичке звездарнице Примоштен.*



Слика 7: *Отварање планетаријума у Загребу.*



Слика 8: *Десет година Астрономског друштва „Отон Кучера“ у Загребу.*

У овом листу, 1966. излази занимљиво обавештење да Савез филателиста Србије у заједници са Друштвом Селенита из Београда, издаје серију коверата посвећену освајачима космоса, са пригодним жиговима, који региструју први дан полетања или годишњице летова у космос,[34] што додатно илуструје интересовање које је побуђивала астрофилателија. На сликама 6-8 дато је још неколико астрофилателистичких коверата првог дана из збирке Сергија Димитријевића.

4. БАЛОНСКА РАКЕТНА И КОСМИЧКА ПОШТА

Поводом геофизичке године, 1957. је у Америци послата пошта помоћу теледиригованих пројектила. Из Неваде је у Калифорнију упућено пет ракета са пет хиљада писама. Вођене радарима, спустиле су се неколико метара од предвиђеног циља, о чему су писали *Филателиста*[35] и *Политика*.[36]

У Југославији, прве експерименте са балонском и ракетном поштом почело је да изводи веома активно филателистичко друштво у Марибору. У овоме граду, оно је од 4. до 12. октобра 1959 организовало „Поштанску недељу пионира“, у оквиру које су млади филателисти пуштали балоне са специјалним ковертима са вишејезичном поруком да им се коверта врати. У време када је о овом подухвату писано у *Филателисту*, од послатих 300 коверата вратило се 73 а један од првих дошао је из Смедерева.[37]

[34] „Пригодни космос коверти“, *Филателиста*, 1961, бр. 111, новембар, стр. 4.
[35] „Ракетна пошта“, *Филателиста*, 1957, бр. 11-12, 196.
[36] *Политика*, 11. август 1957.
[37] Брана, 1959, „Поштанска недеља пионира у Марибору“, *Филателиста*, бр. 11-12, стр. 193.

Први успели покушај преношења поште помоћу ракете у Југославији изведен је такође у Марибору. На дан 18. септембра 1960. Друштво филателиста у овом граду организовало је трећи састанак са филателистима из Аустрије и Италије. Том приликом уз помоћ ракете коју је конструисао М. Шијанец, лансирано је 1500 писама у правцу села Цирковце, где су стигла после лета од осам километара. На њих је полазна пошта у Марибору ставила пригодан жиг и нумерисану налепницу да је писмо пренето ракетом, а жигосала их је и долазна пошта у Цирковцу.[38]



Слика 9: *Прва ракетна пошта у Србији 4. априла 1965.*

У Србији, први експеримент са ракетном поштом организовао је Академски ракетни астронаутички клуб АРАК, на Дан студената, 4. априла 1965. Пред неколико стотина београђана лансирана је са аеродрома Лисичји Јарак ракета АРАК 8, која је пренела мању количину писама са пригодним ковертама и жиговима (сл. 9) до Ковачице.[39]

На сликама 10-13, из збирке Сергија Димитријевића, дато је неколико примера пригодних коверата који су у Југославији преношени ракетном поштом.[40]

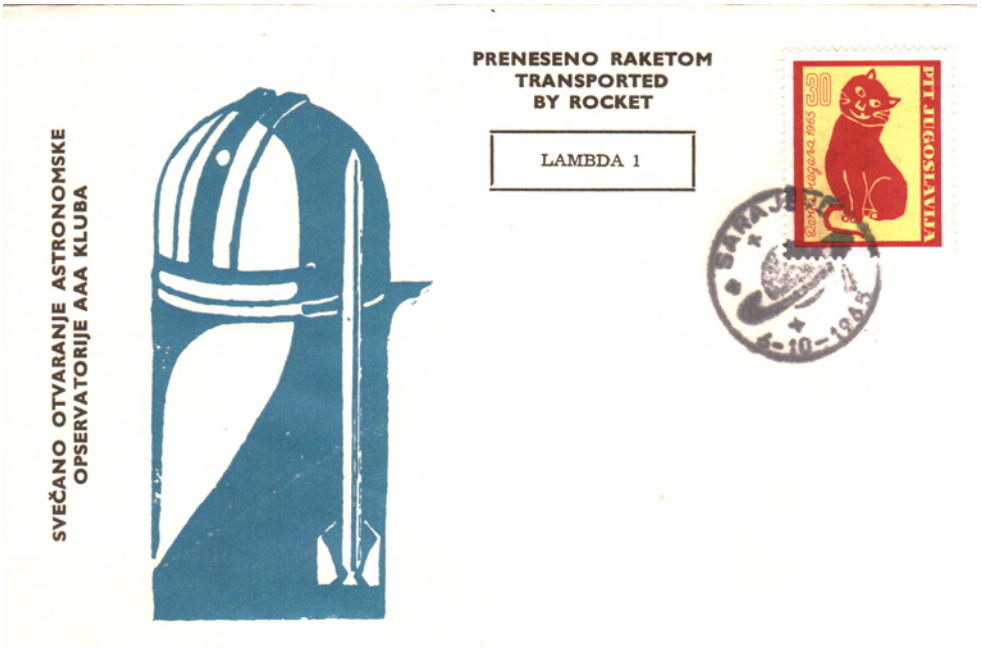
[38]М. К. И., 1960, „Покушај ракетног преношења поште“, *Филателиста*, бр. 9-10, стр. 199.

[39]Бранислав Новаковић, 1965, „Са ракетног полигона“, *Филателиста*, бр. 108, стр. 6. Milan K. Ivanović, 1965, “La vie philatelique en Yougoslavie“, *Филателиста*, бр. 108, стр. 9.

[40]На пример види: Т. К., 1967, „Филателистичко славље у Марибору“, *Филателиста*, бр. 117, стр. 15.
„Ракетни покус АРАК – Београд“, *Филателиста*, бр. 124, стр. 32,



Слика 10: *Нумерисани специјални коверат који је за време Југословенских пионирских игара пренесен ракетном поштом 25. маја 1961.*



Слика 11: *Ракетни транспорт поводом отварања опсерваторије у Сарајеву 6. октобра 1965.*

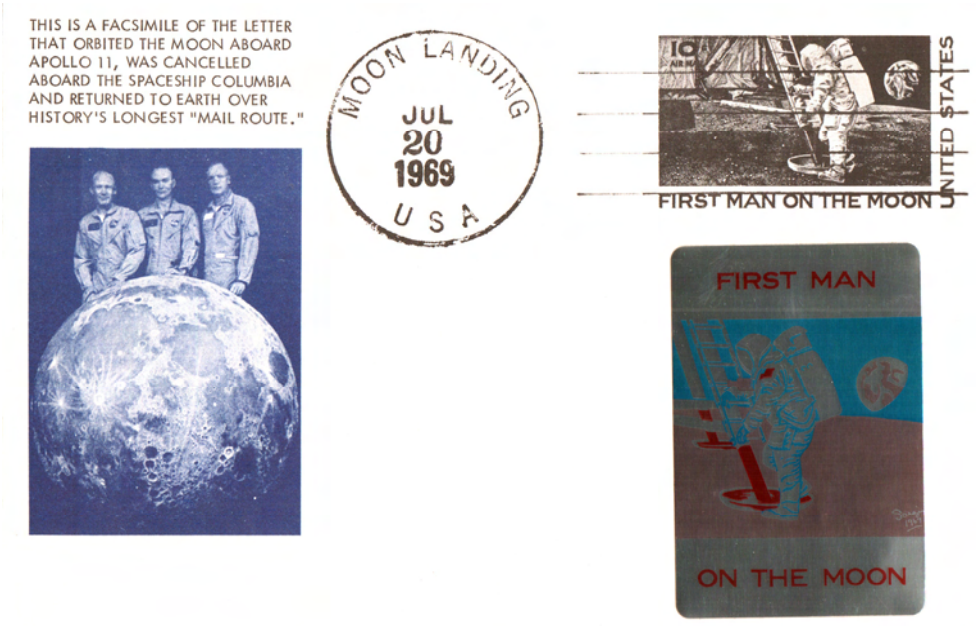


Слика 12: *Ракетна пошта поводом 18. Конгреса међународне астронаутичке федерације у Београду 30. септембра 1967.*



Слика 13: *Ракетни експеримент Академског астрономско астронаутичког друштва у Сарајеву 4. маја 1972.*

Са почетком космичке ере писма пошињу да путују и васионом. Тако *Филателиста* извештава,[41] да је командант ваздушних снага САД послао писмо франкирано марком од седам цента, са ракетом Дискавери 17 у космос. Пошто је 31 пут обишло око Земље и пешло пут од 1,5 милиона километара, вратило се на Земљу. Када је капсула са писмом прихваћена на Пацифику оно је поштом послато команданту у Вашингтон. Једно писмо пошло је и на Месец у Аполу 11 и поништено је док је брод кружио око земљиног пратиоца. После до тада најдужег „поштанскг“ пута у историји, ово писмо, са марком „Први човек на Месецу“, враћено је на Земљу и изложено у Вашингтону. За филателисте, направљен је факсимил, који се налази и у збирци Сегија Димитријевића (сл. 14). За филателистичке сврхе на многим космичким летовима Насе носе се и поштанске пошиљке. Тако је 30. августа 1983. године, када је из космичког центра „Кенеди“ по осми пут полетео „Спејс шатл“ са астронаутима Тралијем, Бранденштајном, Гарднером и Блафордом (први амерички црни космонаут), са њима је у специјалном контејнеру путовало и 260 хиљада коверата са специјалним жигом.[42] Касније се испоставило да је у кабини где су се налазили космонаути било смештено још 1001 писмо, која су обележена бројевима од



Слика 14: *Специјални коверат са факсимилом писма које је на Аполу 11 летело око Месеца*.

[41] „Пошта у свемиру“, *Филателиста*, 1961, бр. 5-6, стр. 76.
[42] „Званична астронаутска пошта“, *Филателиста*, 1983, бр. 198-199, стр. 24.

1 до 1001. *Политика* је писала[43] да су писма из специјалног контејнера продавана по цени од 16 долара а нумерисана писма из кабине са космонаутима дељена као пригодан поклон. Писмо које носи број 1001, или „нулто“ како су га назвали, било је франкирано пробним отиском марке од 9,35 долара и као уникат добило је своје место у филателистичком музеју „The Hall of Stamps”. На слици 15 дат је још један пример писма које је летело у оквиру развоја космичких летилица.



Слика 15: *Писмо које је летело на пробном лету за тестирање система контроле лета за Спејс шатл.*

5. ФИЛАТЕЛИСТИЧКО ДРУШТВО „КОСМОС“

О интересовању у Србији за астрофилателију сведочи и филателистичко друштво, које је под називом „Космос“ основано у Земуну 1976. године при Дому ЈНА. Друштво је 1979. имало 147 чланова, а од тога 52 омладинаца, огранак у Батајници са 17 чланова и огранак у Савезним органима управљања (СИВ) са 16 чланова.[44] У *Филателисти* је 1983 написано да је до те године Друштво издало 16 пригодних коверата, 3 максимум карте и успешно организовало 8 филателистичких изложби.[45] Друштво је

[43]Петар Ачански, 1984, „Писма у космосу“, *Политика*, 3. април.
[44]Хранислав Михајловић, 1979, „Вести, писма, новости“, *Филателиста*, бр. 180, стр. 7.
[45]Владимир Мојсовић, 1983, „Вести из друштава – Земун“, *Филателиста*, бр. 198-199, стр. 29.
Види такође: Х. Михајловић, 1980, *Филателиста*, бр. 188-189, стр. 28.
Р. Недин, 1984, „Филателистичко друштво „Космос“, *Филателиста*, бр. 200, 42.

учествовало и на 29. Конгресу Међународне астронаутичке федерације у Дубровнику од 2. до 8. октобра 1978, на коме је било присутно и шест космонаута (Алексеј Леонов, Виталиј Севастијанов, Валериј Кубасов, Пјотр Климук, Владимир Ремек (Чехословачка) и први пољски космонаут Мирослав Хермашевски). Том приликом, у сарадњи са ЗЛПТТ Друштво је издало комплет пригодних коверата у три различите боје, са марком посвећеном Конгресу, жигом првог дана и амблемом Друштва. Такође је издата и максимум карта са мотивом површине Месеца и Коперниковим кратером.[46]

6. ЗБИРКА МАРАКА „ОСВАЈАЊЕ КОСМОСА“ СЕРГИЈА ДИМИТРИЈЕВИЋА

За астрономе би могло бити занимљиво и да је ауторов отац, Сергије Димитријевић, научник и колекционар, поред највеће приватне збирке српског средњовековног новца коју је завештао САНУ, оформио и збирку марака са космичком тематиком са којом је добио више домаћих и међународних филателистичких награда.



Слика 16: *Надежда и Сергије Димитријевић на Конгресу историчара у Штокхолму августа 1960. године.*

Први успех постигао је на Петој филателистичкој изложби, одржаној од 18. до 25. октобра 1964. У Београду, поводом 20-тогодишњице ослобођења нашег главног града, где је добио златну медаљу за збирку „Освајање

Д. Бабић, Р. Недин, 1987, „Филателистичко друштво „Космос“, Земун, *Филателиста*, бр. 205, стр. 41.
Д. Бабић, Р. Недин, 1988, „Филателистичко друштво „Космос“, 1988. године, *Филателиста*, бр. 206, стр. 42.
„30 година првог лета човека у космос“, *Филателиста*, 1990, бр. 208, стр. 32.
[46]Хранислав Михајловић, *Филателиста*, 1978, бр. 177, стр. 23.



Слика 17: *Повеља у рангу златне медаље Сергију Димитријевићу за збирку „Освајање космоса“ на Петој филателистичкој изложби у Београду 18-25. октобар 1964.*



Слика 18: *Повеља Сергију Димитријевићу од Одеског друштва колекционара, за збирку „Освајање космоса" на Петој филателистичкој изложби у Београду 18-25. октобар 1964.*

космоса" (сл. 17) и бисту Лењина са специјалном повељом Одеског друштва колекционара (сл. 18).[47] У *Филателисту* је поводом те изложбе написано[48] и да се највише љубитеља филателије у свету „ангажује данас на сакупљању филателистичког материјала, који обележава истраживања и летове човека у космос." Напомиње се такође да су организатори с обзиром на до сада показано интересовање за ту област, замолили „професора универзитета друга Сергија Димитријевића да приреди ову групу изложака, пошто свакако располаже најинтересантнијим материјалима из свих крајева света."

[47] „Успела филателистичка изложба у Београду", *Политика*, 20. октобар 1964.
„На филателистичкој изложби; Марке са потписима учесника Београдске конференције", *Политика експрес*, 19. октобар 1964.
„V изложба марака у Београду", *Политика експрес*, 22. октобар 1964.
„Ред за изложбу", *Вечерње новости*, 26. октобар 1964.
Филателен преглед, бр. 3, 1965.
Б. Новаковић, 1964, „Признање", *Филателиста*, бр. 105, стр. 3.
M. K. Ivanovitch, 1964, « L'exposition philatelique nationale a Beograd », *Филателиста*, бр. 104, стр. 4.
[48] „Програм V филателистичке изложбе ; Астрофилателија", *Филателиста*, 1964, бр. 104, стр. 8.



БАЛКАНФИЛА - ВАРНА

1965

ДИПЛОМА

ДАВА СЕ НА

д-р Сергей Димитриевич

ЗА УЧАСТИЕТО МУ В ПЪРВАТА ФИЛАТЕЛНА ИЗ-ЛОЖБА НА БАЛКАНСКИТЕ СТРАНИ С КОЛЕКЦИЯ

„Космос"

И ЗА ПОЛУЧЕНА НАГРАДА

вермей медал

ГЕНЕРАЛЕН КОМИСАР:

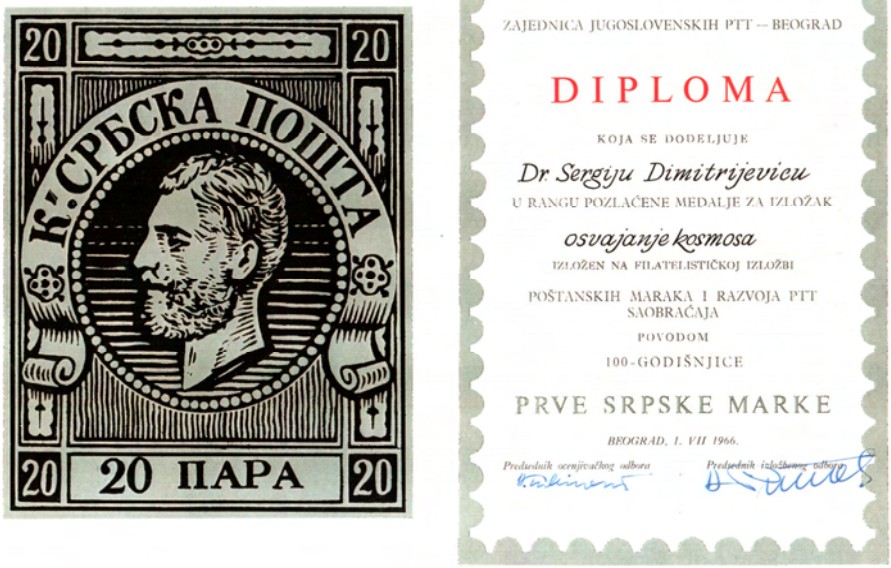
ПРЕДСЕДАТЕЛ НА ЖУРИТО:

7—15 АВГУСТ 1965

Слика 19: *Диплома о позлаћеној медаљи додељеној Сергију Димитријевићу на Првој филателистичкој изложби балканских земаља – БАЛКАНФИЛА – 1965, у Варни, за збирку „Космос“.*

На првој филателистичкој изложби балканских земаља, БАЛКАНФИЛА 1965, од 7. до 15. августа у Варни, Димитријевић добија позлаћену медаљу за збирку „Космос“ (сл. 19),[49] а 1. јула 1966, позлаћену медаљу за експонат

[49] «Балканфила Варна 1965», *Филателиста*, 1965, бр. 111.



Слика 20: *Диплома у рангу позлаћене медаље, додељена Сергију Димитријевићу за збирку „Освајање космоса“ у Београду 1. јула 1966, на изложби поводом 100-годишњице прве српске поштанске марке.*



Слика 21: *Диплома о посребреној бронзаној медаљи додељена Сергију Димитријевићу 8. јуна 1969, на Светској филателистичкој изложби у Софији за збирку „Космос, марке и коверти“.*

«С Прве балканске филателистичке изложбе у Варни», *Политика Експрес*, 9. септембар 1965.
«Балканфила – Варна 1965», *Филателен преглед*, бр. 6, 1965.
«Изложбе», *Филателиста*, бр. 110, 1965.

„Освајање космоса“ на изложби у Београду посвећеној стогодишњици прве поштанске марке у Србији (25. јун – 1. јул).[50] На свечаном завршетку Светске филателистичке изложбе у Софији, 8. јуна 1969. године, Сергије Димитријевић добија сребрну медаљу за збирку „Србија“ и посребрену за колекцију „Космос, марке и коверти“.[51] На БАЛКАНФИЛИ II, 1966. године у Истамбулу (3. до 11. септембра), и III у Букурешту, Сергије Димитријевић је био члан жирија.[52] У Истамбулу, две његове збирке, „Космос“ и „Србија“ излагане су ван конкуренције, а био је и представник Савеза филателиста Србије[53] а у Букурешту му је додељена плакета за успешну сарадњу.[54] Учествовао је и на Шестој републичкој филателистичкој изложби која је одржана у Земуну од 19. до 25. октобра 1971, у просторијама Дома ЈНА,[55] са експонатом „Космос – Човек на Месецу“. У *Недељним новостима* је написано да је то „једна од најбогатијих колекција у нас (и не само у нас) на тему „Човек и космос“.[56] У *Политици* је записано да се Сергије Димитријевић припрема за излагање и на БАЛКАНФИЛИ V у Софији 1975. године.[57]

Треба навести да је на БАЛКАНФИЛИ IX у Букурешту 1983, посребрену медаљу добио Хранислав Михајловић за колекцију „Космос у служби мира“, а бронзану Дарко Михајловић за експонат „Међународни астронаутички конгрес у Дубровнику 1978,“[58] а на БАЛКАНФИЛИ X Станка Новаковић бронзану за збирку „Ракетна пошта Југославије“.[59]

Сергије Димитријевић је на још један начин дао допринос српској филателији. За Дан републике 1996. године, изашла је серија од шест марака под именом „Средњовековни ковани новац на територији Југославије. Ликовна решења дали су академски сликари из Београда Драгољуб Кажић и Стјепан Филеки „користећи нумизматичке комаде из збирке др Сергија

[50]Д. Т., 1966, «Позлаћене плакете на филателистичкој изложби у Београду», *Политика*, 9. јул.

[51]„Резултати изложбе „Софија 69“; Једна позлаћена и две сребрне медаље за Југословене“, *Политика експрес*, 12. јули 1969.

[52]Миодраг Р. Вуковић, 1971, «Балканфила III“, *Политика*, 27. јун.

[53]Сергије Димитријевић, 1966, «Друга балканска филателистичка изложба», *Филателиста*, бр. 116, децембар, стр. 1.

«Балканфила II – Цариград 66“, *Политика Експрес*, 21. јул 1966.

[54]Миодраг Р. Вуковић, 1971, «Наше марке са туристичким мотивима; Успех на Балканфили», *Политика*, 18. јули, стр. 16.

[55]Б. Новаковић, 1971, «Шеста републичка изложба у Београду», *Политика експрес*, 22. октобар.

[56]«VI републичка изложба у Земуну“, *Недељне новости*, 17. октобар 1971.

[57]Дејан Тубиновић, 1975, «Пета «Балканфила» одржаће се у Софији», *Политика*, 3. септембар.

[58]„БАЛКАНФИЛА IX; Резултати и перспективе“, *Филателиста*, 1984, бр. 200, стр. 14.

[59]„Успех југословенских излагача на БАЛКАНФИЛИ X, Враце 1985“, *Филателиста*, 1986, бр. 202-203, стр. 12.

Димитријевића, научног сарадника из Београда“,[60] У *Мађар Соу* је уз податке о овим маркама написано: „Оригиналне примерке дао је др Сергије Димитријевић, познати београдски нумизматичар, који између осталог има у својој збирци 167 комада, који су у нумизматичкој литератури били непознати и ниједан није заступљен у познатој збирци Британ музеума.“[61]

У чланку „Једно пре подне међу београдским филателистима“[62] о ауторовом оцу је забележено:

„Историчар Сергије Димитријевић специјализовао се за збирке са ликовима космонаута из целог света. Већ је на Балканијади у Варни добио сребрну медаљу а у шали каже:

-Сакупљам космонауте док се не отвори директна линија за Месец. Тада ћу продати своје збирке и набавити карту за лет. Уколико дочекам, наравно.

Желео сам да део његове колекције буде изложен на Народној опсерваторији и заједно са тадашњим управником Луком Ч. Поповићем започео припреме за то 2001-2002. године. Догађаји који су следили прекинули су ову активност али сам мали део космичких марка и коверата поклонио Астрономском друштву „Нови Сад“ где су, захваљујући ангажовању Јарослава Францистија, стално изложене у Планетаријуму. Надам се да ће овај прилог деловати инспиративно на наше чланове и приказати им на одговарајући начин астрофилателију, и могућности које она пружа.

FILATELY AND ASTRONOMY

Astronomical topics in philately, with a special focus on astrophilately, commemorative postmarks and envelopes with astronomical themes, balloon and rocket mail in Yugoslavia, and cosmic-mail have been considered. Briefly is presented as well, the activity of Philatelic Society "Cosmos" from Zemun and collection of stamps "Conquest of the Cosmos" of Sergije Dimitrijević.

[60]Бранислав Новаковић, 1966, «Стари ковани новац на маркама Југославије», *Завичај*, год. III, бр. 73, стр. 29 (На марци од 0,30 дин. је новац Ђурђа I Балшића, 0,50 Стевана Томашевића, 0,60 Ђурђа Бранковића, 0,85 новац Љубљане, 2,00 Сплита и 5,00 цара Душана).

„Филателија“, *Политика експрес*, 6. октобар 1966.

„Пригодне марке у част Дана републике“, *Кекец*, бр. 42, октобар 1966.

[61]Imre Verner, “Uj postabélyegeink”, *Magyar Szo* (У породичној архиви, исечак без датума).

[62]Џавид Хусић, 1965, „Једно пре подне међу београдским филателистима; Чаробни и тајанствени албуми; Две најскупље домаће марке. Хоби и посебна страст, а у ствари тиха љубав. Међу сакупљачима највише лекара“, *Политика експрес*, 15. децембар.

Зборник радова конференције "Развој астрономије код Срба VI"
Београд, 22-26. април 2010,
уредник М. С. Димитријевић
Публ. Астр. друш. "Руђер Бошковић" бр. 10, 2011, 931-939

МОТИВИ АСТРОНОМСКИХ ПОЈАВА У ХРИШЋАНСКОЈ УМЕТНОСТИ

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Резиме: На многим хришћанским иконама налазе се мотиви који упућују на астрономско порекло (на пример иконографија светог Илије, прикази Архангела Михајла, описи Армагедона и Апокалипсе и слично). На основу мотива који су присутни у иконографији св. Илије, као и митова који су везани за њега, као што је помињање жртвовања бика, може се претпоставити да овај мит потиче из времена од четвртог до другог миленијума п.н.е., и да мотив ватре с неба вероватно указје на упад комете или неког другог објекта на Земљу, који је у том периоду изазвао катастрофу.

1. УВОД

Постоји велики број мотива у хришћанској уметности који указују на некадашње астрономско порекло. Често је случај да се временом они мењају, тако да касније добијају друга својства, мада бивају смештени на истом месту у композицији слике, па чак и обликом потсећају на оригинални астрономски мотив (звезду, комету и слично).

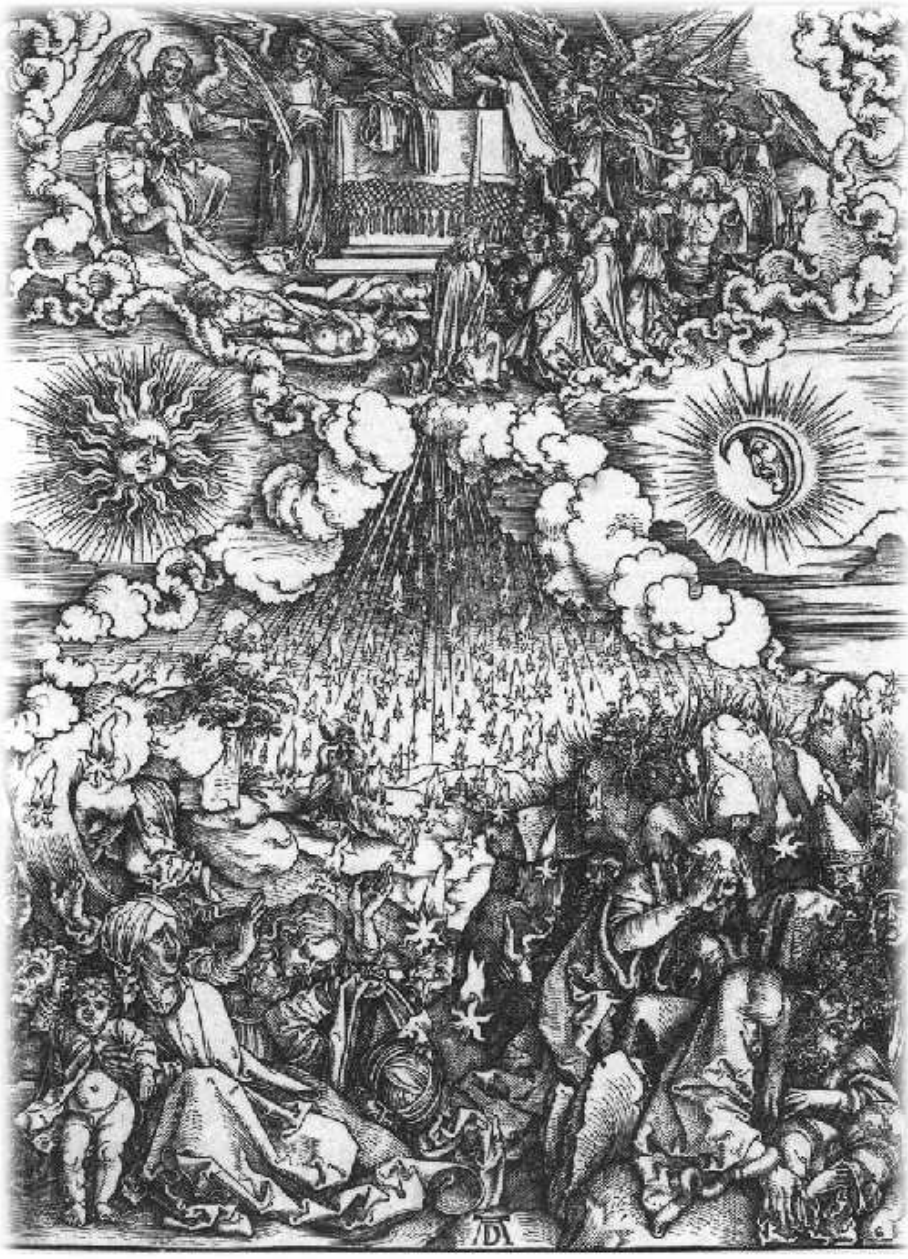
Чести астрономски мотиви су: комета, мач у облику ње, звезде (једна или више), представе сазвежђа (најчешће зодијачких као што су симболи бика, лава, овна, рибе). Такође значајан део мотива је везан за саму основу религије или религијске текстове. Тако постоје сличности са осталим Соларним религијама и култовима, па су главни датуми празника у хришћанству везани за еквинокције или равнодневнице. Такође, честе су представе Исуса у зодијачком кругу, као и његово директно представљање знаком за сазвежђе Риба (што је највероватније имало директну везу са тадашњим положајем тачке пролећне равнодневице која је у то време ушла у сазвежђе Риба). Исусово рођење је најавила звезда на истоку, која на пример на Ђотовој (Giotto di Bondone) фресци (сл. 1.) из 1302. године у капели Скровењи, у Падови има облик Халејеве комете коју је тада сликар видео.



Слика 1: *Ђотова (Giotto di Bondone) фреска из 1302. године у капели Скровењи (Scrovegni Chapel), у Падови, у Италији, са кометом у горњем централном делу слике. Фреска приказује долазак три мага која одају почаст новорођеном Христу (Schechner, 1997).*

2. ПРИКАЗИ УПАДА ОБЈЕКАТА СА НЕБА

У неким религијским текстовима се јављају очигледне аналогије са приказивањима астрономских догађаја, као на пример у тексту о коначној битци на Армагедону, где је до најфинијих детаља веома прецизно описан упад астероида, како се тамо каже: велике усијане камене стене која се зове Луцифер (у преводу са латинског - „онај који доноси светлост“, мада је то име синоним за Сатану или Ђавола) која на крају сравни све, са пропратним појавама, као што су метеорске кише (анђели који бацају усијано камење са неба), земљотреси, уздизање облака прашине који следи.



Слика 2: *Графика Албрехта Дирера "Отварање V и VI трубе из Апокалипсе" из 1498. године*[1] (Schechner, 1997).

[1]Потер Палмер Колекција, 1956.960., фотографија 1996, The Art Institute of Chicago



Слика 3: *Архангел Михаило убија Ђавола мачем у облику репа комете, представљени на икони из Сирије (Athnasiyu, 2002).*

Иначе, он се појављује и са другим називом „Звер“ у истом сегменту Новог Завета, где се за њега везује и знак 666 („знак звери“). Занимљиво је да се овај знак касније тумачи као број и ако се тај начин означавања цифара у Европи није користио све до једанаестог века, након што је у шестом веку доспео у арапске земље из Индије. Дакле, у Европи се користио систем римских означавања бројева, што би значило да би то било записано као VIVIVI, барем у верзијама Библије до дванаестог века, па самим тим таква ознака није могла бити тумачена као шесто шездесет шест. Како се чини, вероватно је „знак звери“ био уцртан, и по нечему је подсећао на то што се у данашњим верзијама Библије означава бројем „666“. С обзиром да је у овом поглављу Библије до детаља описана појава упада неког небеског тела, као и катастрофе која следи након таквог догађаја, вероватно да се овај знак може тумачити у том светлу. Дакле, сасвим је могуће да је ознака која је потсећала на „6“ заправо цртеж комете са главом (доњи део шестице) и репом (њен горњи део), а да су три шестице, заправо три њена дела, која су се виделе на небу пре ове катастрофе која је описана у причи о Армагедону (сл. 2). Можда се комета распала у три дела због плимског дејства Земљиног гравитационог поља на њу (као код пада Шумејкер-Леви комете на Јупитер која се при упаду поделила на двадесет и два). Постојање три дела, која су пала на различитим местима на Земљи, могло би да објасни разлог зашто је овај догађај оставио утисак на религије широм света.

Присуство комете види се и на представама Архангела Михаила, који се често приказује са кометом коју држи у руци уместо мача (видети сл. 3). Ово је један од типичних примера где се може видети како се на иконама из подручја ближих онима у којима је хришћанство оригинално настало могу видети астрономски мотиви (комета у овом случају), док се у каснијим периодима и удаљенијим областима они не виде (тако да остаје само облик обичног мача уместо комете).

3. СВ. ИЛИЈА

Очигледно је да на старијим иконама има више астрономских мотива него на новијим. Такође, на оним које су ближе самом настанку хришћанске религије (Блиски исток) очувало се више таквих мотива него што је то случај када су у питању друга подручја, где су често у иконографију уграђивани мотиви локалних митова и фолклора. Овакав пример се може видети на случају мотива везаних за светог Илију, који се на старијим иконама, и оним ближим подручју Блиског истока појављује у ватреној кочији попут грчко-римског бога Хелија, док се на пример код Словена везује само за грмљавину и назива се још и Илија Громовник.

Само име је настало од „Elijah“ или „Elias“, односно Хебрејског: אליהו, Eliyahu; Арапског: إلياس, Ilyās, у преводу значи „онај чије име (El-i Jahu) значи Јахве је Бог“ (енг. "Yahweh is God"). Потиче са подручја Израела из 9-тог века п.н.е., и по изговору звучи веома слично грчком богу Сунца Хелију

(„Helios“, „Helie“). Оно се, поред Старог завета, појављује у Хебрејској верзији Библије, Талмуду, Мисхнаху, а такође и у Новом завету и Курану.

Према Књизи Краљева, Елијах је подигнут из мртвих, донео је ватру са неба, и отишао у небо у својој кочији. По легенди, сазвао је 450 свештеника бога Баала и 400 свештеника Астаре, које је изазвао на опкладу око тога чији бог ће услишити молитву да донесе “ватру с неба”. Свештеници су се сложили, а као жртву за ову молитву су заклали младог бика. Након неуслишених молитви током дана за остале свештенике, ватра са неба је стигла тек увече, онако како је предвидео св. Илија.

Овде се могу уочити интересантни мотиви, као што су ватра с неба (која се може односити или на метеорски рој или упад негог већег тела), као и то да су као жртву приносили младог бика, што може указивати да је време из кога ово предање потиче, заправо оно када је пролећна равнодневица била у сазвежђу Бика (од краја четвртог до почетка другог миленијума п. н. е.). Веома је важно уочити сличност у осталим делима која је св. Илија чинио, са онима која су касније правили други. Тако, постоји велика сличност са Мојсијевим, што се касније појављују и код Исуса. Ако се узме у обзир да је у случају св. Илије жртва била бик, код Мојсија ован, док се код Исуса појављује риба, то може указивати да се прича везана за св. Илију одигравала у доба када је пролећна равнодневица била у сазвежђу Бика (временски период од четвртог па до другог миленијума п.н.е.), а прича о Мојсију када је она била у сазвежђу Овна (од почетка другог миленијума п. н. е. па до почетка нове ере), што у случају Исуса указује на доба сазвежђа Риба (од почетка нове ере). На основу тога, може се закључити да су почеци ове религије из ранијих времена од оних у којима се сматра да је Стари Завет писан (што се предпоставља да се десило негде између XVI и VI века п.н.е.). Такође то упућује да је у почетку ова религија била везана за култ Сунца, као и да су касније такву улогу преузимали други наследници, попут Мојсија и Исуса. Неки од мотива соларне религије су преживели и код Христа (рођење - на дан зимског солстиција, васкрснуће - око пролећне равнодневице, и сл.). Такође интересантно је да је датум који се везује за св. Илију у данашње време близу летњег солстиција.

4. ПРЕПИСИВАЊЕ МОТИВА

Ово преписивање у многоме потсећа на друге религије, које су преузимале мотиве предходних, само би их приписивали тренутно актуелном главном богу.

Леп пример је вавилонски бог Мардук који је преузео карактеристике предходног главног локалног божанства Бела. Бела су преузели (преписали) од Сумера, где се називао Енлил. Сумерски и акадски богови су били сврстани у тријаде, па је Енлил (акадски - Бел) био у тријади са Ан (акадски - Ану) и Енки (акадски - Еа), где је Енки заправо Мардуков отац, а Ан је најстарији бог и отац свих богова, злих духова и демона, као и бог годишњих

календара и краљева. Код сваког од њих може се приметити да су имали исте мотиве који се појављују код Мардука, само су временом избледели и мало променили форму, како би тренутни главни бог имао све најважније карактеристике.



Слика 4: *Свети Илија представљен на небу у својим ватреним кочијама попут приказа бога сунца Хелија, или Фаетона. На икони се види и ватрени плашт којим је по предању свети Илија ударио о земљу* (Athnasiyu, 2002).

Промене су настајале када доминацију једне цивилизације или народа замени нова. Сумерске ископине везане за најстаријег од ових богова Ана датирају бар 3000 година пре нове ере. Био је обожаван као "велики бик" који је касније одвојен у засебан митолошки ентитет: Небески Бик, кога је поседовао сам Ан (Hory et al., 1995). Ово на известан начин потсећа у приличној мери на мотиве који постоје код св. Илије, као и на слично временско лоцирање у доба када је тачка пролећне равнодневице била у сазвежђу Бика.

5. ЗАКЉУЧАК

Као што се и у другим митовима и религијама дешава, доминација нове религије одбаци или промени карактеристике предходне, и то најчешће тако што се најбитнији мотиви угради у нову или припишу тренутно актуелном богу, задрже се битни датуми тако да прослављају нешто везано за нову, а све сличности са ранијом се замагле тако што се посредно укључе у ту религију (што се може видети на примеру религија насталих око старих Сумера, Акађана, Вавилонаца, или на примеру многих соларних култова и религија).

Може се приметити да су овакви мотиви присутни и у Хришћанској религији. Поред мноштва преузимања из претходних религија, у Хришћанству се примећује и то да је оно еволуирало из неколико јеврејских, из разних периода, које су и саме уграђене у оквиру Старог Завета, почевши вероватно од оне везане за св. Илију (Елие – Хелије), преко Мојсија и неких других пророка, па све до Исуса.

То указује да је у основи религија, везаних за историју јеврејског народа, вероватно стари соларни култ, који је временом задржао неке мотиве које можемо и данас приметити, у нешто промењеној форми или значењу. Такође, поред сличности св. Илије са Хелијем, види се сличност са представом Фаетона, уз помињање ватрених кочија из којих удара огњеним плаштом по води, као и предсказивања доласка ватре с неба.

Ово може упућивати на везу са упадом комете или астероида, који се вероватно догодио у време када је тачка пролећне равнодневице била у сазвежђу Бика, ако се узме у обзир помињање жртвовања ове животиње при предсказивању доласка ватре с неба. То је у сагласности са другим истраживањима које указују на могуће постојање упада објекта из космоса, односно узрока катастрофе из времена старијег од 5000 година (Clube, 1995,. Clube & Napier, 1984, Clube & Napier, 1990, Steel, 1993, Bon et al. 2002, Masse et al. 2006, 2007, Scheffers et al. 2008).

Литература

Athnasiyu, M. H.: 2002, *Encyclopedia of Syrian icons "Damascus"*.
Bon, E., Ćirković, M. M, Milosavljević, I.: 2002, *Astronomische Nachrichten*, **323**, 579.
Clube, S. V. M.: 1995, *Vistas in Astronomy*, **39**, 673.
Clube, S. V. M. and Napier, W. M.: 1984, *Mon. Not. R. Astron. Soc.*, **211**, 953.
Clube, S. V. M. and Napier, W. M.: 1990, *The Cosmic Winter*, Basil Blackwell Ltd, Oxford.
Courtillot, V.: 1999, *Evolutionary Catastrophes*, Cambridge University Press, Cambridge.
Ćirković, M. M.: 2007, *International Journal of Astrobiology*, **6**, 325.
Hori, Y., Carlay, R., Mendelson, P. (eds.): 1995, *Britannica CD 2.0* , Encyclopedia Britannica. Inc.
Krupp E. C.: 1997, *Sky and Telescope*, **93**, 64.
Masse, W. B.: 2007. *The archeology and anthropology of Quaternary period cosmic impact In Comet/asteroid impacts and human society: An interdisciplinary approach*, edited by Bobrowsky P. T. and Rickman H. Berlin: Springer, 25.
Masse, W., Bryant, E., Gusiakov, V., Abbott, D., Rambolamana, G., Raza, H., Courty, M., Breger, D., Gerard-Little, P., Burckle, L.: 2006, *Holocene Indian Ocean Cosmic Impacts: The Megatsunami Chevron Evidence From Madagascar*, American Geophysical Union, Fall Meeting 2006, abstract #PP43B-1244.
Schechner S.: 1997, *Comets, Popular Culture and the Birth of Modern Cosmology*, Prinston University Press.
Scheffers, A., Kelletat, D., Scheffers, S. R., Abbott, D. H., Bryant, E. A.: 2008, *Zeitschrift für Geomorphologie*, **52**, 375
Steel, D.: 1993, *Rogue Asteroids and Doomsday Comets*, Wiley, New York.

ASTRONOMICAL MOTIVES IN CHRISTIAN ART

In the Christian iconography, there are motives that point to their astronomical origin (e.g. iconography of St. Elias, Archangel Michael, description of Armageddon and Apocalypse...). According to the motives that are present in stories and iconography of St. Elias, it is possible that this myth originated in much earlier times than the times when the Old Testament was written. Mentioning of the bull sacrificing could mean that it originated in the epoch from fourth to second millennium B. C., and that it is connected to the catastrophic event caused by fall of celestial body.

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Sv. 43 No. 43

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Astronomska opservatorija u Beogradu

AKTIVNOSTI I KRATKI SADRŽAJI RADOVA 1980–1990

Edited by O. Atanacković-Vukmanović and M. S. Dimitrijević



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FOREWORD

The aim of the present Volume "Astronomical Observatory in Belgrade — Activities and Abstracts of Papers (1980–1990)" is to offer a more complete insight into the fields and the contents of the recent researches performed at this Observatory.

Although of great diversity the Observatory's activity may be classified into the following research entities:

— Fundamental Astrometry
— Earth's Rotation
— Dynamical and Statistical Investigations on Celestial Bodies
— Astrophysical Researches.

The bulk of the Observatory's research activity consists in the acquisition of its own observational data, their processing and analysis as well as the forwarding of the obtained results to the international centres. Further activity consists in the theoretical research in astrometry, astrophysics and related fields (plasma physics, theoretical mechanics) along with the treatment of the observational data obtained from other astronomical centres.

The importance of research at the Belgrade Observatory arises from the fact that it is the only one in this country pursuing on a permanent basis observations of celestial bodies, necessary for the elaboration of stellar catalogues and astronomical ephemeris, for defining the celestial quasi-inertial coordinate frame, time and geographic coordinates determination, for the study of the Earth's rotation and for application in geodesy and geophysics. Multidisciplinary study of the variations in the Belgrade mean geographic coordinates is carried out conjointly with several institutes for geomagnetism, geophysics and seismology. Fundamental research performed at the Observatory in the astronomical spectroscopy finds its application in the physics and technology of plasma and its laboratory sources as well as in the physics and technology of thermonuclear fusion and the light sources.

Considerable part of the Observatory's researches is achieved through fruitful international cooperation. This is evidenced by many joint papers of our and foreign authors. In addition to direct cooperation, realized with a large number of domestic and foreign institutions, the Observatory is a member of several international services while participating in many research programmes under the auspices of the International Astronomical Union.

Among its key supports in the scientific and research activity is the Observatory's library, possessing the richest holdings of astronomical literature in the country: over 4.000 periodicals and 10.000 books.

The Observatory is the editor of *Bulletin de l'Observatoire Astronomique de Belgrade* (founded in 1936), dedicated to publishing the scientific articles and professional papers, and of *Publications de l'Observatoire Astronomique de Belgrade* (founded in 1947) containing chiefly monographs or conference proceedings. The exchange of these editions is effected with about 400 scientific institutions, more than 350 of them from abroad.

To provide a broader insight into the Observatory's interest subjects and activities presented herein is also a list of lectures and seminars having been held at the Observatory in the period 1980–1990.

Considering the thematic and phenomenological diversity of the Observatory's scientific and research activity, which is in steady growth, we hope that the publication thus arranged will, on one hand, furnish useful information to those interested in the current research pursued at this Observatory and, on the other, secure the necessary information to those wishing to better comprehend the development of astronomy on this soil.

Readers interested in more detailed survey of the development and of scientific activity of the Observatory since its foundation in 1887 to our days may refer to the "Publications de l'Observatoire astronomique de Belgrade" No. 36 — "The Hundred Years of Astronomical Observatory in Belgrade".

Editors

PREDGOVOR

Publikacija „Astronomska opservatorija u Beogradu — Aktivnosti i kratki sadržaji radova (1980–1990)" ima za cilj da pruži potpuniji uvid u oblasti i sadržaje najnovijih istraživanja vršenih na ovoj opservatoriji.

Iako vrlo raznovrsna, aktivnost na Opservatoriji se može grupisati u sledeće istraživačke celine:

— fundamentalna astrometrija
— Zemljina rotacija
— dinamička i statistička istraživanja nebeskih tela
— astrofizička istraživanja.

Najveći deo naučno-istraživačke aktivnosti Opservatorije čini prikupljanje sopstvenih posmatračkih podataka, njihova stručna i naučna obrada, kao i dostavljanje dobijenih rezultata medjunarodnim centrima. Ostalu aktivnost čine teorijska istraživanja u astrometriji, astrofizici i srodnim naučnim oblastima (fizici plazme, teorijskoj mehanici), kao i obrada posmatračkih podataka dobijenih iz drugih astronomskih centara.

O značaju rada Astronomske opservatorije govori činjenica da ona jedina u zemlji vrši stalna posmatranja nebeskih tela neophodna za sastavljanje zvezdanih kataloga i astronomskih efemerida, za definisanje nebeskog kvazi-inercijalnog koordinatnog sistema, za odredjivanje vremena i geografskih koordinata, za izučavanje Zemljine rotacije i primene u geodeziji i geofizici. Multidisciplinarna istraživanja promena srednjih geografskih koordinata Beograda vrše se zajedno sa više instituta iz oblasti geomagnetizma, geofizike i seizmologije. Fundamentalna istraživanja koja se na Opservatoriji vrše u oblasti astronomske spektroskopije nalaze primenu u fizici i tehnologiji plazme i njenih laboratorijskih izvora, kao i u fizici i tehnologiji termonuklearne fuzije i izvora svetlosti.

Značajan deo astronomskih istraživanja na Opservatoriji ostvaruje se u okviru plodne medjunarodne saradnje. O tome svedoči veliki broj zajedničkih radova domaćih i stranih autora. Pored neposredne saradnje koju ostvaruje sa velikim brojem ustanova u zemlji i inostranstvu, Opservatorija je član nekoliko medjunarodnih službi, a u okviru Medjunarodne astronomske unije učestvuje u više istraživačkih programa.

Jedan od značajnih oslonaca naučno-istraživačke aktivnosti je biblioteka Opservatorije, koja poseduje najbogatiji fond astronomske literature u zemlji: preko 4.000 naslova periodike i 10.000 knjiga.

Opservatorija izdaje *Bulletin de l'Observatoire astronomique de Belgrade* (osnovan 1936. godine) u kome se štampaju naučni i stručni radovi, i *Publications de l'Observatoire astronomique de Belgrade* (osnovane 1947. godine) koje sadrže monografije ili zbornike radova. Razmenu svojih izdanja Opservatorija vrši sa oko 400 naučnih institucija, od kojih sa više od 350 u inostranstvu.

Da bi se stekao širi uvid u interesovanja i aktivnosti na Opservatoriji u ovoj Publikaciji je dat i pregled predavanja i seminara održanih na Astronomskoj opservatoriji u periodu 1980–1990. godine.

S obzirom na tematsku i pojavnu raznovrsnost naučno-istraživačke aktivnosti Astronomske opservatorije, koja je u stalnom porastu, nadamo se da će ovako priredjena publikacija, s jedne strane, pružiti korisne informacije zainteresovanima za savremena istraživanja koja se vrše na Opservatoriji u Beogradu, a sa druge, obezbediti potrebne podatke onima koji žele da bolje sagledaju razvoj astronomije na ovom tlu.

Čitaocima koji su zainteresovani za detaljniji pregled razvoja i naučne aktivnosti Opservatorije od njenog osnivanja 1887. godine do danas preporučujemo Publikaciju br. 36 „Sto godina Astronomske opsevatorije u Beogradu".

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1. BIBLIOGRAPHY OF STELLAR CATALOGUES AND MAPS
1. BIBLIOGRAFIJA ZVEZDANIH KATALOGA I KARATA

B. M. Ševarlić, G. Teleki: *Katalozi paralaksi, sopstvenih kretanja i radijalnih brzina*, VII Kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Budva-Bečići, (1980), III-12.

B. Ševarlić, G. Teleki, Z. Knežević: *Bibliography of the photographic catalogues of star positions*, in G. Teleki, B. Ševarlić (eds.), *Epitome fundamentorum astronomiae, Pars II, "Photographic catalogues and charts of star positions"*, Publ. Obs. Astron. Belgrade **29** (1982), 71–97.

B. Ševarlić, G. Teleki, Z. Knežević: *Bibliography of stellar atlases, maps and charts*, in G. Teleki, B. Ševarlić (eds.), *Epitome fundamentorum astronomiae, Pars II, "Photographic catalogues and charts of star positions"*, Publ. Obs. Astron. Belgrade **29** (1982), 99–124.

B. M. Ševarlić, G. Teleki: *Epitome fundamentorum astronomiae III — Catalogues of Stellar Parallaxes, Proper Motions and Radial Velocities*, Hvar Obs. Bull. Suppl. **6** (1982) 1, 123–125.

O. Atanacković: *Le troisième volume d'Epitome fundamentorum astronomiae.* Bull. Inform. CDS **28** (1985), 15–16.

The plans for the third volume of the "Epitome fundamentorum astronomiae" are described. The volume deals with catalogs on radial velocities, parallaxes and proper motions.

G. Teleki, I. Pakvor: *Digital designations of catalogues and surveys of star positions (Series 1)*, Publ. Astron. Obs. Belgrade **140** (1989), 131–140.

Digital designations for first 60 catalogues and surveys of star positions are given. The designations contain 16 information groups with a total of 50 digits for observational catalogues and 10 groups with a total of 36 digits for other catalogues (derived, fundamental) and surveys.

B. Ševarlić, G. Teleki, O. Atanacković-Vukmanović, I. Pakvor: *Bibliography of catalogues and papers on parallaxes*, Publ. Obs. Astron. Belgrade **40** (1990), 79–128.

A comprehensive list of catalogues and articles on parallaxes, containing 763 bibliographical entries is given.

B. Ševarlić, G. Teleki, I. Pakvor, O. Atanacković-Vukmanović: *Bibliography of catalogues and papers on proper motions*, Publ. Obs. Astron. Belgrade **40** (1990), 129–238.

Bibliography of catalogues and articles on proper motions containing 1617 entries is given.

B. Ševarlić, G. Teleki, O. Atanacković-Vukmanović, I. Pakvor: *Bibliography of catalogues and papers on radial velocities*, Publ. Obs. Astron. Belgrade **40** (1990), 239–285.

Bibliography of catalogues and articles on radial velocities containing 686 entries is given.

2. DEVELOPMENT AND HISTORY OF ASTRONOMY
2. RAZVOJ I ISTORIJA ASTRONOMIJE

S. Sadžakov: *Influence of the progress in science and technology in astrometry*, Bull. Applied Math. (BAM), Budapest, **54** (1980), 85–90.

The accuracy of astromeric measurements has achieved a high degree. Astrometry is used today for the purpose of studying the nonuniformities in the Earth's rotation and in the Universal Time, as well as the terrestrial polar motion; attempts are done in order to notice movements of the continents, to investigate fine effects of various motions of the Earth. New directions in technology make the field of astrometric application more extensive, so that a new era in astrometric development begins which lies in the field of fundamental astrometry.

M. S. Dimitrijević: *Milutin Milanković and an attempt for explaining Michelson-Morley's experiment*, Dijalektika **15** (3–4), Beograd, (1980).

Milutin Milanković, famous astronomer, mathematician and geophysicist, whose name bears a crater on the invisible side of the Moon, the first Serbian doctor of technical sciences, of same age as Einstein, the first lecturer of the Relativity theory at the University of Beograd, did not accept immediately some of the Einstein's ideas. He published two papers in which he tried to explain the negative result of the Michelson-Morley's experiment in the framework of the classical mechanics, considering that relativistic interpretation can be replaced "without a collision with the experience" starting with another set of assumptions. These two papers are presented and reviewed.

G. Teleki: *O astronomskoj aktivnosti u periodu 1660–1880*, VII kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Budva-Bečići, (1980), III-12.

G. Teleki: *Astronomija danas i sutra — u svetu i kod nas*, VII kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Budva-Bečići, (1980), III-12.

G. Teleki: *An outlook on future development of the fundamental astrometry*, Zbornik "Zadachi sovremennoj astrometrii v sozdanii inertsial'noj sistemy koordinat", Izd. "Fan", Tashkent, (1981), 362–367.

S. Sadžakov: *Organization of specialized education in our country and the position of astronomy in it*, Publ. Obs. Astron. Sarajevo, **1** (1981), 51–57.

The topic is the idea and the direction of changes in pedagogy and education in this country. Formation of an educational system as a unique system of permanent education which is in accordance with the necessities of our society is mentioned as well.

G. M. Popović: *Aktivnost astronomske opservatorije u Beogradu od 1972. godine do 1981. godine na projektu podizanja visinske astronomske stanice*, Publ. Obs. Astron. Belgrade **31** (1981), 7.

G. Teleki: *Csillagaszat az egyes délszláv területeken a XIX. Század végén és a XX. század elején*, Vasi Szemle, Szombathely, XXXV, évf. (1981), 550.

G. Teleki: *On the instrumentation-observational development of astrometry in Yugoslavia*, Hvar Obs. Bull. Suppl. **6** (1982) 1, 91–97.

Proceeding from the present-day tendencies in astrometry, prospective development trends of astrometry in Yugoslavia, bearings upon instrumentation and observation, are analysed. With regard to the material, technical and manpower capabilities, the continuations with the already existing instruments is suggested, with the proviso, however, their programmes are strictly selected. Yugoslavia should join, in the years ahead, the VLBI stations network and the Hipparcos programme.

G. Teleki: *Astrometrical activity in the period 1600 to 1880*, "Compendium in Astronomy", D. Reidel Publ. Comp., Dordrecht-Boston-London, (1982), 23.

M. Protić, V. Protić-Benišek: *Milutin Milanković i astronomska opservatorija u Beogradu (Milutin Milankovitch et l'Observatoire astronomique à Belgrade)*, Zbornik radova "Život i delo Milutina Milankovića 1879–1979", Naučni skupovi Srpske akademije nauka i umetnosti, knj. XII, Predsedništvo, knj. **3** (1982), 181–190.

Le nom du Prof. M. Milankovitch est très étroitement lié aux tentatives et aux efforts entrepris pour élever à Belgrade un Observatoire astronomique moderne, dont l'équipement coûteux a été commandé et déjà livré.

G. Teleki: *Kozmikus asztrometria: a Hipparcos és Tychotervek*, Csillagászati Evkönyv 1984, Gondolat, Budapest, (1983), 169.

G. Teleki: *Kozmikus asztrometria*, Letnja škola mađarskih astronoma, Višegrad, (1983), 15.

G. Teleki: *A fundamentalis rendszer problémái*, Letnja škola mađarskih astronoma, Višegrad (1983), 3.

M. S. Dimitrijević: *Milutin Milanković i pokušaj objašnjenja Majkelson-Morlijevog ogleda*, Matematičko-fizički list **140** (1) (1984/85), 5.

V. Protić-Benišek: *Astronomical Observatory in Belgrade during 1941–1945*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985).

M. S. Dimitrijević, A. Tomić: *Radovan Danić — popularizator astronomije: I — Štampani radovi*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 41.

A. Tomić, M. S. Dimitrijević: *Radovan Danić — popularizator astronomije: II — Predavanja i kursevi*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 47.

G. M. Popović: *Prilog pregledu astronomskih izraza s kraja 18. stoleća u slavenoserbskom jeziku*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 111.

V. Trajkovska: *A note on Copernicus from 1837*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 127.

This paper contains description of proposal dating from 1837 to build a monument to N. Copernicus.

Dj. Teleki, O. Atanacković: *Rast znanja o astronomskoj refrakciji*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 151–155.

S. Sadžakov, M. Dačić: *Istorijski razvoj zvezdanih kataloga u svetu i kod nas*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 181.

V. Kršljanin: *Contemporary cosmology and philosophy (Some aspects of relationships and possibilities of overcoming the present difficulties)*, Publ. Obs. Astron. Belgrade **33** (1985), 107.

Experimentally proved and uncontrovertable part of contemporary cosmological theories is considered in the feed-back with the philosophical principles, especially with the principles of materialistic dialectics. A survey is presented of ideas and facts which are, according to the author, most relevant for this relation (definition of the subject of cosmology, relation of cosmology to other fundamental fields of physics; relation of the scientific cosmology to the old prejudiced ideas, especially in connection with infinity; vulgar-materialistic superficiality and creationistic speculations).

Most attention is paid to some latest theories and results (instability of proton; inapplicability of energodominacy to actual polarisation of vacuum, which resulted in de Sitter-Starobinsky solution without initial singularity)

which, together with heuristic philosophical principles, served as the basis for suggesting the solutions of some problems and for the possibility to consider relations of cosmology and philosophy more systematically.

S. Ninković: *On Astrophysics Teaching in the Secondary Schools*, Publ. Obs. Astron. Belgrade, **33** (1985), 116.

The author presents his own three-year-long experience in astrophysics teaching at a Belgrade secondary school. Special attention is paid to the interest expressed by pupils in this subject and, their, in recent time, increased interest in performing their professional praxis in the field of astrophysics.

G. Teleki: *Growth of the knowledge of stellar positions*, Bull. Obs. Astron. Belgrade **135** (1985), 40–44.

An analysis is performed of the growth of the number of catalogues of star positions, the number of the catalogue positions, as well as the accuracy of the observational and fundamental catalogues. One of the conclusions is that the accuracy has been increasing faster than the number of catalogue positions and also faster than the number of the stars in the fundamental catalogues (FC-NFK-FK3-FK4 series).

G. Teleki: *Bibliography of papers of the Belgrade Astronomical Observatory research associates published in the period 1980–1983*, Bull. Obs. Astron. Belgrade **135** (1985), 64–70.

In the four years period 1980–1983 the researching results of the present and retired associates of the Belgrade Astronomical Observatory were published under 205 titles (articles, notes, abstracts, observations data) in a number domestic and foreign periodicals and editions.

G. Teleki: *A Kozmikus Csillagászat Fejlődése*, Fizikai Szemle, Budapest, (1986), 129.

G. Teleki: *The need for better co-operation and intercomparison in fundamental astrometry*, in "Astrometric Techniques", H. K. Eichhorn and R. J. Leacock (eds.), (1986), 749–755.

The present status and practice in the fundamental astrometry are analysed, and relying upon the findings the author suggests the organization of an international action aimed at achieving better co-operation in the star position observations and celestial reference system determinations, as well as performing the intercomparison of the different techniques and methods.

M. Djokić: *How the Observatory of the High School in Beograd was founded*, "Vasiona", Revue d'Astronomie, **8** (1987), 3–7.

The history of the actions lead by Milan Nedeljković from 1887 to 1891 which resulted by the foundation of the Astronomical and Meteorological observatory in Beograd is presented.

M. Djokić: *How the instruments for the Observatory of the High School and the University of Belgrade were obtained*, "Vasiona", Revue d'Astronomie **8** (1987), 91–95.

It is described how the astronomical instruments of the Belgrade High School and University observatory were obtained from reparation after First world war.

V. Protitch-Benishek: *Centenary of the Astronomical observatory in Belgrade*, Vasiona, **3–4** (1987), 64–70.

The history of the Astronomical observatory in Belgrade is presented.

G. Teleki: *Bibliography of papers of the Belgrade Astronomical observatory research associates published in the period 1984–1986*, Bull. Obs. Astron. Belgrade **137** (1987), 91–98.

Bibliography of papers of the Belgrade astronomical observatory research associates published in the period 1984–1986 is presented and analyzed.

S. Tolchel'nikova-Murri, S. Sadžakov, M. Dačić, Z. Cvetković: *The present situation with absolute methods of observations in fundamental astronomy*, Colloq. **100** IAU, Beograd, (1987).

M. S. Dimitrijević: *II workshop: Astrophysics in Yugoslavia*, Bull. Obs. Astron. Belgrade **139** (1988), 72.

M. Djokić: *Belgrade University observatory between 1924 and 1926*, IX Nacionalna konferencija astronoma Jugoslavije, Zbornik rezimea, Sarajevo, (1988), 42.

The data concerning the Observatory of Belgrade University between 1924 and 1926 are presented. That time is characterised by the division of the Observatory between an astronomical and meteorological one as well as by the constituting of the Astronomical Observatory as a separate establishment.

M. B. Protitch, V. Protitch-Benishek: *Data revision of the Babylonian and some Arabian lunar and solar eclipses used in the Newcomb's researches*, IX Nacionalna konferencija astronoma Jugoslavije, Sarajevo, (1988).

On the basis of Ptolomy's original manuscripts concerning Babilonian-Hellenic observations of lunar eclipses and analysing some Arabian notes about solar and lunar eclipses — for which S. Newcomb determined considerable deviations from the appropriate theory — the re-analysis of his results and conclusions was undertaken. The results of ancient data revision are also based on Newcomb's alternative presumption that such discrepancies are caused by one or more unknown long-term inequalities in the motion of the Moon. A quantitative result of analyse of ancient eclipse observations unambiguously indicates that these observations are, by no means, to be rejected. Of course, if they are interpreted in an appropriate way.

M. Mitrović, J. Arsenijević, I. J. Pakvor: *1987 — the hundredth year of Belgrade astronomical observatory life time*, Publ. Astron. Obs. Beograd **36** (1989), 13–22, (srpskohrvatski).

The activities concerning hundred years anniversary celebration are presented.

B. Ševarlić, J. Arsenijević: *One hundred years of activity of Belgrade Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 25–37, (srpskohrvatski).

The short report about the foundation and scientific activity of Belgrade Astronomical Observatory during one hundred years of its life is presented.

R. Grujić: *Latitude group of Belgrade Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 41–44, (srpskohrvatski).

A short review on the work on the geographic latitude determination for Belgrade from the begining (in 1947) until nowadays is given. An information on the programme of latitude derivation resulted from the changes done in the framework of the service itself, as well as in the framework of the IAU (MERIT) is given. It is also given another information concerning the state in the service at the moment of introducing of the new technic in the world. Furthermore, we inform on the results of comparison programme observations aimed at the declination determination for zenith stars. The results are positive and in such a way they indicate that such instruments should be also used in the future for these purposes, both in Yugoslavia and throughout the world. A short rewiew on the development of the service viewed in the light of the accuracy of the latitude determination and of the declination determination for zenith stars, as well as one on the service direction in the course of time, is presented.

G. M. Popović, D. J. Zulević: *Double stars Group*, Publ. Astron. Obs. Belgrade **36** (1989), 51–62, (srpskohrvatski).

S. Sadžakov: *Work on Meridian Circle of the Belgrade Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 63–71, (srpskohrvatski).

The review of the activity on the Meridian Circle of the Belgrade Astronomical Observatory is presented. The instrument rectification, the results of the investigation of vital parts of the instrument, the first observations as well as the results of the observations during last twenty years are described. Also, some data about the members of the group and their scientific results are given. The future work is mentioned too.

M. Mijatov, V. Trajkovska: *Activity of the Absolute Declination Group*, Publ. Astron. Obs. Belgrade **36** (1989), 71–81, (srpskohrvatski).

In this paper is presented the activity of the Group of Absolute Declinations since its formation in 1960 until nowadays. The main task of the group has been observation with the Large Vertical Circle. This instrument was received

from Germany after the first World War as a result of the war reparations, but because of lack of money it was not mounted before 1960. However, the regular observations were initiated as late as in 1976 due to serious problems, at first with the pavilion, itself, and later on because of technical disadvantages of the instrument. The instrument was prepared for observations as late as after a detailed reconstruction done by the chief engineer of Pulkovo Observatory, D. S. Usanov in late 1974. The reconstruction comprised changes concerning the functioning of the vertical axis and of the horizontal one. During 1976–1980 an absolute catalogue comparising 308 northern stars (declination zone $+65°$–$+90°$) from FK4 and BS catalogues was compiled. All the stars were observed both in the upper and lower culminations. The average number of observations per star was 10. The analysis is still being done. During the period 1983–1985 213 stars from FK4 catalogue were observed (declination zone $-30°$–$+90°$) by use of the absolute method. A major part of the observations was carried out in the Küstner series. All the stars satisfying $\delta > +60°$ were observed in the lower culmination, too. The average number of observations per star was 8. The analysis is still being done. Since 1982 meridian observations of the major and minor planets have been done by use of the quasiabsolute method and of the relative one. In addition to the observations an extended refraction research has been done. This kind of research has been mostly done by Dr G. Teleki, who was Chairman of the Working Group for the Study of Astronomical Refraction of Commission 8 of the IAU since its foundation in 1971 until his death in early 1987. Two parts of a multivolume edition of the bibliography of star catalogues "Epitome fundamentorum astronomiae" have been published and the third part is in preparation. In addition to the mentioned work the members of the group have dealt with testing of the instruments and equipment, with the problems of latitude and climatology, as well as with history, development and teaching astronomy. In the future the observations will be continued and in addition to the already existing ones other actual programmes of international importance, which can be done with the instrument, will be accepted.

I. J. Pakvor: *Activity of absolute right ascensions division*, Publ. Astron. Obs. Beograd **36** (1989), 83–87, (srpskohrvatski).

A complete history of the activity of Absolute Right Ascensions Division is given. Development of the Division is very close to the development of the Large Transit Instrument and its investigations. One of the most important point of this development is the foundation of vacuum meridian marks, an international recognized contribution.

V. Protić-Benišek: *Fifty years of activity: minor planets, comets and sattelites department of Belgrade Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 89–96, (srpskohrvatski).

This paper presents a review of the scientific and observational work in the Department of minor planets, comets and sattelites since 1935 till today at the Astronomical Observatory of Belgrade.

J. Arsenijević: *Astrophysical Group of the Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 97–101, (srpskohrvatski).

The activity of Astrophysical Group since its foundation in 1960. is briefly presented. Its scientific work has been covering three topics: physics of variable stars, solar physics and spectroscopy of astrophysical plasma. Short note about the future development has been given.

D. Petrović, J. Arsenijević: *The Observatory library*, Publ. Obs. Astron. Belgrade **36** (1989), 103–106, (srpskohrvatski).

The main data about the Observatory libary, the richest astronomical library in Yugoslavia, are presented.

M. Djokić: *How the Observatory of the High School in Belgrade was founded*, Publ. Obs. Astron. Belgrade **36** (1986), 143–151, (srpskohrvatski).

The foundation of the Belgrade High School Observatory is described and some characteristic archives' documents are presented.

V. Protić-Benišek, M. Djokić: *Dr V. V. Michkovitch and his election at the Belgrade faculty of philosophy in 1925*, Publ. Obs. Astron. Belgrade **36** (1989), 153–158.

Professor and Academician Dr. Vojislav V. Michkovitch was born in Fužine, Croatia, on 18th January 1892. The following year his parents moved to Serbia, where he graduated from high school in 1910 (Novi Sad) and took up his studies in Budapest and Göttingen. At the end of World War I, as one of the survived wariors of famous Serbian "students battalion", was sent to France where he graduated studies in astronomy in 1919 and obtained the position of an assistant of the Observatory in Marseille. Than, in 1922 he joined the staff of the Nice Observatory. He got Doctor's degree in 1924 on the thesis "Etudes de Statistique stellaire" (Study on Stellar Statistics). In 1926 he came back to Yugoslavia and was appointed professor of Practical Astronomy at the University of Belgrade. By his initiative a modern Astronomical observatory was erected in Belgrade in 1932. In 1939 he became elected regular member of the Serbian Academy of Sciences (from 1929 he was corresponding member), and soon, the General Secretary of this institution. He had become the member of International Astronomical Union in 1935. During World War II professor Mishkovitch was imprisoned by Gestapo.

His principal concerns were minor planets, especially the identifications of those unsufficient observed. In that scope he published a good number of studies and articles. He was a founder of the Astronumerical Institute of Serbian Academy of Sciences, Also, he initiated and was editor-in-chief for a lot of scientific publications. Among them worth to mention are: "Annuaire", which cover ephemeris of 240 stars for International Time Service, "Bulletin de l'Observatoire Astronomique de Belgrade", and others. In his final years he turned his attention to the history of astronomy and his several studies in this field were published by Serbian Academy of Sciences. He died on 25 November 1976 at the age of 85.

I. J. Pakvor: *An episode from the history of the foundation of modern astronomical observatory in Belgrade*, Publ. Astron. Obs. Beograd **36** (1989), 159–165, (srpskohrvatski).

Sixty years ago an attempt was done to build modern Astronomical Observatory outside of urban locality, on the mountain Fruška gora, 70 kms north-west form Belgrade, at place called Zmajevac. A group of eminent professors from Belgrade University entered into negotiations with local authorites, unfortunately without positive solution.

G. M. Popović: *From the observer's notebook of P. Djurković*, Publ. Obs. Astron. Belgrade **36** (1989), 165–176, (srpskohrvatski).

M. Djokić: *The archives' documents about Belgrade High School and University Observatory in the period 1887–1924*, Publ. Obs. Astron. Belgrade **36** (1989), 177–326, (srpskohrvatski).

The selection of archives documents about Belgrade High School and University Observatory from time of its foundation in the 1887 until 1924 — the year of dividing the Observatory into Astronomical Observatory and Meteorological Observatory — were presented.

G. Ivanišević, N. Djokić: *Bibliography of the papers published by Belgrade Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 333–397, (srpskohrvatski).

M. S. Dimitrijević, A. Kubičela, J. Arsenijević, V. Kršljanin: *Position of astrophysics at the Astronomical observatory in Belgrade*, III Seminar „Astrofizika u Jugoslaviji", Zagreb, (1989), 17.

S. Sadžakov, S. A. Tolchel'nikova-Murri: *A contribution to the problem of the choice of observational methodics and international cooperation in fundamental astrometry*, Problemy postroeniya koordinatniykh sistem v astronomii, GAO AN SSSR, Leningrad, (1989), 79–87.

In order to make the international cooperation in fundamental astrometry efficient it is necessary to solve the two following problems:

1. To explain the role of absolute methods of reference frame formation as means to divide the observed relative motions of celestial bodies into the owen ones, existing for various observed bodies, and parallactic ones due to the displacements of terrestrial reference objects and of the Earth. This will enable an essential simplification in solving the problem of relationship among various reference frames including also the new ones based on space and radio observations. 2. To extend the compilation methodics of the fundamental catalogue on the basis of a suitable planning of observations for the following epoch. Observations of such kind can be organised on the basis of optical services of terrestrial rotation.

V. Protitch-Benishek: *Astronomical photography in Serbia*, Publ. SANU, No. 69, (1990).

3. INSTRUMENTS AND DATA REDUCTION METHODS
3. INSTRUMENTI I METODI OBRADE PODATAKA

T. Sotirović, M. S. Dimitrijević: *Problem analize i sinteze trakastih vodova*, 23 ETAN u pomorstvu, Zadar 1981, 272.

Lj. Varga, V. Protić-Benišek: *Transistorised servo-regulator of the Askania astrograph drive mechanism of the Belgrade Observatory*, Proceedings of the National Conference of Yugoslav astronomers, Publ. Obs. Astron. Sarajevo **1** (1981), 153–155.

After one serious defect of the centrifugal servo-regulator in 1977, it was decided to remove it and to equip the instrument with DC electromotor drive with a transistorized control system. During 1977 an experimental drive was constructed. It was found that this drive system had a satisfactory stability over long time intervals. This is important in view of the instrument having constructive deficiencies, especially concerning its balance system.

L. A. Mitić: *Investigation of the level division inequalities with an extrafocally adjusted collimator*, Bull. Obs. Astron. Belgrade **131** (1981), 9–12.

Graduation of two astronomical 1″ levels has been investigated from close distance (4.7 m) with a collimator (8/100 cm) whose micrometer was adjusted extrafocally by 32 cm. High precision of settings of the level graduation lines (mean error of settings ranged from ±0.″0020 to ±0.″0014) permitted the inequalities in the division values to be firmly established. These inequalities, however, rarely exceed ±0.″02.

V. Trajkovska: *An analysis of the division errors of the Belgrade Large Meridian instrument*, Publ. Astron. Obs. Sarajevo **1** (1981), 85.

An account is given of the results of investigation of the circle division errors of the Belgrade Observatory Large Meridian instrument. By the linear correlation method, interrelation of the circle corrections, found from the investigations carried out in 1966, 1968 and 1977, is established. In employing the spectral analysis method (Blackman-Tukey method) a periodic component with 2° period has been identified, supposed to be a consequence of the way of circle manufacturing.

A. Kubičela, M. Rakić: *Fotodioda PS-100-30 kao senzor položaja u astronomiji*, Saopšteno na VI Nacionalnoj konferenciji jugoslovenskih astronoma, Hvar, 1983.

Z. Stančić, M. Mijatov: *Nova određivanja kolimacije i savijanja na VMK AO u Beogradu*, VIII Kongres MFAJ i VIII Nacionalna Konf., Priština, (1985).

Dj. Bozhichkovich: *An Efficient Method of Determining and Removing the Inclination of the Microscope-Micrometers*, Astron. Tsirk. No. **1395** (1985), 4–5.

The use of plane-parallel glass is suggested for determining and removing the inclination of the microscope-micrometers.

A. Kubičela, M. Rakić: *Photodiode PS-100-30 as a position sensor in astronomy*, Publ. Obs. Astron. Belgrade **33** (1985), 23.

Position-sensing photodiode PS-100-30 has been preliminarily tested as the position encoder at a spectrogram measuring machine. It has been found that it would be necessary to keep determing the calibration constants as well as some systematic corrections depending on the position. Only taking care of such precautions the micrometer accuracy might be achieved.

V. Trajkovska: *Investigation of the graduation error of the Belgrade Meridian Circle*, Bull. Obs. Astron. Belgrade **136** (1986), 126.

Account is given of the organization and analysis of investigation of the graduation of the Belgrade Meridian Circle performed in 1977. Measurements are made at half-degree spacing, Bruns' method having been applied. Inquiry is made for possible temperature effects on the measurements.

D. Olević, S. Šegan and R. Pavlović: *Accuracy of the astrographic positions obtained with the Belgrade short-focus astrograph*, Bull. Obs. Astron. Belgrade **136** (1986), 36–39.

By analyzing astrographic position obtained with the Belgrade short-focus astrograph (Zeiss, $D = 16\,\mathrm{cm}$, $F = 80\,\mathrm{cm}$) the following has been estabilshed: a) Higher accuracy is reached by making reduction according to Terner's method involving 3 coefficients ($T(3)$) than the one associated with the reduction of Terner's equations involving 6 coefficients ($T(6)$); b) Considerably higher accuracy is reached in declination $|\Delta\delta| = 0''.3 \pm 0''.3$ in comparison with the one in right ascension $|\Delta\alpha| = 0''.7 \pm 0''.7$, attributable, in the authors' opinion, to defects in the measuring engine; c) Chief prerequisite for expecting optimum results lies in such a selection of reference stars that the object is placed not beyond 43 arc minute from their gravity centre, and d) The plate ought to be measured in two positions differing by 180°.

Z. Stančić, M. Mijatov: *Variations of collimation and flexure of the Belgrade Large Meridian Circle under the daytime conditions*, Bull. Obs. Astron. Belgrade **137** (1987), 85–90.

Results of the laboratory examination of the collimation and flexure constants of the Belgrade Large Meridian Circle (LMC) in the periods 1977–1980 and 1984–1985 are presented. Thereby are established: significant effects of the medium in which the instrument is placed; significant systematic differences in the measurements made at different hours of the day; significant seasonal variations; a difference between the laboratory evaluations of these quantities and their values resulting from the regular star observations; and a difference between the values obtained in the two periods. The measuring accuracy in the second period was twice better than the one in the first period.

B. Jovanović: *An approximation of tabulated function*, Publications de l'Institut Mathématique, Nouvelle série, tome **41** (**55**) (1987), 143–148.

Using a recurrent approach a method for approximate analytical representation of tabulated function as the sum of linear function, harmonics and

pairs of exponential functions is derived. The method is demonstrated by two examples.

B. Jovanović: *An analytical representation of ephemeris data*, Celestial Mechanics **45** (1989), 317–320, Kluwer Academic Publishers.

An algebraic method for the resolution of tabulated function into a class of elementary functions is examined on the high precision ephemeris data from the JPL DE 200.

S. Sadžakov: *Behaviour of second levels in the field of horizontal temperature gradients*, Bull. Obs. Astron. Belgrade **140** (1989), 31–36.

On the basis of level examinations, done in a laboratory and during star observations, a nonnegligible temperature influence on the measuring results is found. For practical purposes, such as reductions of observational materials, expressions are proposed which should be taken into account in coordinate derivations of observed celestial bodies and, in our case, in the derivation of the geographic latitude.

S. Sadžakov: *Behaviour of levels in the conditions of asymmetrical heating*, Bull. Obs. Astron. Belgrade **142** (1990), 79–81.

The subject of the paper is the earlier and present importance of second level examinations. The data of a general analysis are presented. They indicate net only some problems of second levels, but also give informations on level triers whose properties are weakly known at present.

4. ASTROMETRY
4. ASTROMETRIJA

4.1. Large Meridian Circle
4.1. Veliki meridijanski krug

4.1.1. *Determination of Star Positions and Proper Motions*
4.1.1. *Određivanje položaja i sopstvenih kretanja zvezda*

M. Dačić, K. G. Gnevisheva: *Preliminary results of an investigation of the declination system of the Belgrade Observatory Meridian Circle*, Izv. GAO AN SSSR Pulkove **197** (1980), 40–42.

The declination system of the meridian circle in Belgrade was obtained from twenty two series of observations of fundamental stars with declinations from $-25°$ to $+90°$ and including lower culminations to 65°. The systematic errors $\Delta\delta_\delta$ are due mainly to the horizontal flexure of the instrument which during some rights is as large as $2''$–$3''$. Residuals of the observed declinations from those of the fundamental catalogue on the average have a total amplitude of about $0''.5$. The position of the instrument (circle-east, circle-west) does not significantly affect the system of the instrument.

S. Sadžakov. G. Kosin, V. A. Fomin: *An estimation of proper motions of stars of the compiled catalogue of latitude stars and AGK3*, Izv. GAO AN SSSR Pulkove **197** (1980), 12–16.

On the basis of a comparison with ILS data (observations made during 1899–1972) the $\Delta\mu_\alpha$ systematic errors (Table 3) were derived for proper motions of the compiled catalogue of latitude stars and AGK3. The data in the table are given as 10 year proper motions in $0''.001$.

S. Sadžakov, D. Šaletić, M. Dačić: *Properties of the NPZT star catalogue*, VII Kongres MFAJ i V Nacionalna Konf., Bečići, (1980).

S. Sadžakov, M. Dačić, D. Šaletić: *Programme of observations of the catalogue of double and Pulkovo stars with the Belgrade Large Meridian Circle*, VII Kongres MFAJ i V Nacionalna Konf., Bečići, (1980).

S. Sadžakov, D. Šaletić, M. Dačić: *An examination of $\Delta\delta_\alpha$ type systematic errors for the preliminary Belgrade catalogue of NPZT programme stars*, Trudy 21 Astrometr. Konf. SSSR, Tashkent, (1981), 157–160.

The Preliminary Star Position Catalogue has resulted from observations performed with the Large Meridian Circle of Belgrade Observatory during 1972–1978. It is compared with KŠZ, SKŠZ, AGK3 and with Yasuda's preliminary catalogue. On the basis of the obtained results existence of systematic errors in the preliminary Belgrade catalogue, as well as in the PZT latitude observations of various observatories in the northern hemisphere, is apparent.

S. Sadžakov, V. A. Fomin: *On the Belgrade catalogue of the NPZT stars*, Astr. Cirk. AN SSSR, Moskva, **1194** (1981), 7–8.

A survey of the works performed for the NPZT Catalogue is given. The root-mean-square error of a single observation is $\varepsilon_\alpha \cos\delta = \pm 0^s.038$ and $\varepsilon_\delta = \pm 0''.26$. The root-mean-square error of position is $\pm 0^s.015$ and $\pm 0''.10$. The mean observational epoch is 1977.0 and 1976.8.

S. Sadžakov, D. Šaletić, M. Dačić: *Catalogue of NPZT programme stars*, Publ. Obs. Astron. Belgrade **30** (1981), 1–88.

The catalogue of NPZT stars is obtained on the basis of the observational material compiled by use of the Meridian Circle of Belgrade Astronomical Observatory during 1973–1980. It contains 1838 stars with magnitudes $6.5 \leq m \leq 8.5$. The mean epoch of observations is 1977.02 in α and 1978.78 in δ. The rms-error of the right ascension $\varepsilon_\alpha \cos\delta$ is $\pm 0^s.030$ and of declination ε_δ is $\pm 0''.26$. Comparison with the FK4 of about 340 stars yields an error in α of $\pm 0^s.015$ and in δ of $\pm 0''.14$.

S. Sadžakov, D. Šaletić, M. Dačić, V. Trajkovska: *Characteristics of the preliminary results obtained in elaborating the catalogue of NPZT stars*, Publ. Obs. Astron. Sarajevo **1** (1981), 167–172.

Results of the comparison are given of the right ascension and declination of fundamental stars, as obtained from observations undertaken within the elab-

oration of the catalogue of NPZT stars, with the corresponding coordinates in the FK4.

In addition the comparison is accomplished of the coordinates of the programme stars, obtained in the preliminary catalogue of NPZT stars, with those obtained at Moscow, Hamburg and Richmond latitude stations.

The results obtained reveal that the systematic difference of coordinates are affected by the "instrument's system" and there could be discerned the existence of the systematic errors of the $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ types.

S. Sadžakov, V. A. Fomin: *A comparison of the AGK3 star catalogue declinations with the results of latitude observations with Zenith-Telescopes and Photographic Zenith Tubes*, Izv. GAO AN SSSR Pulkove **199** (1982), 36–40.

A comparison of the AGK3 catalogue declinations with the declinations obtained from 27 northern sky latitude programs observations during the last 15–20 years is made. The results of the comparison show that the $\Delta\delta_\alpha$ systematic errors may be present both in the declination system of the AGK3 catalogue and in the declinations deduced from latitude observations.

S. Sadžakov, M. Dačić, V. A. Fomin: *An investigation of the systematic errors of the Belgrade NPZT and AGK3 catalogues on the basis of modern PZT observations*, 18 IAU General Assembly, Patras, (1982).

S. Sadžakov, M. Dačić, D. Šaletić, B. Ševarlić: *Results of comparison of the Belgrade and the Bordeaux catalogs of the northern PZT stars*, Bull. Obs. Astron. Belgrade **132** (1982), 7–13.

Results are presented of comparison the NPZT star catalogs compiled in Belgrade and Bordeaux, systematic differences between them derived and analysed with respect to the right ascension, declination, apparent magnitudes and spectral classes.

S. Sadžakov, D. Šaletić, M. Dačić: *Properties of the north PZT star catalogue*, Hvar Obs. Bull. Suppl., Vol. 6, **1** (1982), 99.

Observations of the north PZT stars with the Belgrade Large Meridian Circle have been carried out in the period from June 1973 to May 1980. There were in all 283 observing tours about 16000 recorded transits. The determination of both coordinates, that is, right ascensions and declinations, proceeded simultaneously.

An observing tour lasted at least three hours and at the most five hours. The number of the programme stars observed within the scope of one tour varied from about 60 to about 100, while that of the reference stars amounted to at least 12. The stars of this programme were observed within five zones: $(+10, +25)$, $(+35, +38)$, $(+39, +45)$, $(+47, +52)$ and $(+53, +59)$. The reference stars (owing to their scarcity within the corresponding zones) had to be taken from wider zones then those just indicated.

From the results obtained it follows that the error of a single determination of right ascension is $\varepsilon_\alpha \cos\delta = \pm 0^s.038$ and that of declination $\varepsilon_\delta = \pm 0''.26$.

The catalogue, with the corresponding discussion, is due to appear as Volume N. 30 of the Publications of the Belgrade Observatory.

S. Sadžakov, M. Dačić, D. Šaletić: *Programme of observations of the catalogue of double and Pulkovo stars with the Belgrade Large Meridian Circle*, Hvar Obs. Bull. Suppl., Vol. 6, **1** (1982), 101–105.

Criterions are presented of the selection of a double and Pulkovo stars programme, composed in Pulkovo and U.S. Naval Observatory, along wiht their distribution according to zones. The programme will be observed by relative method with the Belgrade Large Meridian Circle in the period 1981 to 1985. Each star will be observed four times.

S. Sadžakov, M. Dačić: *Variation in time of the parameters* $(u + m)$ *and* M_0 *of the Belgrade Meridian Circle*, Bull. Applied Math. (BAM), Budapest, **190** (1983), 13–17.

Dependence of the parameters $(u + m)$ and M_0 on the time of observation has been investigated using the methods of the correlation analysis.

The hypothesis of absence of a linear correlation between the Bessel constant $(u + m)$ and the time of observation, as well as the same hypothesis relating to M_0 (equator point) and the time of observation, has been confirmed in the most of the observed series. The absence of a non-linear correlation has been confirmed with the for lesser number of star series, an indication of how necessary it is to find out the variation in time, as reliable as possible of the quantities $(u + m)$ and M_0 for each individual observing night.

S. Sadžakov, M. Dačić, V. A. Fomin: *A comparison of star positions in the Belgrade catalogue with those in the AGK3 on latitude measurements*, Bull. Applied Math. (BAM), Budapest, **151** (1983), 119–126.

The results obtained on the basis of the comparison indicate existence of the systematic errors of $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ types which may have a seasonal character in the Belgrade Catalogue of NPZT stars. Systematic errors in the proper motions of the AGK3 stars are also apparent on high declinations.

S. Sadžakov, M. Dačić: *Systematic errors of Belgrade NPZT programme star catalogue*, Bull. Applied Math. (BAM), Budapest, **197** (1983), 121–126.

Results of a comparison — Belgrade NPZT programme star catalogue to six other catalogues, compiled by use of meridian circles of the same, or similar properties are given. Existence of small systematic errors of $\Delta\alpha_\alpha$ and $\Delta\delta_{\rm sp}$ type is found.

S. Sadžakov, M. Dačić, D. Šaletić: *On the catalogue of the stars positions in the NPZT programme*, Astrometr. Astrophys. Kiev **48** (1983), 58–59.

The paper deals with compilation of the catalogue of the NPZT stars in Belgrade. Some characteristics of this catalogue are given. The catalogue has

been already used in compiling the general catalogue of the NPZT stars by Yasuda.

S. Sadžakov, M. Dačić: *Primena korelacione analize na ispitivanje tačaka ekvatora i $(u+m)$ fundamentalnih zvezda merenih sa meridijanskim krugom u Beogradu*, VI Nacionalna Konf., Hvar, (1983).

M. Dačić: *Sistem meridijanskog kruga u Beogradu*, VI Nacionalna Konf., Hvar, (1983).

S. Sadžakov, M. Dačić: *Sistematske greške beogradskog kataloga zvezda programa SFZT*, VI Nacionalna Konf., Hvar, (1983).

S. Sadžakov, M. Dačić, V. A. Fomin: *Investigation of the systematic errors of the Belgrade NPZT and AGK3 catalogues*, Astron. Astrophys. Suppl. Ser. **52** (1983), 455–462.

Systematic errors of the $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ types are derived by comparing star positions in the NPZT and AGK3 catalogues with those deduced from the observations made with the PZTs at ten latitude stations.

S. Sadžakov, M. Dačić, V. A. Fomin: *Comparison of the Potsdam PZT catalogue with four NPZT catalogues*, VI Intern. Lohrmann Colloq., Dresden, (1983).

M. Dačić: *Instrument system of the Belgrade Meridian Circle*, Bull. Obs. Astron. Belgrade **134** (1984), 1–8.

Investigation has been executed of the sysematic difference "FK4 system minus instrument system" of the Belgrade meridian circle. The data, used in the present analysis, were acquired during two periods — 1973/75 and 1977/78 — by the observation of Küstner series, with a total of about 1000 transits. The data processing was accomplished in two stages. The first stage consisted in the instrument parameters being calculated by the method of least squares. In the second stage $(O-C)$ deviations in both coordinates have been determined. The instrument system is presented in the form $\Delta\alpha_\delta \cos\delta$ and $\Delta\delta_\delta$. Thus it was established that the instrument systems at both clamps were close to each other and that the mean instrument system kept steady over several years.

S. Sadžakov, V. A. Fomin, M. Dačić: *Comparison of Tokyo PZT catalogues with AGK3 and with three other independent catalogues*, Sympos. 109 IAU "Astronomic Techniques" Gainsville, Florida, (1984).

S. Sadžakov, M. Dačić: *Značaj određivanja položaja zvezda u okolini radio izvora*, VII Nacionalna Konf., Beograd, (1984).

S. Sadžakov, M. Dačić: *Preliminary results of observations of double stars and the stars near radio sources with the Belgrade Meridian Circle*, 19 IAU General Assembly, New Delhi, (1985).

S. Sadžakov: *Analysis of systematic $\Delta\delta_\alpha$ deviations of GCLS and AGK3 catalogues from 20 catalogues obtained from latitude observations*, 19 IAU General Assembly, New Delhi, (1985).

S. Sadžakov, M. Dačić: *Position determination of stars in the neighbourhood of radio sources*, Bull. Applied Math. (BAM), Budapest, **296** (1985), 149–152.

The forming of the inertial coordinate system implied, at the present-day status of astrometry two stages. In the first stage one achieves what called fundamental system of the mean equator coordinates while in the second stage its absolute rotation is ascertained up to an anticipated accuracy. As a result, an inertial coordinate system is aproximated.

S. Sadžakov, M. Dačić, Z. Stančić: *Ocena tačnosti položaja zvezda u katalogu dobijenom pomoću automatskog meridijanskog kruga u Brorfeldu*, VIII Kongres MFAJ i VIII Nacionalna Konf., Priština, (1985).

S. Sadžakov, M. Dačić: *Sistematske greške sopstvenih kretanja u katalozima GC, IKŠZ i AGK3*, VIII Kongres MFAJ i VIII Nacionalna Konf., Priština, (1985).

S. Sadžakov, V. A. Fomin, M. Dačić: *Issledovanie sistematicheskikh oshibok belgradskogo kataloga SFZT*, XXIII Astrom. Konf., Leningrad, (1985).

S. Sadžakov, M. Dačić: *Predvaritel'nye rezul'taty meridiannykh nablyudenij po programmam "dvojnye zvezdy" i "opornye zvezdy v okrestnostyakh radioistochnikov"*, XXIII Astrom. Konf., Leningrad, (1985).

S. Sadžakov: *Analysis of sistematic $\Delta\delta_\alpha$ deviations of GCLS and AGK3 catalogues from 20 catalogues obtained from latitude observations*, Bull. Applied Math. (BAM), Budapest, **426** (1986), 1–10.

To enable as dependable an estimate as possible of the quality of positions and proper motions of stars contained in GCLS (IKSZ, Sadzakov, 1978) and AGK3 (1975) catalogues we compared them with their homologues in 20 latitude stars catalogues listed in the enclosed Tables.

S. Sadžakov, M. Dačić, V. A. Fomin: *Investigation of systematic $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ type errors of Bucharest NPZT catalogue*, in: Bucharest Catalogue of NPZT Stars, Declination Zone +49° to +50°, Equinox 2000.0 (E. Toma, M. Tudor, M. Liculescu), Central institute of physics, Bucharest astronomical observatory, Center for astronomy and space science, Bucharest, (1986), 73–78.

Results are presented of the comparison of Bucharest NPZT Catalogue in the zone +41° to +63° declination with the catalogues obtained from latitude observations with PZTs and meridian circles. Systematic $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ errors are stated in both PZT and meridian circle observations. Seasonal effects are prominent in all the cited catalogues, some of the catalogues (Herstmonceux) even having their coordinate origins shifted in reference to the origins of the majority of other catalogues.

Z. Stančić: *Instrumental systems of the Belgrade Large Meridian Circle in the period 1981–84*, Bull. Obs. Astron. Belgrade **136** (1986), 119–125.

Results are exposed of determination of the Belgrade Large Meridian Circle's instrumental systems in right ascension and declination from the Küstner series observations performed in the period 1981–1984. Comparison is also made of the collimation error and of the flexure values as furnished by the Küstner series observations during 1984 to those resulting from the laboratory measurements.

S. Sadžakov, M. Dačić, V. A. Fomin: *Comparison of the Potsdam PZT catalogue with four NPZT catalogues*, Astron. Astrophys. Suppl. Ser. **65** (1986), 379–381.

Comparison is made of the Potsdam PZT star catalogue with four NPZT star catalogues. A clear systematic deviation of the Potsdam catalogue positions with respect to all four catalogues, in addition to the random differences, has been established.

S. Sadžakov, M. Dačić: *Comparison of Tokyo PZT catalogues with AGK3 and with three other independent catalogues*, Astrometric Techniques by the IAU, (1986), 571–580.

Results are presented of the comparison of five Tokyo PZT catalogues with the AGK3 and three independent catalogues obtained with meridian circles.

S. Sadžakov: *Systematic errors in visual and photographic latitude star catalogues*, Astron. Nachr. **308** (1987), 363–374.

The point discussed is the importance of investigation of the systematic errors of $\Delta\delta_\alpha$ and $\Delta\mu_\alpha$ types and their effects on stellar positions as obtained from visual and photographic observations.

S. Sadžakov, M. Dačić, Z. Cvetković: *A catalogue of double stars compiled from observations with the Belgrade Meridian Circle*, Colloq. 100 IAU, Beograd, (1987).

S. Sadžakov: *Investigation of the systematic errors in the Belgrade General Catalogue of Latitude Stars (IKŠZ)*, Sympos. 133 IAU, Prag, (1987).

S. Sadžakov, M. Dačić, Z. Cvetković: *Characteristics of the catalogue containing stars situated in the vicinity of radio sources*, Colloq. 100 IAU, Beograd, (1987).

S. Sadžakov, M. Dačić: *Preliminary results of meridian observations in the framework of the programmes "Double Stars" and "Reference Stars in the Vicinity of Radio Sources"*, Sovremennaya astrometriya, AN SSSR, Leningrade, (1987), 64–66.

The topics is observational programmes of Double stars and stars in the vicinity of radio sources. The distribution of stars in right ascension (every six hours) and declination (every 30°) is presented in a table. The values of the mean errors of star coordinates in FK4, as well as of the quantities $u + m$

and M_0 obtained from observations of double stars and those in the vicinity of radio sources, are presented.

S. Sadžakov, M. Dačić, V. A. Fomin: *An investigation of systematic errors of the Belgrade NPZT stars catalogue within the declination zone* 35°–40°, Izv. GAO AN SSSR, Pulkove **204** (1987), 41–47.

The results of comparison of the Belgrade NPZT Stars catalogue and the AGK3 catalogue with 5 Tokyo PZT stars lists compiled in 1959–1978 reveal some significant systematic $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ errors of the Belgrade NPZT stars catalogue within the declination zone 35°–40°.

S. Sadžakov, D. Šaletić: *Systematic differences in positions and proper motions between ILS catalogues and the main astrometric catalogues*, Astron. Astrophys. Suppl. Ser. **74** (1988), 53–61.

Using the results of many authors (see Refs.), we carried out direct comparison of the declination of star pair centres of the IKŠZ (AGK3) catalogue with the declination of star pairs centres obtained by latitude observations on ILS stations.

S. Sadžakov: *Characteristics of the General Latitude Star Catalogue*, Bull. Acad. Serbe Sci. Arts **30** (1988), 11–22.

The values of declinations and proper motions in General Catalogue were derived on the basis of about 36000 star positios, the rms error of their determination from 0.″20 to 0.″62 with the average being ±0.″35. The rms error of the determination of a single position is $\varepsilon_\delta = \pm 0.''08$ and the proper motion $\varepsilon_\mu = \pm 0.''005$ with a mean epoch of 1954.44. The systematic differences for the errors in proper motions exist in the AGK3, GC, N30, FK4. The error of determination of $\Delta\delta_\delta$, $\Delta\delta_\alpha$, $\Delta\mu_\alpha$ indicate existence positions and proper motion. Existence of small $\Delta\delta_\alpha$ type systematic errors for the catalogue of the order up to ±0.″2 and $\Delta\mu$ of the order up to ±0.″01 is seen.

S. Sadžakov, M. Dačić: *Preliminary results of observations of double stars and the stars near radio sources with the Belgrade Meridian Circle*, Bull. Acad. Serbe Sci. Arts **16** (1988), 17–22.

Some particulars on the double stars (DS) programme and of the one stars surrounding the radio sources (RS) are presented. Preliminary results of the relevant observations, currently under way, with the Belgrade Meridian Circle, are given.

S. Sadžakov: *Tačnost određivanja položaja zvezda dobijenih posmatranjima sa VMK u Beogradu*, IX Nacionalna Konf., Sarajevo, (1988).

S. Sadžakov, M. Dačić: *Estimate of proper motions for 453 double stars of Belgrade catalogue*, 20 IAU General Assembly, Baltimore, (1988).

S. Sadžakov, M. Dačić, Z. Cvetković, G. Damljanović: *Karakteristike beogradskog kataloga rektascenzija i deklinacija fundamentalnih zvezda (FK4)*, IX Nacionalna Konf., Sarajevo, (1988).

S. Sadžakov, M. Dačić, Z. Stančić: *Accuracy of the corrections determined for FK4 stars*, Bull. Obs. Astron. Belgrade **139** (1988), 7–14.

The results of observations of fundamental stars in series (zones) at the corresponding MC position are presented. The errors are $\varepsilon_\alpha \cos\delta = \pm 0^s.022$, $\varepsilon_{u+m} \cos\delta = \pm 0^s.005$ in the right ascension, $\varepsilon_\delta = \pm 0''.32$, $\varepsilon_{M_0} = \pm 0''.08$ in the declination.

S. Sadžakov: *Application of Brosche's method to examinations of coordinate differences for stars of two catalogues*, Bull. Obs. Astron. Belgrade **139** (1988), 14–21.

A short review concerning the method, itself, is presented, as well as the results obtained from the comparison of the IKŠZ Catalogue with the FK4, N30 and AGK3 ones.

S. Sadžakov, M. Dačić, Z. Stančić: *Analysis of results obtained from observations with meridian circles in Belgrade and Brorfelde*, Bull. Obs. Astron. Belgrade **138** (1988), 9–13.

Characteristics of the instruments used for the purpose of compilation of the here analysed observational material are given. The systematic errors of $\Delta\alpha$ and $\Delta\delta$ types in the right ascension, declination, magnitude and spectrum are determined.

S. Sadžakov, M. Dačić, Z. Cvetković, Z. Ćatović: *Characteristics of the Belgrade double stars catalogue*, Sympos. 141 IAU, Leningrad, (1989).

S. Sadžakov, M. Dačić, Z. Cvetković: *A presentation of the work performed with the Belgrade Large Meridian Circle during the period 1968–1988*, Sympos. 141 IAU, Leningrad, (1989).

R. S. Izmailov, N. G. Litkevich, S. Sadžakov, V. D. Simonenko, T. I. Suchkova, S. A. Tolchel'nikova-Murri, V. L. Turenko: *The comparison of the accuracy of the determination of right ascension by means of transit instruments of different types*, Sympos. 141 IAU, Leningrad, (1989).

S. Sadžakov, S. R. Izmailov, N. T. Litkevich, V. D. Simonenko, S. A. Tolchel'nikova-Murri: *A comparison of the accuracy of the right ascension determination with transit instruments of different types*, Inertial coord. system on the sky, Reidel Publ., (1990), 456.

A special series of observations of the groups of stars performed in Pulkovo, Chile, Kharkov and Belgrade were used to compare the mean errors of the right ascension by means of the method eliminating the influence of the errors

of the source catalogue. The results show the advantage of the small transit instruments over transit circle of the classical type.

S. Sadžakov, M. Dačić: *A catalogue of right ascension and declination of FK4 stars*, Astron. Astrophys. Suppl. Ser. **77** (1989), 411.

This catalogue contains the positions of 576 FK4 stars observed 1981–87. The mean epoch is 1983.90 for α and 1983.84 for δ with mean errors for a single observation of $\pm 0^{s}.022$ in α and $\pm 0''.32$ in δ.

S. Sadžakov, M. Dačić, Z. Cvetković, Z. Ćatović: *Characteristics of the Belgrade double star catalogue*, Bull. Obs. Astron. Belgrade **141** (1989), 1–5.

The results of the comparison of the Belgrade catalogue to a few others, as well as the systematic errors of the types $\Delta\alpha$, $\Delta\delta$, are presented.

S. Sadžakov, M. Dačić: *Belgrade catalogue of double stars*, Publ. Obs. Astron. Belgrade **38** (1990), 1–110.

In the period between March 1981 and April 1987, 1576 stars were observed in Belgrade during the Double Star Programme. The measurements and the treatment of the observational material were performed by use of the relative method. Both coordinates α and δ were observed simultaneously, on the average every three minutes. The rms error of a single observation of double stars between $-30°$ to $+60°$ is $\varepsilon_\alpha \cos\delta = \pm 0^{s}.026$ and $\varepsilon_\delta = \pm 0''.32$.

S. Sadžakov, Z. Cvetković, M. Dačić: *A presentation of the work performed with the Belgrade Large Meridian Circle during the period 1968–1988*, Inertial coord. system on the sky, Reidel Publ., (1990), 489–491.

The work performed with the Belgrade Large Meridian Circle and the results obtained during the last twenty years are presented.

S. Sadžakov, M. Dačić, Z. Cvetković: *A catalog of positions of 290 stars situated in the vicinity of radio sources*, Astron. Journal **101** (1991), 713–733.

With the Large Meridian Circle of the Belgrade Observatory we carried out in the period 1982–1987 visual measurements by using the relative method of the coordinates of 290 stars from 78 parts of the sky situated in the vicinity of radio sources. Each program star was observed on the average 5.5 in α and 5.8 times in δ. The rms-error of a single observation in right ascension is $\varepsilon_\alpha \cos\delta = \pm 0^{s}.024$ and in declination $\varepsilon_\delta = \pm 0''.30$. A comparison between the fundamental stars observed and those from the FK4 yields a position error of $\pm 0^{s}.010$ in α and $\pm 0''.13$ in δ.

4.1.2. *Observations of the Sun and Planets*
4.1.2. *Posmatranja Sunca i planeta*

S. Sadžakov, M. Dačić, D. Šaletić: *Results of observation of the Sun, Mercury and Venus 1974 to 1979*, Publ. Obs. Astron. Sarajevo **1** (1981), 69–79.

Description is given of the equipment and the procedure of observation, along with the mean $(O-C)$ values of the right ascensions and declinations, according to years, and computed corrections to the orbital elements. It is inferred that the quality of the observations is satisfactory.

S. Sadžakov, M. Dačić, D. Šaletić: *Positions of the Sun and inner planets obtained with the Meridian Circle of the Belgrade Observatory*, European Regional Meeting in Astronomy, VI ERMA, Dubrovnik, (1981).

The results of observations of the Sun, Mercury and Venus during the eight years period (1973–1981) are given. The corrections ΔA, $\Delta\delta_0$, ΔL_0, $\Delta\pi$ and $\Delta\varepsilon$ with respective mean square errors are derived.

The mean square error of a single observation, calculated for the equinox, ranges from: $\pm 0''.16$ to $\pm 0''.40$ and $\pm 0^s.015$ to $\pm 0^s.028$ for the Sun, $\pm 0''.16$ to $\pm 0''.50$ and $\pm 0^s.026$ to $\pm 0^s.040$ for Mercury and $\pm 0''.24$ to $\pm 0''.43$ and $\pm 0^s.012$ to $\pm 0^s.036$ for Venus.

S. Sadžakov, M. Dačić, D. Šaletić: *Results of observations of the Sun, Mercury and Venus with the Belgrade Large Meridian Instrument*, Bull. Obs. Astron. Belgrade **132** (1982), 45–53.

The apparent right ascensions and declinations of the Sun and two planets obtained from our observations are compared with the ephemeris positions and the results are given in Tables 1, 2, 3.

S. Sadžakov, M. Dačić, D. Šaletić, B. Ševarlić: *Observations of the Sun and inner planets with the Large Meridian Circle in Belgrade*, Sun and Planetary System, Reidel Publ., (1982), 445–446.

Observed apparent right ascensions and declinations of the Sun and the planets; the corrections of the orbital elements Sun, Mercury, Venus and the errors (σ) of their determination, based on the observations in the period 1975–1981.

S. Sadžakov, M. Dačić, D. Šaletić: *Observations of the Sun, Mercury and Venus with the Belgrade Meridian Circle in the period 1979 to 1981*, Bull. Obs. Astron. Belgrade **133** (1983), 45–50.

The results of observations of the Sun, Mercury and Venus with the Belgrade large meridian instrument in the period from 1979 to 1981, are presented.

S. Sadžakov, M. Dačić: *Observations of the Sun and planets with the Belgrade Large Meridian Circle*, Bull. Obs. Astron. Belgrade **135** (1985), 47–54.

Results are presented of the Sun, Mercury, Venus and Mars observations made with Large Meridian Circle of the Belgrade Observatory in the period September 1981 – November 1983.

S. Sadžakov, M. Dačić: *Nablyudeniya Solntsa i bol'schikh planet na meridiannom kruge v Belgrade*, XXIII Astron. Konf., Leningrad, (1985).

S. Sadžakov, M. Dačić: *Observations of the Sun and inner planets with the Large Meridian Circle Belgrade*, Colloq. 100 IAU, Beograd, (1987).

S. Sadžakov, M. Dačić: *Observations of the Sun and of planets with the Belgrade Meridian Circle*, Sovremennaya astrometriya, AN SSSR, Leningrade, (1987), 325–329.

On the basis of the differences $(O-C)_\alpha$ and $(O-C)_\delta$ we determined the corrections of the equinox and equator, as well as some of the corrections of orbital elements for the Earth, Mercury and Venus.

S. Sadžakov, M. Dačić, Z. Stančić: *Results of diurnal measurements for the Sun, Mercury, Venus and Mars obtained in the period 1984–1986*, Bull. Obs. Astron. Belgrade **138** (1988), 78–85.

In the paper we present the results $(O-C)_\alpha$ and $(O-C)_\delta$ obtained in the period 1984–1986 in Belgrade from diurnal observations of the Sun, Mercury, Venus and Mars with the large meridian circle "Askania" No 88077, $2r = 190\,\text{mm}$, $f = 2578\,\text{mm}$.

M. Dačić, S. Sadžakov, Z. Cvetković: *Observations of the Sun and planets with the Belgrade Large Meridian Circle*, Bull. Obs. Astron. Belgrade **140** (1989), 49–53.

Results are presented of the Sun, Mercury, Venus and Mars observations made with Large Meridian Circle of the Belgrade Observatory in the period March 1987 – Sept. 1988.

4.2. Large Vertical Circle: Determination of Absolute Declinations of Stars and Planets

4.2. Veliki vertikalni krug: Određivanje apsolutnih deklinacija zvezda i planeta

Dj. Bozhichkovich: *New method of measurement for the corrections determination of the totality of circle diametres*, Publ. Astron. Obs. Sarajevo **1** (1981), 93.

Instead of the classical procedure of measurements for the determination of the circle division corrections it is proposed that a uniform rotation be imparted to the circle under investigation. From the registered times of transit of the individual division lines in front of the photoelectrical gadgets, the division lines corrections would be determined by some of the currently existing methods. The efficiency of the method of measurements propsed may be judged from this author's estimate that all the measurements, requisite for the correction determination by Bruns' method of 5400 diameters, assotiated with $2'$ circle division, would require only 105 hours of actual measurements.

Dj. Bozhichkovich: *Determination of declinations with a uniformly rotating vertical or meridian circle*, Publ. Astron. Obs. Sarajevo **1**, No. 1 (1981), 103.

Instead of the standard method of declination determination, implying a *static* instrument (the vertical or meridian circle), it is proposed that the necessary measurements be performed with the instrument (the tube and the circle as a whole) uniformly *rotating* about its horizontal axis during the star's passage over the field of view. It is estimated that the mean error of a single declination determination, using the method suggestd, would be less than $\pm 0''.10$.

M. Mijatov, Dj. Bozhichkovich, G. Teleki: *Preliminary results of Determinations of 308 Bright Stars Declinations in the Zone from $+65°$ to $-90°$ obtained with the Vertical Circle of the Belgrade observatory*, Zbornik Zadachi savremenoj astrometri v sazdani inertsial'noj sistemy koordinat, Izd. Fan, Tashkent, (1981), 154.

M. Mijatov, Dj. Bozhichkovich: *Preliminary results of the flexure investigation of the Belgrade Large Vertical Circle in the period 1976–1979*, Bull. Obs. Astron. Belgrade **132** (1982), 3.

An account is given of the preliminary results of the flexure determinations of the Large Vertical Circle of the Belgrade observatory, carried out regularly under the observing program of bright strs in the period 1976–1979. A satisfactory accuracy of the measurements is stated, except for the year 1976, namely $\pm 0''.20$. Of particular importance is the finding that the flexure of our LVC keeps its properties over longer time intervals. More intense investigations of this parameter is recomended.

Dj. Bozhichkovich, M. Mijatov: *Investigation of the divided circle of the Belgrade Large Vertical Circle*, Bull. Obs. Astron. Belgrade **134** (1984), 16.

Corrections for 1080 dimeters at $10'$ spacing of the $2'$ divided circle of the Belgrade Large Vertical Circle are determined according to Nikolić's method. All the diameter corrections are within $\pm 1''.5$ limits, the accuracy being ± 0.11. The values of the corrections are tabulated and illustrated graphically.

M. Mijatov, V. Trajkovska: *Analysis of some characteristics of the levels of the Belgrade Vertical Circle*, Bull. Obs. Astron. Belgrade **134** (1984), 9.

On the basis of laboratory examinations of the levels of the Belgrade Vertical Circle, executed in the period 1963 to 1981, mean division values, as well as their dependence on time, air temperature and bubble length, are derived. The formulae (4) and (5) are proposed for use in the reduction of astronomical observations. The level division values, as derived by laboratory measurements, proved to fit in the regular astronomical observations made with our Vertical Circle.

V. Trajkovska: *Preliminary results of planet observations with the Belgrade Vertical Circle*, Bull. Obs. Astron. Belgrade **136** (1986), 100.

Account is given of the method, organization and results of obseervations of outer planets with the Belgrade Vertical Circle, carried out in the period

April 1983 to November 1984. The $O - C$ differences for all the observed planets, as well as the mean errors of observations are given.

Dj. Bozhichkovich: *Investigation of levels of the Belgrade Vertical Circle*, Bull. Obs. Astron. Belgrade **136** (1986), 40.

Two levels attached to the Belgrade Vertical Cirle have been investigated both on the examinator and on the instrument itslf. Data obtained by both methods are analysed. It could be found that the results provided by the measurements on the instrument itself, using the mercury horizon, were notably more realistic than those obtained with the examminator under laboratory conditions. In addition to the accounting for the temperature and the buble length effect on the level division value determination and accounting for the systematic effects of the irregulatries in the inner sliding surface and its graduation is suggested.

B. Jovanović, Dj. Bozhichkovich: *On division errors of the Belgrade Vertical and Meridian Circles*, Bull. Obs. Astron. Belgrade **137** (1987), 41.

By using the spectral analysis method the corrections of the division for the Meridian Circle and for the Vertical Circle of Belgrade Observatory are treated. A prominent term of a period of two degrees has been found for the former instrument, but not for the latter one. Both instruments were produced by "Askania".

V. Trajkovska: *Results of planet observations with the Belgrade Vertical Circle (Supplement I)*, Bull. Obs. Astron. Belgrade **138** (1988), 85.

Results of observations of five major planets with the Belgrade Vertical Circle, carried out in the period April 1985 to December 1986, are presented. The $O - C$ differences for the observed planets, as well as the mean errors of observations are given. Differences of the observed apparent and the ephemeris apparent semi-diameters of the planets Mars, Jupiter and Saturn are given, too.

M. Mijatov, V. Trajkovska: *Flexure of the Belgrade Large Vertical Circle in the period 1976–1980*, Bull. Obs. Astron. Belgrade **140** (1989), 37–42.

In the present paper an analysis of the variations in the flexure of the Large Vertical Circle of Belgrade Observatory between 1976 and 1980 is given. The examinations show a very prominent temperature dependence a significant variation during an observation night, and a dependence on observers and on quality of measurements; no dependence on meteorological parameters such as the pressure and humidity, as well as on weather conditions under which the measurements were made (cloudiness, wind, etc.) was found. Seasonal variations, being most prominent during the autumn season, are found. The most important systematic influences are collimator displacement and the tube refraction. The accuracy of the flexure determination is $\varepsilon_b = \pm 0''.22$.

4.3. Large Transit Instrument: Determination of Absolute Right Ascensions

4.3. Veliki pasažni instrument: Određivanje apsolutnih rektascenzija

I. Pakvor: *On the Observations of the Bright Polar Stars with the Large Transit Instrument at the Belgrade Observatory*, Publ. Astron. Obs. Sarajevo **1** (1981), 79–85.

The first regular observation program which is being carried out at the LTI of the Belgrade Observatory contains the determination of absolute right ascension of stars in the northern declination zone 70°–90°. The application of the vacuum meridian marks gives special interest to this program. The analysis of the instrument's constants is shown.

I. Pakvor: *Progress Report on Vacuum Meridian Marks*, Mitt. Lohrmann Obs. Tech. Univ. Dresden **6**, 51 (1984), 127–130.

I. Pakvor: *Progress report on the Belgrade catalog of absolute R.A.s of bright polar stars*, Trans. IAU, Proc. XIX IAU GA 1985, New Delhi.

A progress report on the *Belgrade Catalog of Absolute RA's of Bright Polar Stars* was given by I. Pakvor, Belgrade Observatory, Yugoslavia. He indicated that the observations of absolute RA's of bright polar stars from the list of 308 stars in the declination zone +65° to +90° with the Large Transit Instrument (LTI) of the Belgrade observatory were finished early in 1983. This is the first absolute RA catalog observed by the LTI of Belgrade observatory. These observations involve the first use of vacuum meridian marks for determining the values of differential azimuth and collimation errors. The annual variations of these constants were given. Reductions are in progress and the chain method is in use.

I. Pakvor: *The stability analysis of the vacuum meridian marks of the Large Transit Instrument at Belgrade Observatory*, Bull. Obs. Astron. Belgrade **136** (1986), 75–78.

The stability analysis of the vacuum meridian marks of the Large Transit Instrument at Belgrade Observatory is shown using the variation of the angle between the southern and northern meridian mark. The review of similar examinations at some other observatiories and the comparison of the results are given. For Belgrade meridian marks a significant annual variation is determined.

L. Mitić, I. Pakvor: *Vacuum meridian marks at Belgrade Observatory*, Proc. IAU Symp. 109, "Astrometric Techniques", Gainesville, Florida, D. Reidel Publ. Comp. (1986), 525–527.

More than a dozen years ago vacuum meridian marks were built for the Belgrade Large Transit Instrument with the purpose of completely keeping the air from interfering with the meridian mark readings. Information is presented on the favorable results achieved as regards both accidental and systematic accuracy.

5. EARTH ROTATION
5. ZEMLJINA ROTACIJA

5.1. Small Transit Instrument: Time Determination
5.1. Mali pasažni instrument: Astronomsko određivanje vremena

M. Jovanović, L. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzhba vremeni BL (Belgrad)*, Vsemirnoe Vremya, Byulleten' E 21–E 24, Moskva, 1980.

(M. Jovanović), (L. Djurović), *Daily values of UTO-UTC. transit instrument — Belgrade*, Monthly Notes of the Int. Polar Motion Service, Mizusawa, Nos. 1–12. 1980.

M. Jovanović: *Analiza vremenskih serija posmatranja na pasažnom instrumentu u Beogradu*, VII Kongres matem., fiz. i astronoma Jugoslavije, Budva-Bečići, (1980), III-6.

M. Jovanović, L. Djurović: *Svodka astronomicheskih nablydenij sluzhb vremeni. Sluzhba vremeni BL (Beograd)*, Vsemirnoe Vremya, Byulleten' E 25–E 28, Moskva, 1981.

(M. Jovanović), (L. Djurović), *Daily values of UTO-UTC. transit instrument — Belgrade*, Monthly Notes of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1981.

M. Jovanović, L. Djurović: *Détérmination astronomique de l'heure*, Bull. Obs. Astron. Belgrade **131** (1981), 45–48.

M. Jovanović, L. Djurović: *Sistematske greške rezidua pri određivanju geografskih koordinata dužine i širine astronomskim promatranjima*, in: M. Muminović (ed.), Proceedings of the IV Nat. Conf. of Yugoslav Astronomers, Sarajevo, 1979 = Publ. Astron. Obs. Sarajevo **1** (1981).

M. Jovanović, L. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzhba vremeni BL (Belgrad)*, Vsemirnoe Vremya, Byulleten' E 29–E 32, Moskva, 1982.

(M. Jovanović), (L. Djurović): *Daily values of UTO-UTC transit instrument — Belgrade*, Monthly Notes of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1982.

M. Jovanović, L. Djurović, B. Jovanović, D. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzhba vremeni BL (Belgrad)*, Vsemirnoe Vremya, Byulleten' E 33–E 36, Moskva, 1983.

(M. Jovanović), (L. Djurović), (B. Jovanović), (D. Djurović): *Daily values of UTO-UTC. Transit instrument — Belgrade*, Monthly Notes of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1983.

M. Jovanović: *Selenografija i selenologija*, Vojna enciklopedija, Beograd, (1983).

U radu je data savremeno shvatanje naučnog dostignuća najbližeg Zemljinog suseda Meseca. Takođe je dat osvrt na sastav i oblik zemljinog suseda.

(M.Jovanović), (B. Jovanović), (L. Djurović): *Daily values of UTO-UTC. Transit intrument — Belgrade*, Monthly Not. of the Int. Polar Motion Service, Mizusawa Nos. 1–12, 1984.

M. Jovanović, B. Jovanović, L. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzhba vremeni BL (Belgrad)*, Vsemirnoe vremya, Byulleten' E 37–E 40, Moskva, 1984.

M. Jovanović, B. Jovanović: *Služba vremena Astronomske opservatorije u Beogradu — polje rada, problemi, perspektive*, in: Proc. VIII Gen. Assembly, Union of Societes of Mathematicians. Physicists and Astronomers of Yugoslavia (VIII Kongres matematičara, fizičara i astronoma Jugoslavije — Saopštenja), Priština, (1985), 351.

M. Jovanović, L. Djurović: *A survey of meridian observations carried out with the transit instrument of the Belgrade Observatory in the period 1952 to 1983*, Bull. Obs. Astron. Belgrade **136** (1986), 130–132.

M. Jovanović, B. Jovanović, L. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni, Sluzhba vremeni BL (Belgrad)*, Vsemirnoe vremya, Bulleten' E 41–E 44, 1985.

(M. Jovanović), (B. Jovanović), (L. Djurović), *Daily values of UTO-UTC, Transit instrument — Belgrade*, Monthly Not. of the Int. Polar Motion. Service, Mizusawa, Nos. 1–12, 1985.

M. Jovanović, B. Jovanović, L. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzba vremeni BL (Belgrade)*, Vsemirnoe vremya, Bulleten' E 45–E 48, 1986.

(M. Jovanović), (B. Jovanović), (L. Djurović): *Daily values of UTO-UTC, Transit instrument — Belgrade*, Monthly Not. of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1986.

5.2. Zenith Telescope: Latitude Determination
5.2. Zenit teleskop: Određivanje geografske širine

Dj. Teleki, R. Grujić: *O EW-WE efektu kod Beogradskih širinskih posmatranja*, VII Kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Budva-Bečići, (1980), III-5.

R. Grujić, Dj. Teleki: *Analiza karakteristika Talkotovih libela Beogradskog zenit-teleskopa*, VII Kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Budva-Bečići, (1980), III-5.

B. Kolaczek, G. Teleki: *On reference coordinate systems used in polar motion determinations*, E. M. Gaposchkin and B. Kalaczek (eds.), Reference Coordinate Systems for Earth Dynamics, (1981), 165–173.

A short review of the reference pole presently used in polar motion determinations by classical astrometric methods is followed by a discussion of the systematic differences between systems of polar coordinates and the influence of the mean latitude of stations on pole position. The importance of homogenous processing astrometric data is stressed.

V. Milovanović, G. Teleki, R. Grujić: *On the influence of the external factors on the accuracy of determination of latitude variations*, Publ. Obs. Astron. Sarajevo **1** (1981), 131–141.

In the period 1968–1970 certain alterations have been implemented in the Latitude Service of the Belgrade Observatory, aimed at reducing, to maximum possible degree, the influence of the external factors on the latitude determinations. These alterations are related to: thermal insulation of the zenith-telescope, improving the construction of its pavilion and the modification of the observing procedure and the data processing. Explanation is given as to what necessitated these changes and why a wider astrometric significance is attached to them. The anlysis of the observational data, acquired with this instrument, showed that the effects of the external factors can successfully be reduced, resulting in a considerably increased accuracy of the determination of the latitude varations. To that purpose comparisons were made with the observational results of other zenith-telescopes (with those obtained at Interntional Latitude Service stations in particular).

M. Djokić: *Comparison of the micrometer screw corrections of the Belgrade zenith telescope in the different systems*, Pub. Obs. Astron. Sarajevo **1** (1981), 163–166.

For estimating the validity of the different observation programs used the micrometer screw correction of the Belgrade zenith telescope were analysed in the catalog system AGK3 and SAO.

R. Grujić, M. Djokić: *Observations à la lunette zenithale (de 110 mm) du Service de la latitude de l'Observatoire de Beograd en 1979*, Bull. Obs. Astron. Belgrade **131** (1981), 43–44.

The results of latitude observations under new Belgrade latitude program for 1979 are presented.

R. Grujić, M. Djokić: *Observations à la lunette zenithale (du 110 mm) du Service de latitude de l'Observatoire de Belgrade en 1980*, Bull. Obs. Astron. Belgrade **132** (1982), 53–54.

On présente les valeurs de latitude ansi que quelques données météorologiques prises au cours d'observations.

B. Kolaczek, G. Teleki: *On investigations of mean latitude variations*, Sun and Planetary System, D. Reidel Publ. Comp. Dordrecht, Holland – Boston, U.S.A. – London, England, (1982), 191.

S. Sadžakov, V. Fomin, M. Dačić, D. Šaletić: *Systematic errors in latitude observations of various observatories*, 18 IAU General Assembly, Patras, (1982).

G. Teleki, R. Grujić: *Investigations of the EW-WE effect in the latitude determinations with the Belgrade zenith-telescope*, Hvar Obs. Bull. Suppl., Vol. 6, **1** (1982), 61–69.

Belgrade latitude data have been analysed with regard to the possible sources of the EW-WE effect whereby the equation (1) has been utilized. The strongest source proved to be the instrument itself, especially its levels, but other sources are not negligible either: the observer, declination system, seasonal changes.

R. Grujić, G. Teleki: *An analysis of the characteristics of the Talcott levels of the Belgrade zenith-telescope*, Hvar Obs. Bull. Suppl., Vol. 6, **1** (1982), 71–80.

It has been established by laboratory investigations that the mean division angular values of the Belgrade zenith-telescope levels are systematically undergoing changes with time. The reality of these changes has been confirmed by using the inclination values as determined in the course of latitude observations with this zenith-telescope.

M. Djokić: *Analysis of the latitude differences obtained from the subgroups of the new Belgrade's latitude program*, Suppl. Obs. Bull. Hvar **6** (1982), 81–90.

Temperature induced differences in the latitudes obtained from the subgroups of the new Belgrade latitude program are considered.

M. Djokić: *Closing errors of the Belgrade latitude observations and temperature influences*, Astrophysics and Space Science Library **96** (1982), 195–196.

The correlations between temperature differences and closing errors of latitudes under old Belgrade's observation program were demonstrated.

R. Grujić, M. Djokić: 1982, *Observations à la lunette zenithale (de 110 mm) du Service de latitude de l'Observatoire de Belgrade en 1980*, Bull. Obs. Astron. Belgrade **132** (1982), 53–54.

The results of latitude observations under new Belgrade latitude program for 1980 are presented.

R. Grujić, R. Krga, Z. Stančić: *Ispitivanje „greške noći" kod beogradskih širinskih posmatranja u periodu 1960–1980*, VI Nacionalna Konf., Hvar, (1983).

R. Grujić, G. Teleki: *Investigation of wind effects on the Belgrade latitude observations*, Bull. Obs. Astron. Belgrade **134** (1984), 26–31.

It is demonstrated that the alterations (thermal insulation of the zenith telescope, rebuilding of the pavilion improvements in the observational procedure and data processing) effected in the period 1968–1970 (Milovanović et al., 1981) resulted in a notable reduction of the wind effects on the Belgrade latitude observations and a general enhancement of the accuracy of observation. It is found that in the period 1976–1981 the systematic effects of winds from N-W quadrant are stronger than those produced by winds from S-E quadrant (most of our observations are made by S-E winds). The suitability to application of some expressions for the calculation of wind effects on latitude is considered.

R. Grujić, R. Krga, Z. Stančić: *"Night error" in the Belgrade latitude observations made in the period 1960–1980*, Publ. Obs. Astron. Belgrade **33** (1985), 62–65.

"Night error" in the Belgrade latitude observations, made in the period 1960 through 1980, has been investigated and found that, being significant prior to the instrumental and methodical improvements implemented in 1969–1971, it has substantially been reduced in the subsequent period. The dependence of this error on the observer has been demonstrated, too.

M. Djokić: *Correction to the angular value of the screw revolution of the Belgrade zenith-telescope micrometer derived from latitude observations*, Publ. Obs. Astron. Belgrade **33** (1985), 70–74.

Correction to the angular value of the screw revolution of the Belgrade zenith-telescope micrometer is being determined and discussed for period 1971.9–1982.5.

G. Teleki, R. Grujić: *Effects of the level bubble length variation on the latitude values*, Publ. Obs. Astron. Belgrade **33** (1985), 66–69.

The level bubblelength variations during observation are found to affect the latitude values derived by Talcott method. The real amount of these effects is hard to bring out. Hence, one has to be careful at deducing the daily variations of latitude as these effects must not be ignored.

R. Grujić, Dj. Teleki: *O katalogu deklinacije Beogradskih zenitskih zvezda*, VIII Kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Priština, (1985), 345.

M. Djokić: *Constant of aberration from the latitude observations with the Belgrade zenith-telescope*, Bull. Obs. Astron. Belgrade **136** (1986), 29–30.

Values of the constant of aberration are determined from the latitude observed under the new Belgrade latitude program and compared with those derived from observations under the old program as well as the results obtained at other observatories.

R. Grujić, G. Teleki: *Investigations of the EW-WE effect in the latitude determinations with the Belgrade zenith-telescope in the period 1969.0–1981.0*, Bull. Obs. Astron. Belgrade **137** (1987), 11–29.

The EW-WE effect in the latitude determinations with the Belgrade zenith-telescope in the period 1969.0–1981.0 have been analysed and it was concluded that they are smaller ones as well as more accurately determined than in the period 1960.0–1969.0 (Teleki, Grujić, 1982). This is due to alterations (thermal insulation of the instrument, rebuilding of the pavilion improvements in the observational procedcure and data processing) executed in the period 1968–1970 (Milovanović et al., 1981). The results obtained by formula (3) point to several sources giving rise to the EW-WE effects, but it can be proved that the influences of these sources are remarkably weaker in the period 1969.0–1981.0 then before that.

R. Grujić, G. Teleki, B. Jovanović: *Declination variations of zenith stars*, IAU Coll. 100, Belgrade, Sept. 8–11, (1987).

G. Teleki, R. Grujić: *Catalogues of declinations and proper motions of 36 Belgrade zenith stars*, Astron. Astrophys. **177** (1987), 313–316.

Using observations made with the Belgrade zenith telescope in the period 1960.0–1981.0, catalogues (in three systems) of the declination and proper motions in declination of 36 zenith stars were calculated for the equinox and epoch of 1970.0. Analyses show that, relatively, the most accurate are the system 1 declinations ($BZS1_{70}$). The declinations systems of our catalogues are in good agreement with the corresponding FK4 system. But the system of proper motions in declination is less comparable with the FK4 system. It follows that the Belgrade zenith telescope is capable of yielding star declinations with relatively high precision (currently about $0''.22$).

G. Teleki, R. Grujić: *Belgrade catalogues of declinations and proper motions of zenith stars*, Bull. Obs. Astron. Belgrade **137** (1987), 5–10.

The analyses are given of three Belgrade catalogues of declinations and proper motions in declination of 36 zenith stars for the equinox and epoch 1970.0. These stars were observed with zenith telescope. The catalogues are based on the observation data collected in the period 1960.0–1981.0. The conclusion is that the results ar highly satisfying.

R. Grujić, G. Teleki: *The widened Belgrade latitude observational programme and its characteristics*, Bull. Obs. Astron. Belgrade **137** (1987), 14–29.

The original Belgrade latitude observational programme (Ševarlić, Teleki, 1960), which was observed from 1960.0, needed some improvement and therefore a widened programme was developed. The paper gives some informations on the characteristics of this new, widened programme. The preliminary value of sistematic differences between the latitudes obtained in the complete and the original programmes is $0''.010$.

R. Grujić, M. Djokić, B. Jovanović: *Analysis of the change in the geographic latitude between 1969.0 and 1975.0*, IX Nac. konf. astronoma Jug., Zbornik rezimea, Sarajevo, (1988), 29.

Period 1969.0–1975.0 is chosen to be analysed because it is the most favourable one taking into account the program of observation, the influence of the error in the micrometer screw revolution and the number of observations.

It is represented the change of mean latitude (0″.1) and annul z-term which is correlated with the change of Talcott levels inclination.

G. Teleki, R. Grujić: *Personal errors of observer in visual determinations of latitude by the Talcott method*, Kinem. i Fiz. Nebesn. Tel, Vol. 4, **1** (1988), 71–74.

Using latitude data obtained with the Belgrade Astronomical Observatory zenith telescope during 1960.0–1986.0, we investigated latitude differences determined by two experienced observers. It was established that these differences (the result of the observers' individual errors) are significant and that they correlate with the inclination of the moving micrometer hair. Certain recommendations pertaining to organization of observations are given.

R. Grujić, M. Djokić, R. Krga, S. Šegan, N. Djokić: *Observations à la lunette zenithale (de 110 mm) du Service de latitude de de l'Observatoire de Belgrade en 1981, 1982, 1983, 1984, 1985*, Bull. Obs. Astron. Belgrade **140** (1989), 69–81.

On présente les valeurs de latitude ansi que quelques données météorologiques prises au cours d'observations.

6. EARTH'S ATMOSPHERE
6. ZEMLJINA ATMOSFERA

6.1. Astronomical Refraction
6.1. Astronomska refrakcija

G. Teleki: *Evolution of the Earth's atmosphere and the astronomical refraction*, Publ. Astron. Obs. Sarajevo 1 (1981), 111–114.

The author reaches the conclusion that the evolution of the Earth's atmosphere over the last millenniums did not practically affect the value of the refractional influences and that the same might be expected in the near future. Thus, the present-day (good) tables of refraction may well continue to be used unchanged during the time of mankind's civilisation.

G. Teleki: *On the modern invetigations of refraction influences*, Zbornik *Zadachi sovremenoj astrometrii v sozdanii inertsial'noj sistemy koordinat*, Izd. Fan, Tashkent, (1981), 423–427.

G. Teleki: *New tendencies of the research into the astronomical refraction*, Bull. Obs. Astron. Belgrade **131** (1981), 3–8.

A review is given of the more recent researches into the refrectional influences, with special emphasis on those new tendencies in studying or eliminating the infuence of the astronomical refraction (prevention, three-dimensional refraction, multi-wave methods, the use of the artifical satellites) of which it is expected to considerably promote our knowledge of this phenomenon.

G. Teleki, J. Saastamoinen: *Problems of three-dimensional refraction in astrometry*, Sun and Planetary System, D. Reidel Publ. Comp., Dordrecht, Holland – Boston, U.S.A. – London, England, (1982), 455.

G. Teleki, O. Atanacković: *The growth of knowledge on astronomical refraction I.* Rep. No. 19, Dep. of Geodesy, Univ. of Uppsala, Sweden, (1983), 255–271.

After the short historical survey on astronomical refraction, the growth of knowledge of this phenomenon is assessed proceeding from the number of the published papers dealing with that matter as well as the accuracy of the refraction tables. The growth of the published papers in the course of time has had a non-uniform pattern, being, however, very fast after the Second World War. The accuracy of the refraction tables has been increasing since Tycho's time up to the present, the time of doubling being about 26 years. It is demonstrated that the accuracy growth of the refraction tables proceeded at a slower rate than that of the observational catalogues of stellar positions. It is therefore understandable that the obstacles in the accounting for the atmospheric — the refractional ones inclusive — effects on the astrometric observations set limits to the development of the ground-based astrometry.

G. Teleki: *Progress report on the astronomical refraction*, Bull. Obs. Astron. Belgrade **134** (1984), 39–47.

A presentation is given of works on astronomical refraction, published in the period 1979 to 1982. Particular emphasis is given to research currently of special interest to astrometry, as for instance that relating to three dimensional refraction, atmospheric turbulence etc.

A. Yu. Yatsenko, G. Teleki: *Harzer's works on astronomical referaction viewed from today's standpoint*, Bull. Obs. Astron. Belgrade **135** (1985), 1–15.

A detailed survey and a critical analysis of P. Harzer's ideas and methods of computation of astronomical refraction in a three-dimensional medium is presented. On stating that Harzer's conceptions were of interest, ways of their possible application in the current astronomical practice are indicated.

G. Teleki: *Sadašnje mogućnosti u određivanju refrakcijskih uticaja*, VIII Kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Priština, (1985), 350.

G. Teleki: *Optical refraction: therminology and standards*, Publ. Astron. Obs. Belgrade **35** (1987), 338–342.

In continuation of the fundamentals and definitions advanced earlier by this author (Teleki, 1974), two more definitions relating to the optical refraction: "real (astronomical) refraction" (astronomical refraction taking place in the naturally distributed air layers of the Earth global atmosphere) and "OL (Oriani-Laplace) refraction" (refractional infuences over zenith distances less than 70° are suggested. Standards associated with the atmospheric models, pure refraction and OL refraction are given.

G. Teleki, C. Sugawa: *On the nature of astronomical refraction*, Publ. Astron. Obs. Belgrade **35** (1987), 1–16.

A survey is presented of factors — astrometric and meteorological — iluminating the nature of astronomical refraction. As a result of the general circulation of the atmosphere, the tilting of equal refractivity in the troposphere is really compensated by the reversed tilt in the lower stratosphere. From all the analysis there follows a general conclusion that, provided the surface airstrata are not excessively perturbed, the actual refraction influences are — for zenith distances under 70° — representable by the pure (normal) refraction with an error less than 0.″1. The Oriani-Laplace's theorem proves to be applicable on the (mean) three-dimensional atmosphere too.

G. Teleki: *Present-day potentialities of refraction influences determination and perspective developments*, Bull. Obs. Astron. Belgrade **136** (1986), 61–72.

A critical survey and analysis is presented of those questions that are of acute interest in the astronomical refraction investigation. Special weight is accorded to the development and the present accuracy in the refraction determination as well as to the prospective ways of its further improvement. Regarding further development put under scruting are: implementation of more accurate formulae in the refraction calculus; introduction of atmospheric models better matching the reality, accounting for the refraction influences within an instantaneous meteorological field; instrumental determination and the supression of refraction influences; prevention and more rigorous turning to advantage of the laws governing the radiation propagating. The effects associated with the radio refraction are discussed separately. The conclusion is derived that a marked accuracy improvement in the determination of the refraction influences might be expected in the years ahead.

6.2. The Quality of the Atmosphere — Site Testing
6.2. Kvalitet atmosfere — site testing

J. Arsenijević: *Selection of potential high altitude sites for an optical astronomical station*, Publ. Obs. Astron. Belgrade **31** (1981), 87.

A set of parameters relevant in selecting an astronomical observing station has been considered and a three-step procedure proposed. The first step is

shown in detail. A review of 7 different parameters in 17 regions qualifying a site for the next selecting steps has been given. Qualification of diferent sites according to four of those parameters has been applied. The mean rank gave the priority sequence of sites (the last column in Table I) from the aspect of their suitability for astronomical observations. The first five sites are in Macedonia, followed by two sites in Serbia.

J. Arsenijević, A. Kubičela, I. Vince, G. Djurašević, Z. Ivanović: *Some results of site-testing photometric measurements*, Publ. Obs. Astron. Belgrade **31** (1981), 89.

Stellar fluxes, extinction coefficients and sky brightness have been measured at Belgrade Astronomical Observagtory and several potential mountain observatory sites in SR Serbia during 1976–1980 period. All measurements, although not frequent, point to the very poor observing conditions at Belgrade and much better ones at the mountain sites. The photometrical differences among the potential observatory sites seem to be unsubstantial. The influence of urban sky glow of Prokuplje and Niš at Vidojevica have been examined more thoroughly and a definite location of the future high altitude station has been proposed at Jovanova Glava, 1020 m above the see level.

I. Vince, A. Kubičela: *Polarimetric measurements of relative air turbidity*, Publ. Obs. Astron. Belgrade **31** (1981), 49.

Based on measurements of sky polarization parameters a method for comparing various observatory sites according to their for daylight and one for night observations have been constructed. The observations during 1978 preliminarily indicate Preslap as the best considired location. The method is suitable for long-term monitoring of large-scale air polution.

G. Teleki: *Astrometric site selection*, Sun and Planetary System, D. Reidel Publ. Comp., Dordrecht, Holland – Boston, U.S.A. – London, England, (1982), 483.

J. Arsenijević: *Seasonal variations of the Hvar extinction coefficients*, Publ. Obs. Astron. Belgrade **33** (1985), 36.

Mean montly values of the extinction coefficients, measured at the Hvar Observatoy in the period 1972–78, and the gas density of some atmospheric layers at +45° latitude are discussed. High anticorrelation of these quantities over the atmospheric layers up to 7.5 km is stated. The amount of the gas component in total extinction is variable during the year, being minimum in the summer period when the extincion coeficient is maximum. The seasonal variations of the extinction are mainly the result of the aerosol component variations. The gas component causes a lessening of the effect of aerosol component variation in the total extinction.

O. Atanacković: *Preliminary investigation of the image motion at the Belgrade Observatory*, Publ. Obs. Astron. Belgrade **33** (1985), 83–87.

Image motion at different zenith distances has been investigated on the basis of star trails recorded photographically. Correlation between the image motion and meteorological parameters has been established. Correlation proved

rather close with the wind velocity and with relative humidity. The image motion amplitude is several tenths of arc second and its average period about 2.5 sec for the zenith distances 0° through 70°.

G. Teleki: *Atmospheric effects and selection of places for astrometric stations*, Kinematika i fizika nebesnyh tel **1**, No. 2 (1985), 85–91.

The paper deals with the Earth's atmosphere effect on astrometric instruments and on the stellar seeing. The problems of the protection against the atmospheric effect as well as the criteria for selection of places for astrometric stations are discussed.

7. PLANETARY SYSTEM
7. PLANETSKI SISTEM

7.1. Origin and Dynamics of the Earth-Moon System
7.1. Poreklo i dinamika sistema Zemlja-Mesec

P. Savić, G. Teleki: *Origin and dynamics of Earth's core*, Acta Geodaet., Geophys. et Montanist. Hung., Budapest, **20**, 1 (1985), 13.

P. Savić, G. Teleki: *Comments on "The origin of the Earth-Moon system"*, Earth, Moon and Planets **36**, 2 (1986), 139.

M. B. Protitch, V. Protitch-Benishek: *Quelques remarques sur l'hypothèse de la nonuniformité de la rotation terrestre*, IAU Colloquium No. 100 "Fundamentals of astrometry", (1987), Belgrade, Yugoslavia.

V. Protitch-Benishek, M. Protitch: *On the lunar secular acceleration: a possible approach*, Proc. of the 141st Symposium of IAU "Inertial Coordinate system on the Sky", Leningrad, (1990), 201–202.

On the basis of an original approach to the problem of secular acceleration of the Moon and fluctuations, lunar observations in the period 1861–1985 are analysed.

V. Protitch-Benishek, M. B. Protitch: *An approach to the problem of secular acceleration of the Moon*, Bull. Obs. Astron. Belgrade **142** (1990), 17–21.

If we adopt the solution of extended method in the Delaunay theory of the Moon as real and entirely logical and substitute the square term in the Moon's mean longitude by the very long period inequality, the remaining residuals — fluctuations — can be treated as the consequence of collected effect of a few other inequalities. The frequencies of these periodical terms correspond to the identical relative positions of the Moon's node, Sun and Earth. On the basis of such an approach to the problem of secular acceleration of the Moon and fluctuations, lunar observations in the period 1681–1985 are analysed. The results are quite consistent with values presented by other authors.

7.2. Astrometric Aspects of Eclipses, Transits and Occultations
7.2. Astrometrijski aspekti pomračenja, prolaza i okultacija

V. Protich-Benishek: *Occultations of stars by the Moon observed at the Belgrade astronomical observatory in the years 1978 and 1979*, Bull. Obs. Astron. Belgrade **131** (1981), 38–39.

During the period 1978–79, 63 occultations of stars by the Moon were observed at the Belgrade Astronomical Observatory with Askania refractor 135/1600 by the author. The UTC timings, corrected for personal equation in amount of $0^s.3$, $O-C$ residual distances of the stars from the computed positions of the Moon's outline for the given times of occultations, and all other relevant data are presented in two tables.

V. Protitch-Benishek: *Occultation de la planète Venus par la Lune du 20 janvier 1980 observée à Belgrade*, Bull. Obs. Astron. Belgrade **131** (1981), 40–42.

This paper gives the results of the observation of occultation of Venus by the Moon on 1980 January 20th, made with Askania astrograph of Belgrade Astronomical Observatory.

V. Protitch-Benishek: *Some results of the Mercury transit observations in 1970 and 1973 at Belgrade observatory*, in: W. Fricke, G. Teleki (eds.), Sun and Planetary System, D. Reidel Publ. Comp. (1982), 447–448.

The transits of Mercury across the solar disk in 1970 and 1973 have been observed at the Belgrade Observatory too. The photographs in 1970 have been taken in the focal plane of the refractor 650/10550 mm, whereas those in 1973 were achieved with the refractor guidescope of the astrograph 11/128 mm to which a special solar camera was attached. 56 in 1970 and 28 photographs in 1973 were obtained. Even though the revision of the observations of Mercury's transits made in Belgrade has been undertaken principally with the aim of deducing solar parallax in spite of the long prevaling view of the unsuitability of these transits for such refined calculation, we determined also other parameters connected with this phenomenon. In this paper the times of the contacts, the time of the least angular distance of centers and the semi-diameters of the Sun and Mercury are given.

V. Protitch-Benishek: *Transits of Mercury: results of Belgrade observations in 1970 and 1973*, Astron. Nachr. **304**, 6 (1983), 313–315.

Photographic observations of the transits of Mercury over the solar disk in 1973 at the Belgrade Observatory were used not only in order to determine the classical parameters, as the times of contacts and least distances to determine the apparent radii of the Sun and Mercury. The mean value of the Sun semi-diameter reduced to the distance unit differes from Auwers' value by about $1''.3$ while radius of the Mercury is in good agreement with Le Verrier's value. On the basis of quite homogenous observational material and precise observing data it was possible to derive the parallax of the Sun by means of the angular distance changes due to the parallactic effect in the course of transit. The

values are determined as: $8''.800 \pm 0''.008$ (1970) and $8''.788 \pm 0''.032$ (1973). The mean value resulting from the two transits is $\pi_s = 8''.794 \pm 0''.013$, an amount in striking agreement with that currently used.

V. Protitch-Benishek: *Merkurovi prolazi i paralaksa Sunca (Transits of Mercury and Solar Parallax*, (M.Sc. Thesis) (monografija sa bibliografijom), Publ. Obs. Astron. Belgrade **32** (1984), 1–159.

V. Protitch-Benishek, H. Božić: *Occultation of Sigma Sagittarii by Venus on 17 november 1981 observed from Hvar observatory*, Bull. Obs. Astron. Belgrade **136** (1986), 82–83.

Essentials are reported of the occultation of Sigma Sagittarii (Nunki) by Venus on November 17, 1981 observed at Hvar Observatory (Yugoslavia). The parameters of such exeptional phenomenon are given and analysed.

V. Protitch-Benishek: *Occultations of stars and planet Venus by the Moon observed at the Belgrade Astronomical Observatory in the years 1980–1984*, Bull. Obs. Astron. Belgrade **139** (1988), 67–69.

The paper contains results of visual observations of hundred stellar occultations and planet Venus by the Moon during the years 1980–1984 with Askania refractor 135/1600 at the Belgrade Observatory. The timings of Sigma Sagittarii occultation by Venus on 17 November 1981, observed from Hvar observatory, are also given.

7.3. Asteroids
7.3. Asteroidi

Z. Knežević: *Positions of minor planets obtained in 1979*, Bull. Obs. Astron. Belgrade **131** (1981), 33–37.

K. Pavlovski, Z. Knežević, M. Muminović: *Photometry of the asteroid (5) Astraea*, Proceedings of the IV Nat. Conf. of Yugoslav Astronomers, Sarajevo 1979, Publ. Astron. Obs. Sarajevo **1** (1981), 225–230.

Z. Knežević: *Observations made at Belgrade*, Minor Planet Circular, No. 5255.

Z. Knežević: *Observations made at Belgrade*, Minor Planet Circular, No. 7067.

Z. Vizi, Z. Knežević: *Observations made at Piskestet*, Minor Planet Circular, No. 7107.

Z. Knežević, V. Zappala: *An improved representation of the average opposition magnitudes of asteroids*, in: W. Fricke, G. Teleki (eds.), Sun and Planetary System, D. Reidel Publ. Comp., (1982), 299–302.

Z. Knežević: *Variation of the mean and median inclinations in the numbered minor planet sample*, Bull. Astron. Inst. Czech. **33** (1982), 267–231.

Z. Knežević, G. Djurašević, K. Pavlovski: *A review of photoelectric photometry of asteroids made at Hvar observatory*, Hvar Obs. Bull. **6** (1982) 1, 141–146.

A brief review is presented of results of the photoelectric observations of asteroids made at Hvar. The lightcurves are shown, and the interpretation of data demonstrated. Special attention is paid to the unusual case of 216 Kleopatra.

D. Olević, D. Djurović: *Contribution to the statistical analysis of Kirkwood's gaps*, Bulletin T. LXXIX de l'Académie Serbe des Sciences et des Arts — 1982, Classe des Sciences mathématiques et naturelles, Sciences mathématiques **12**.

On the sample of 2042 mumerated asteroids the statistical stability of width of Kirkwood's gaps (KG) has been investigated. On the basis of those data the authors show that asteroids the absolute magnitude $B(1,0)$ of which is greater than 13.0 do not affect the KG width. The correlation between the angle of eccentricity and the width of KG has been identified. The population density of the external side of vicinity of KG is greater than the internal one.

V. Zappala, M. di Martino, F. Scaltriti, G. Djurašević and Z. Knežević: *Photoelectric analysis of asteroid 216 Kleopatra: Implications for its shape*, Icarus **53** (1983), 458–464.

In some recent theoretical papers it has heen suggested that gravitationally bound "rubble piles" in hydrostatic equilibrium possibly exist among the asteroids. For a higher-than-critical value of the angular momentum acquired by such a body, the instability phenomena can produce fission into a binary system. S. J. Weidenschilling [*Icarus* **44**, 807-809 (1980)] suggestcd that 216 Kleopatra may represent a binary asteroid, since it has a large light curve amplitude (1.3–1.4 mag). In this paper new observations of Kleopatra are presented suggesting the equal plausibility of the single triaxial ellipsoid model. Namely when phase and aspect effects are taken into account, the actual maxiellipsoid model. Namely when phase and aspect effects are taken into account, the actual maximum amplitude is reduced to about 0.9 mag at 90° of aspect which is close to the value predicted by theory for the instability limit. Moreover, multiple-scattering effects [M. Poutanen, E. Bowell, and K. Lumme, *Bull. Amer. Astron. Soc.* **13**, 725 (1981)] can reduce the axial ratio a/b even more. If the single-body model is adopted, the density of Kleopatra should be on the order of $1.7\,\mathrm{g/cm^3}$. This low value seems reasonable for "rubble pile" models.

V. Zappala, Z. Knežević: *Photoelectric investigations of asteroids: selected observational programs for 1984*, Minor Planet Bull. **4** (1983), 29–31.

Z. Knežević: *The minor planet premature and related discoveries*, Bull. Obs. Astron. Belgrade **133** (1983), 16–26.

V. Zappala, P. Farinella, Z. Knežević, P. Paolicchi: *Collisional origin of the asteroid families: mass and velocity distributions*, Icarus **59** (1984), 261–285.

V. Zappala, Z. Knežević: *Rotation axes of asteroids: results for 14 objects*, Icarus **59** (1984), 436–455.

V. Zappala, M. Di Martino, Z. Knežević, and G. Djurašević: *New evidence for the effect of phase angle on asteroid lightcurve shape: 21 Lutetia* (research note), Astron. Astrophys. **130** (1984), 208–210.

New observations of the asteroid 21 Lutetia, obtained in 1981 and 1983 apparitions, are presented. They allowed a definitive value of the rotation period ($8^h.17$) to be deduced, instead of the previously adopted value of $6^h.133$. A comparison between 1962 and 1981 lightcurves, obtained at nearly the same ecliptic coordinates, revealed new convincing evidence for the phase angle effect on the lightcurve shape. This effect is very important for understanding asteroid morphology, but it sometimes leads to erroneous determinations of rotation periods.

Z. Knežević, P. Farinella: *Recent work on asteroid families*, XIX IAU Gen. Assembly, Commission 15, New Delhi, 1985.

M. Geffert, S. Wagner, S. Ninković: *Photographic observations of Minor Planets*, Acta Astronomica **35** (1985), 181.

40 positions of 11 minor planets are given which were measured on plates of the astrograph at Hoher List Observatory.

H. Debehogne, V. Protitch-Benishek: *135 precise astrometric positions of minor planets obtained at the GPO telescope of ESO — La Silla*, Bull. Obs. Astron. Belgrade **135** (1985), 56–63.

135 precise astrometric positions of minor planets observed at the GPO ($F = 4\,\mathrm{m}$, $D = 40\,\mathrm{cm}$) of the European Southern Observatory (ESO), La Silla, Chile, during February-March 1984 are presented. The observations have been made by H. Debehogne and G. G. Vieira. Two new asteroids were discovered during this mission. The plates were measured on the Ascorecord Zeiss measuring machine of the Observatoire Royal de Belgique. The reductions were performed with the Univac 9200 computer of the Observatoire Royal de Belgique, Institute Royal metéorologique and Institute d'Aeronomie Spatiale, using the dependence method by means of five reference stars. Data on reference stars, including dependences, are also given.

Z. Knežević: *Comparison of the asteriod proper elements obtained from various theories*, in: Asteroids, Comets, Meteors II (C. I. Lagerkvist, B. A. Lindblad, H. Lundstedt, H. Rickman, Eds.), (1986), 129–134.

D. Olević, S. Šegan and R. Pavlović: *Fundamental asteroid positions obtained with the Belgrade Zeiss astrograph*, Bull. Obs. Astron. Belgrade **136** (1986), 104.

Presented are 147 geocentric positions of the "fundamental" asteroids observed in the period 1967 to 1983. The reduction was implemented by the

method of dependences using 4 to 11 reference stars whose positions are taken from AGK3 and SAO catalogues.

H. Debehogne, V. Protitch-Benishek, D. Olević: *275 precise astrometric positions of minor planets obtained at the GPO telescope of ESO — La Silla*, Acta Astronomica **36**, 3–4 (1986), 457–462.

Precise astrometric positions of minor planets: 120 Lachesis, 366 Vincentina, 659 Nestor, 883 Mattarania, 1254 Erfordia, 1273 Helma, 1280 Baillauda, 2759 Idomeneus, 1984 SN 4, 1984 SO 4, 1984 SP 4 and 1984 SQ 4 obtained at the Grand Prism Objectif (GPO, $f = 4\,\mathrm{m}$, $D = 40\,\mathrm{cm}$) of the European Southern Observatory (ESO), La Silla, Chile, during September-October 1984 are presented here. Four new asteroids were discovered during this second mission in 1984 (see Bull. Obs. Astron. Belgrade **135**).

P. Farinella, P. Paolicchi, Ch. Froeschlè, Cl. Froeschlè, R. Gonczi, M. Carpino, V. Zappalá, and Z. Knežević: *Numerical experiments on the orbital evolution of family asteroids*, Bull. Amer. Astron. Soc. **18** (1986), 792.

V. Zappalá, Z. Knežević: *Pole coordinates of the asteroid 511 Davida as determined via the amplitude-magnitude method*, Icarus **65** (1986), 122–128.

Z. Knežević: *Comparison of the asteroid proper elements obtained from various theories*, in: Asteroids, Comets, Meteors (C. I. Lagerkvist, B. A. Lindblad, H. Lundstedt, and H. Rickman, Eds.), (1986), 129–134.

A. Milani, Z. Knežević: *Asteroid proper elements and secular perturbations: a second order theory*, Bull. Amer. Astron. Soc. **20** (1988), 864.

Z. Knežević: *Asteroid mean orbital elements*, Bull. Obs. Astron. Belgrade **139** (1988), 1–6.

Z. Knežević, M. Carpino, P. Farinella, Ch. Froeschlè, Cl. Froeschlè, R. Gonczi, B. Jovanović, P. Paolicchi, and V. Zappalá: *Asteroid short-periodic perturbations and the accuracy of mean orbital elements*, Astron. Astrophys. **192** (1988), 360–369.

Z. Knežević, B. Jovanović: *Asteroid short-periodic perturbations: critical ecentricity and inclination for analytically derived mean semimajor axes*, Proceedings 10th ERAM: Interplanetary matter (Z. Ceplecha and P. Pecina, Eds.), (1988), 107–109.

Cl. Froeschlè, P. Farinella, M. Carpino, Ch. Froeschlè, R. Gonczi, P. Paolicchi, V. Zappalá, and Z. Knežević: *Asteroid families*, in: The Few-Body Problem (M. Valtonen, Ed.), D. Reidel Publ. Co., Dordrecht, (1988), 101–116.

P. Farinella, Cl. Froeschlè, and Z. Knežević: *The puzzle of asteroid families*, in: Long-Term Dynamical Behaviour of Natural and Artifical N-Body Systems (A. E. Roy, Ed.), Kluwer Acad. Publ., (1988), 237–244.

H. Debehogne, V. Protitch-Benishek: *Orbite elliptique de l'asteroide E 3776 decouvert a La Silla*, Acta Astronomica **38** (1988), 153–155.

This paper contains the precise photographic observations of the new discovered minor planet with the Grand Prism Objective (GPO) at the ESO, La Silla in September 1986. On the basis of such minor planet positions the elliptic orbit is derived by Gauss-Encke method.

Z. Knežević: *Sopstveni elementi malih planeta kao parametri klasifikacije u familije*, Ph.D. thesis. Belgrade Univ., (1989).

Z. Knežević: *Report on the workshop "Proper elements and dynamical familes of asteroids"*, in: Asteroids, Comets, Meteors III (C. I. Lagerkvist, H. Rickman, B. A. Lindblad, M. Lindgren, Eds.), Uppsala Univ., (1989), 599–600.

P. Farinella, M. Carpino, Ch. Froeschlè, Cl. Froeschlè, R. Gonczi, Z. Knežević, and V. Zappalá: *The ages of asteroid families*, Astron. Astrophys. **217** (1989), 298–306.

Z. Knežević: *Asteroid long-periodic perturbations: the second order Hamiltonian*, Celestial Mechanics **46** (1989), 147–158.

G. B. Valsechi, A. Carusi, Z. Knežević, L. Kresàk, and J. G. Williams: *Identification of asteroid dynamical families*, in: Asteroids II (R. P. Binzel, T. Gehrels and M. S. Matthews, Eds.), Univ. Arizona Press, Tucson, (1989), 368–385.

Z. Knežević, A. Milani: *Asteroid proper elements from an analytical second order theory*, in: Asteroids II (R. P. Binzel, T. Gehrels and M. S. Matthews, Eds.). Univ. Arizona Press, Tucson, (1989), 1073–1089.

H. Debehogne, V. Protitch-Benishek: *Precise minor planet positions obtained at ESO — La Silla in February 1985*, Bull. Obs. Astron. Belgrade **140** (1989), 53–68.

During the first mission in 1985, 258 accurate positions of minor planets were obtained from observations in February by GPO telescope of ESO, La Silla, Chile. The measurements were carried out on a measuring machine Optronics at ESO, Garching and with Ascorecord Zeiss of the Observatoire Royal de Belgique. Three new minor planets were discovered.

H. Debehogne, D. Olević, V. Protitch-Benishek: *546 precise astrometric positions of minor planets obtained at the GPO telescope of ESO — La Silla*, Bull. Obs. Astron. Belgrade **141** (1989), 15–45.

Precise astrometric positions of minor planets: 383 Janina, 1111 Reinmuthia, 1586 Thiele, 1674 Groeneveld, 2682 Soromundi, 2911 1938 GJ, 3009 Coventry, 3032 Evans and 19 new ones, which provisional designations 1986 QB_1 – 1986 QC_3 have been given by the Minor Planet Center, are presented in this paper. Photographic observations of minor planets were carried out in August

and September 1986 with Grand Prism Objective (GPO) at the European Southern Observatory, La Silla, Chile, by H. Debehogne.

H. Debehogne, V. Protitch-Benishek, D. Olević: *Les orbites elliptiques des petites planètes E 3777 et E 3778 découvertes a La Silla*, Acta Astronomica **40** (1990), 4.

In this paper the precise astrometric positions of two new-discovered minor planets, observed with GPO at the ESO — La Silla in 1986, are presented. On the basis of such positions the elliptic orbits are calculated by Gauss-Encke method.

V. Zappalà, A. Cellino, P. Farinella, Z. Knežević: *Asteroid families. I. Identification by hierarchical clustering and reliability assessment*, Astron. J. **100**, 6 (1990), 2030.

Substantial discrepancies between the existing classifications and inconsistencies with the results of physical studies have motivated a research program aimed at deriving an improved classification of asteroids in dynamical families. We analyzed a set of 4100 numbered asteroids, whose proper elements had been computed by a new second-order, fourth-degree secular perturbation theory [Milani and Knežević 1990, Celestial Mech. (submitted)], and checked with numerical inegrations to assess their long-term stability. A mulitivariate data analysis technique (*hierarchical clustering*) was applied to build for each zone of the belt a *dendrogram* in the space of proper elements, with a distance function related to the incremental velocity needed for orbital change after ejection from a fragmented parent body. Families were then identified by comparing this dendrogram with a similar one, derived for a quasirandom distribution of elements matching the large-scale structure of the real distribution. A significance parameter was associated with each family, measuring its departure from random concentrations, and two robustness parameters were obtained by repeating the classification procedure after varying the elements by small amounts (consistent with the results of numerical tests of their long-term stability) and changing the coefficients of the distance function. The most significant and robust families are those associated with Themis, Eos, and Koronis, that collectively include about 14% of the known main-belt population; but 12 more reliable and robust families were found throughout the belt, most of which partially match those found in previous classifications. In the Flora region of the inner belt, a reliable identification of families is difficult, since the background has a high density and the accuracy of proper eccentricities and incilinations is poor, mainly because of the proximity to the strong ν_6 secular resonance. Other results include: a relatively populous Eunomia family, lacking large C-type members; a small family having Vesta as its largest object; the disappearance of the unlikely association in one family (Nysa-Hertha) of M, F, and E types; the existence of two small, but robust families with sizeable largest members in the Themis region, at moderate inclinations.

A. Milani, Z. Knežević: *Secular perturbation theory and computation of asteroid proper elements*, Celestial Mechanics and Dynamical Astronomy **49** (1990), 347–411.

A new theory for the calculation of proper elements, taking into account

terms of degree four in the eccentricities and inclinations, and also terms of order two in the mass of Jupiter, has been derived and programmed in a self contained code. It has many advantages with respect to the previous ones. Being fully analytical, it defines an explicit algorithm applicable to any chosen set of orbits. Unlike first order theories, it takes into account the effect of shallow resonances upon the secular frequencies; this effect is quite substantial, e.g. for Themis. Short periodic effects are corrected for by a rigorous procedure. Unlike linear theories, it accounts for the effects of higher degree terms and can thus be applied to asteroids with low to moderate eccentricity and inclination; secular resonances resulting from the combination of up to four secular frequencies can be accounted for. The new theory is self checking: the proper elements being computed with an iterative algorithm, the behaviour of the iteration can be used to define a quality code. The amount of computation required for a single set of osculating elements, although not negligible, is such that the method can be systematically applied on long lists of osculating orbital elements, taken either from catalogues of observed objects or from the output of orbit computations. As a result, this theory has been used to derive proper elements for 4100 numbered asteroids, and to test the accuracy by means of numerical integrations. These results are discussed both from a quantitative point of view, to derive an a posteriori accuracy of the proper elements sets, and from a qualitative one, by comparison with the higher degree secular resonance theory.

7.4. Comets
7.4. Komete

V. Protić-Benišek: *Parabolic orbit of the comet 1977m – Kohler*, Proceedings of the National Conference of Yugoslav astronomers, Publ. Obs. Astron. Sarajevo **1** (1981), 287–291.

On the basis of photographic observations of the comet 197m – Kohler, carried out at the Belgrade Observatory from 3 October to 22 November 1977, its parabolic orbit was derived. The Olbers' method, adjusted to the given case, was employed. Three positions, equidistant with respect to the mean time of observations, were selected from the whole series and the first system of elements was derived. The $(O - C)$ values were then smoothed and a final system established. A good accordance of our orbital elements with those of B. Marsden, derived on the basis of a large number of observations of this comet, covering a considerable longer time interval, can be stated.

V. Protitch-Benishek: *Comet astrographic positions obtained at Belgrade astronomical observatory during 1977–1982*, Bull. Obs. Astron. Belgrade **135** (1985), 54.

During the period 1977–1982 the photographic observations of the four bright comets: 1977 m Kohler, 1979 l Bradfield, 1980 u Panther and 1982 f Chyrymov-Gerasimenko were carried out with the Askania astrograph of the Belgrade Astronomical Observatory. 43 astrographic positions for the equinox 1950.0 were obtained.

V. Protitch-Benishek: *Observations of comet Panther from Belgrade astronomical observatory*, Minor Planet Circular, No. 9437, (1985).

V. Protitch-Benishek: *Observations of comet Chyrymov-Gerasimenko from Belgrade astronomical observatory*, Minor Planet Circular, No. 9513, (1985).

V. Protitch-Benishek: *Precise astrographic positions of comet Giacobini-Zinner observed from Belgrade astronomical observatory*, Minor Planet Circular, Nos. 9981, 9988, 9989, (1985).

The comet Giacobini-Zinner was observed over a nearly two months period, from 22 July to 14 September 1985, mostly with the 125/1000 mm Askania photo-visual equatorial. According to the number of its observations this Observatory stands at the 27th place among 61 participants in the Giacobini-Zinner comet imaging. These astrographic positions, together with observations of other observatories, served for establishing accurate comet's orbit (IHW orbit No 31), shortly before its encounter with the ICE spacecraft. A curious event took place on 14 September: the comet Giacobini-Zinner approached apparently Halley as closely as 2°. However, since it was Halley that we tracked, a diffuse Giacobini-Zinner comet's trail appears on our photograph in consequence of its apparent motion having been considerably faster.

V. Protitch-Benishek: *Observations of comet P/Halley from Belgrade astronomical observatory*, Minor Planet Circulars, Nos. 10209–10211, (1985).

This paper contains the results of comet H alley observations from September 11, 1985 until 27 May 1986, when it was observed as many as 75 times. On 9 December 1985 the occultation of BD +6°5207 by Halley was observed.

V. Protitch-Benishek: *Results of comet Halley observations at the Belgrade observatory*, Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, Heidelberg, 27–31 October 1986, ESA SP-250 (1986), 265–266.

With fifty years experience and tradition in Comet observation and research the Belgrade Observatory joined the International Halley Watch as soon as the Comet got within the reach of its instruments — actually not earlier than September 1985. Comet Halley observations were carried out from September 1985 through June 1986, 75 plates in all having been acquired during this period. The resulting precise astrographic positions were immediately communicated to the IHW Center. The periodic comet Giacobini-Zinner was also systematically observed during the period June-September 1985, the observations having particularly been intensified in the interval just preceding the ICE spacecraft's closest approach to it. On 9 December 1985 the occultation of BD +6°5207 by Halley was observed. The results of observing this event are briefly reviewed in the present paper.

V. Protitch-Benishek: *Precise astrographic positions of Halley comet*, Minor Planet Circular, No. 10331, (1986).

Some of astrographic precise positions of comet Halley after its perihelion passage are presented.

Komete — svedoci prošlosti, editori: J. Arsenijević i Dj. Teleki, Astronomska opservatorija i Astronomsko društvo "Ruđer Bošković", Beograd, (1986), pp. 142.
- V. Kršljanin: *Nastanak i poreklo kometa*, 7.
- Dr. M. Dimitrijević: *Izgled i struktura kometa*, 33.
- Mr. I. Vince: *Stanje materije u kometama*, 45.
- Dr. V. Vujnović: *Otkuda potječe svijetlost kometa*, 55.
- Dr. M. Dimitrijević: *Uticaj kometa na Zemlju*, 63.
- S. Jankov: *Prošlost Halejeve komete*, 69.
- Dr. Dj. Teleki: *Ujedinjenim snagama u istraživanje Halejeve komete*, 79.
- N. Čabrić: *Vidljivost Halejeve komete iz Beograda*, 99.
- Mr. V. Protić-Benišek: *Prvi plodovi istraživanja Halejeve komete u 1985–86. god.*, 105.
- N. Janković: *Kometa u srpskim zapisima i letopisima*, 111.
- M. Protić: *Smrt jedne komete*, 121.
- Mr. J. Arsenijević: *Neki podaci o kometama*, 125.
- Mr. V. Protić-Benišek: *Posmatranja kometa sa Astronomske opservatorije u Beogradu*, 127.
- M. Prosen: *Astronomi-amateri i komete*, 135.
- M. Djokić: *O nastanku termina kometa i neki stari pokušaji objašnjenja kometskih pojava*, 141.

V. Protitch-Benishek: *Comet astrometry in the post-Halley era*, IX Nacionalna konferencija astronoma Jugoslavije, Sarajevo, (1988).

This paper presents a brief review on the major astrometric results collected during the IHW Astrometric Network and attention is drawn to different aspects of such future investigations.

8. SUN
8. SUNCE

A. Kubičela, J. Arsenijević, S. Manola, Z. Stokić, N. Uzelac, I. Vince: *Flash spectrum observations during total solar eclipse, 1980*, Proc. Symp. Phys. Ion. Gases (SPIG), Ed. B. Čobić, **298** (1980).

A. Kubičela: *Ortogonalne komponente prividne godišnje precesije Sunca*, Saopšteno na VII Kongresu MFA Jugoslavije, Bečići, (1980).

A. Kubičela, M. Karabin: *Detailed treatment of syndic solar rotation*, Publ. Dept. Astron. Univ. Beograd **11** (1981), 35.

Begining with a previous vectorial results about the synodic solar rotation dependance on the inclination of solar equator, the classical definition of synodic solar rotation has been reconsidered in some detail. The angular difference between one synodic and sidereal solar rotation turn, $\Delta\lambda$, as a function of the longitude of the Earth and the inclination of the solar equator,

β, indicates a substantially different nature of trigonometric and vectorial definition of synodic solar rotation. Only a long-term mean value of $\Delta\lambda$ does not depend on β. For the extreme case, $\beta = 90°$, $\Delta\lambda$ shows a purely geometrical discontinuity. On the contrary, the sidereal, apparent annual and synodic rotations of the solar globe are smooth and can be described by the corresponding vectorial angular velocities.

A. Kubičela, M. Karabin: *Line-of-sight velocity field of synodic solar rotation*, Saopšteno na VI Evropskom regionalnom astronomskom sastanku, Dubrovnik, (1981).

A. Kubičela, M. Karabin: *An integral supergranular contribution to the global-scale photospheric line-of-sight velocity field*, Publ. Astron. Obs. Sarajevo **1** (1981), 185.

Taking the contribution of an unresolved supergranular line-of-sight velocity of a given sign as proportional to the mean velocity and to the relative area under the same given velocity, and taking into account the curvature of the photosphere within a supergranule, a new integral effect of higher contribution of approaching velocities in supergranules has been found. It is not negligible near the limb and must be of certain importance in photospheric global-scale velocity and limb effect observations.

A. Kubičela: *Observation of total solar eclipse of 16. February 1980*, Observation of the Total Solar Eclipse of February 16th 1980, ed. S. K. Trehan, Indian National Sci. Academy (1981), 16.

The electronic and photographic equipment used by Belgrade solar expedition in India to observe the partial phases of the eeclipse, the flash spectrum, and the polarization of the corona, as well as the obtained results have been described.

A. Kubičela, V. Ruždjak: *Near future research in solar physics in Yugoslavia*, Near Future Plans for Solar Research, ed. C. Jordan, Oxford, (1981), 78.

The research programs in solar physics of Belgrade Astronomical Observatory and Hvar observatory in 1980-ies have been envisaged. The former one is concentrated on very large scale photospheric velocity research observing with the existing equatorial solar spectrograph. In cooperation with Ondřejeov Observatory, the last one focuses its interest on various photespheric and chromospheric physical aspects of active regions. The need for young astrophysicists and international cooperation has been stressed.

A. Kubičela, M. Karabin: *Line-of-sight velocity field of synodic solar rotation*, Proc. VI European Regional Meeting in Astronomy, ed. W. Fricke, G. Teleki, Reidel Publ. Co., (1982), 73.

Angular velocity components of synodic solar rotation have been treated as vectors. A colinear and a perpendicular components with respect to the solar

rotation axis have been found. Factor $\cos 7°.25$ has been introduced into the apparent efect of the Earth's orbital motion.

A. Kubičela: *Orthogonal components of the apparent yearly precession of the Sun*, Hvar Obs. Bull. Suppl., **1** (1982), 39.

Starting from the apparent yearly precession of the Sun described elsewhere, the components of that motion in the plane of the solar disk have been calculated. A westward apparent velocity amounting up to $2.2\,\mathrm{ms}^{-1}$ has been found.

A. Kubičela, I. Vince: *Effects of extrafocal observation wth the solar spectrograph of the Belgrade astronomical observatory, I. Solar Rotation Line-of-sight Velocities*, Bull. Obs. Astron. Belgrade **133** (1983), 1.

The optical averaging of line-of-sight velocities in regions $3'.8 \times 3'.8$ at the solar disk has been numerically imitated. The contributions of local line-of-sight velocities at any point of the disk have been assumed as proportional to the photospheric continuum intensity at the same point. Such a procedure yields systematically smaller line-of-sight velocities of the solar rotation. The necesary corrections depending on heliographic parameters P and B_0 have been fond.

A. Kubičela, M. Karabin: *Another view of synodic solar rotation*, Solar Phys., **84** (1983), 389.

Adding the angular velocity of sidereal solar rotation and the apparent rotational effect of the Earth's revolution vectorially, a new synodic solar rotation vector has been obtained. The sidereal and synodic solar rotation axes (and equators) are separated. Using the known parameters of the Earth's orbital motion, the synodic rotation angular velocity and the inclination of the synodic equator, the corresponding sidereal rotation parameters have been calculated ($\omega = 2.915 \times 10^{-6}\,\mathrm{rad\,s}^{-1}$ and $i_1 = 6°.76$). Various linear rotational velocities at the solar globe are briefly described.

A. Kubičela, I. Vince: *Effects of extrafocal observation with the solar spectrograph of the Belgrade astronomical observatory, II. Cases of Various Wavelengths and Space-resolutions*, Bull. Obs. Astron. Belgrade **134** (1984), 37.

According to an already published procedure, the space-averaging of the solar image within square regions from $3'.8$ to $0'.5$ side and for wavelengths 630 nm, 500 nm and 400 nm have been calculated. For a selected sample of P and B_0 the effect has been found amounting up to $33\,\mathrm{ms}^{-1}$.

A. Kubičela: *Dva prodora u dinamici sunčeve fotosfere*, Pregledno predavanje na VIII Kongresu MFA Jugoslavije, Priština, 1985.

A. Kubičela, M. Karabin, Z. Ivanović: *Merenje radijalnih brzina tačaka na Sunčevom disku*, Saopšteno na VIII Kongresu MFA Jugoslavije, Priština, 1985.

A. Kubičela, I. Vince, Z. Ivanović: *Effects of extrafocal observation with the solar spectrograph of the Belgrade astronomical observatory, III. Integration of the limb effect*, Bull. Obs. Astron. Belgrade **135** (1985), 21.

Besides six already konwn limb effect functions, another one (the Belgrade-Oxford function) has been evaluated. Simulating numerically extrafocal observations of the solar disk, a set of corrections for space-integration of solar radiation within the squares of 3'.8, 2'.0 and 1'.0 sides has been calculated for all the limb effect functions. The corrections amount up to $112\,\mathrm{ms}^{-1}$ (or up to $4\,\mathrm{ms}^{-1}$ in the case of Belgrade observations).

Z. Ivanović, I. Vince: *Correction to the solar line-of-sight velocities for topocentric motion of the observer*, Publ. Obs. Astron. Belgrade **33** (1985), 19–22.

Method for determining the radial velocity of an observer moving around the Sun is described. The Julian day (JD) as a unique independent variable is used. The method is developed for the reduction of data obtained at Belgrade astronomical observatory in the course of the solar spectral line shift observations. The accuracy is about $\pm 0.1\,\mathrm{m/s}$.

A. Kubičela, M. Karabin, I. Vince, Z. Ivanović: *Further Belgrade results of the large-scale photospheric velocity research*, Bull. Obs. Astron. Belgrade **136** (1986), 1.

From a series of FeI 630.25 nm Doppler shift observations solar equatorial rotational velocity of $2.82\,\mu\mathrm{rad\,s}^{-1}$ has been found. There is a difference between the active and quiet photosphere. The central meridian and equatorial limb effect curves as well as the meridian excess have been evaluated and discussed.

A. Kubičela: *Problem sinodičke rotacije Sunca*, Saopšteno na I Seminaru "Astrofizika u Jugoslaviji", Ljubljana, (1986).

A. Kubičela: *Relation between solar sidereal and synodic rotation axes*, Solar Phys. **106** (1986), 403.

Kinematic picture concerning the solar synodic and sidereal rotation axes has been considered in some detail. Large changes in the synodic rotation pole have been found for some hypothetical cases of out-of-ecliptic intra-Mercurian orbits. The influence of solar differential rotation and variable planetary velocity along the orbit have been taken into account and a continuous set of co-existing synodic poles oscillating around a mean position has been found. The relevant numerical values for the Earth are given and the possibility of detecting the existence of the two rotation axes has been pointed out.

M. Vukićević-Karabin, J. Arsenijević: *Solar and stellar activity phenomena*, Bull. Obs. Astron. Belgrade **136** (1986), 53.

A review is presented of highlghts in the solar and stellar activity researches based on latest information, published in the works of other authors, and on the measurements caried out at the Belgrade Observatory. New assumptions

are advanced concerning discret magnetic solar field of 1–2 KG strength in tubes of 200–400 km diameter. Dependence is outlined of the stellar rotation rate and magnetic activity on stellar age. It is demonstrated that stars with covective zone display magnetic activity which in some of the stars is cyclically repetitive.

E. Ribes, J.-C. Ribes, I. Vince, Ph. Merlin: *On the oscillation of the solar diameter*, C. R. Acad. Sci. Paris **307**, Serie II (1988), 1195–1201.

Systematic visual measurements of the solar diameter (both polar and equatorial) made with the meridian circle have been carried out at the Belgrade astronomical observatory from 1975. The measurements indicate an oscillation similar to that obtained by Laclare with the astrolabe measurements, i.e. a similar period, phase and amplitude. This result confirms the solar (or terestrial atmosphere) nature of the observed oscillation, thus eliminating the personal equation and instrumental biases.

E. Ribes, J.-C. Ribes, I. Vince, Ph. Merlin: *A survey of historical and recent solar diameter observations*, Adv. Space Res. Vol. **8**. No. 7 (1988), 129–132.

We report new observational evidence of periodic changes in the solar diameter. Progress has been made at two levels:

— Systematic measurements of the solar diameter (both horizontal and vertical) have been made using a Meridian Circle at the Belgrade Observatory, from 1974 to 1986. An oscillation (amplitude of ± 0.20 arcsec, period of about 900 days) is present in both diameters. Although the data are fewer and noisier than the astrolabe measurements made by Laclare (1987), they provide an independent confirmation of the presence of the damped oscillation reported by Delache et al. (1985), with the same phase, period and amplitude.

— A Fourier analysis of the solar diameters observed by La Hire (6.797 values), from 1683 to 1718, has been made. The analysis exhibits a number of peaks, all of which are present in the power spectrum of modern diameter data. In paraticular, a peak at 9.6 years is clearly visible. This result indicates that the solar cycle occured during the Maunder minimum, although the dearth of sunspots at the solar surface is confirmed. Some possible implications of these findings are suggested with respect to climatic variability on Earth.

A. Kubičela: *Problem of synodic solar rotation*, Bull. Obs. Astron. Belgrade **140** (1989), 105.

The problem of combining solar sidereal rotation and Earth's revolution in order to determine the solar synodic rotation is pointed out. The early attempts to solve the problem — the hypothesis of the apparent yearly precession and the projection of angular velocity vectors onto the solar rotation axis — are reviewed, and the ripening of the Belgrade hypothesis of separate synodic and sidereal solar rotation axes, as well as some of its results, are presented.

E. Ribes, I. Vince, E. Ferreira: *Meridian Circulation and Solar Rotation Over Solar Cycle 21.*, in: The Sun and Cool Stars: Activity, Magnetism, Dynamics, IAU Colloquium 130 (1990), 51.

M. Vuletić, P. Cugnon, J. Arsenijević: *Changes in residual polarization of the corona and the solar activity cycle*, Proc. 6th Europ. Meeting on Solar Phys., The dynamic Sun, Debrecen, ed. L. Dezső, (1990), 106.

9. STARS
9. ZVEZDE

9.1. Double and Multiple Star Systems
9.1. Dvojni i višestruki zvezdani sistemi

S. Kříž, J. Arsenijević, J. Grygar, P. Harmanec, J. Horn, P. Koubský, K. Pavlovski, J. Zverko, F. Ždárský: *Strongly interacting binary RX Cas*, Bull. Astron. Inst. Czech. **31**, 5 (1980), 284.

UBV photoelectric observations of RX Cas made in the years 1975 to 1977 at Hvar and Skalnaté Pleso Observatories are presented. The asymmetry of the light curve and the long-term light variations with the period of 516 days are most conspicuous in the U colour. The high increase of the orbital period ($\Delta P/P = 6.3 \times 10^{-7}$ per cycle) leads to an estimated rate of mass exchange greater than 10^{-6} m/year. The spectroscopic elements by Struve (1944) are re-computed. The case B of mass transfer or the second reverse transfer seems to be appropriate for RX Cas. Possible explanations of light anomalies are discussed.

G. M. Popović: *Orbites nouvelles (ADS 1976)*, Circ. Inf., No. 81, UAI, Comm. des Etoiles Doubles, (Juin 1980).

G. M. Popović: *Étoiles doubles nouvelles (GP 156)*, Circ. Inf., No. 81, UAI, Comm. des Etoiles Doubles, (Juin 1980).

D. J. Zulević: *Orbites nouvelles (ADS 1548, 8145, 10085, 16368)*, Circ. Inf., No 81, UAI, Comm. des Etoiles Doubles, (Juin 1980).

V. Erceg: *Orbites nouvelles de ADS 2301 = A 2414*, Circ. Inf., No. 81, UAI, Comm. des Etoiles Doubles, (Juin 1980).

V. Erceg: *Les orbites de deux etoiles doubles visuelles. (ADS 2301 = A2414 et ADS 2531 = A 829)*, Bull. Obs. Astron. Belgrade **131** (1981), 20–22.

The autor presents: the orbitae elements, the dynamical parallaxes, the Thiele-Innes constants, the masses, the absolute magnitudes and the ephemerides.

V. Erceg: *Orbite nouvelle de ABS 1345 = A 1*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

V. Erceg: *Orbites nouvelles de ADS 674 = A 921AB*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

V. Erceg: *Orbites nouvelles de ADS 1393 = HU 804*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

D. J. Zulević: *Orbits of five visual binaries*, Bull. Obs. Astron. Belgrade **131** (1981), 15.

Orbits and dynamical parallaxes are presented for five visual binary systems: ADS 1548, ADS 8145, ADS 10085, ADS 16131 and ADS 16368. Calculated positiona are compared with observations and ephemerides are given for each system.

D. J. Zulević: *Micrometer measures of double stars (ser. 32)*, Bull. Obs. Astron. Belgrade **131** (1981), 27.

Presented here are 153 measures of 78 Double Stars made with 65/1055 cm refractor of Belgrade Observatory.

D. J. Zulević: *Orbites nouvelles (ADS 1371, 7758, 11989, 16877)*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

G. M. Popović: *Orbites nouvelles (ADS 3174)*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

G. M. Popović: *Étoiles doubles nouvelles (GP 158, 162, 163, 161, 157, 165)*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

G. M. Popović: *New double stars discovered in Belgrade with the Zeiss refractor 65/1055 cm, Supplement VI*, Bull. Obs. Astron. Belgrade **131** (1981), 23.

G. M. Popović: *Glavni pravci i dostignuća savremenih ispitivanja višestrukih sistema*, Publ. Astron. Obs. Sarajevo **1**, No 1, (1981), 269.

D. Olević, D. Djurović: *The periodicity of residuals $\Delta\rho$ and $\Delta\theta$ of the double star ADS 11520*, Publ. Department of Astronomy, Univ. Belgrade **11** (1981).

The periodical variations of the residuals of radius $(O - C)_\rho$ and positional angle $(O - C)_\theta$ of double star ADS 11520 was remarked. From the observations made in period 1900–1976 the corrections of Van den Boss's orbital elements are computed and it is shown that the periodical variations of residuals relative to the new orbital elements exist.

V. Erceg: *Les orbites de trois étoiles doubles visuelles: (ADS 674=A921AB, ADS 1445=AL et ADS 1393=HU 804)*, Bull. Obs. Astron. Belgrade **132** (1982), 22.

The autor presents: the orbital elements, The Thiele-Innes constants, the dynamical parallaxes, the masses and ephemerides.

V. Erceg: *Orbites nouvelles de ADS 2609AB=BU 787AB*, Circ. Inf., UAI, Comm. des Etoiles Doubles.

V. Erceg: *Orbites nouvelles de ADS 3058 = HU 302*, Circ. Inf., No. 88, UAI, Comm. des Etoiles Doubles, (Oct. 1982).

D. J. Zulević: *Orbits of four visual binaries*, Bull. Obs. Astron. Belgrade **132** (1982), 17.

Orbits and dynamical parallaxes are presented for four visual binary systems: ADS 1373, ADS 7758, ADS 11989 and ADS 16877. Calculated positions are compared with observations and ephemerides are given for each system.

D. J. Zulević: *Micrometer measures of double stars (ser. 33)*, Bull. Obs. Astron. Belgrade **132** (1982), 25.

Presented here are 289 measures of 134 Double Star made sith 65/1055 cm refractor of Belgrade Observatory.

G. M. Popović: *An unidentified object in the constellation Cetus from 1911*, Bull. Inf. Cent. Données Stellaires, No. 22 (1982), 96.

G. M. Popović: *Orbites nouvelles (ADS 5958)*, Circ. Inf., No. 86,, UAI, Comm. des Etoiles Doubles (Février 1982).

G. M. Popović: *Étoiles doubles nouvelles, (GP 169, 171, 170, 172)*, Circ. Inf., No. 88, UAI, Comm. des Etoiles Doubles, (Octobre 1982).

G. M. Popović: *Orbital elements of visual binary systems Σ 248 = ADS 1786 and Σ 535 = ADS 3174*, Bull. Obs. Astron. Belgrade **132** (1982), 13.

G. M. Popović: *Micrometer measures of double stars (series 34)*, Bull. Obs. Astron. Belgrade **132** (1982), 34.

V. Erceg: *Orbites nouvelles de ADS 2111 = BU 83*, Circ. Inf., UAI, Comm. des Etoiles Doubles, (1983).

V. Erceg: *Orbites nouvelles de GLE 1 = IDS 04148S6072*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (1983).

V. Erceg: *Orbite nouvelle de ADS 8636 = A3009*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (Oct. 1983).

V. Erceg: *Orbite nouvelle de HU 1566 = IDS 05312S5108*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (Oct. 1983).

G. M. Popović: *Orbites nouvelles (ADS 13028AB)*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (Oct. 1983).

G. M. Popović: *Étoiles doubles nouvelles (GP 178 AB, AC, 173)*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (Oct. 1983).

G. M. Popović: *Orbital elements of the binary system ADS 5958 = Σ 170*, Bull. Obs. Astron. Belgrade **133** (1983), 27.

G. M. Popović: *Micrometer measures of double stars (series 35)*, Bull. Obs. Astron. Belgrade **133** (1983), 31.

D. J. Zulević: *Orbites nouvelles (ADS 4)*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (1983).

D. J. Zulević: *Micrometer measures of double stars (ser. 36)*, Bull. Obs. Astron. Belgrade **133** (1983), 38.

Presented here are 167 measures of 77 double stars made with 65/1055 cm refractor of Belgrade Observatory.

V. Erceg: *Les orbites de quatre Etoiles doubles visuelles. (ADS 2111 = BU 83, ADS 2609AB = BU 787AB, ADS 3058 = HU 302, GLE 1)*, Bull. Obs. Astron. Belgrade **134** (1984), 54.

The autor presents: the orbital elements, the Thiele-Innes constants, the dynamical paralaxes, the masses and ephemerides.

V. Erceg: *Orbites nouvelles de ADS 5707AB = A 3042*, Circ. Inf., No. 93, UAI, Comm. des Etoiles Doubles, (Juin 1984).

D. Olević, V. Erceg: *Orbites nouvelles de ADS 8718 = HU 641*, Circ. Inf., No. 95, UAI, Comm. des Etoiles Doubles, (Feb. 1984).

D. J. Zulević: *Micrometer measures of double stars (ser. 38)*, Bull. Obs. Astron. Belgrade **134** (1984), 64.

Presented are 262 measures of 107 double stars made with the 65/1055 cm refractor of Belgrade Observatory.

D. J. Zulević: *Orbits of two visual binaries*, Bull. Obs. Astron. Belgrade **134** (1984), 58.

Orbits and dynamical parallaxes are presented for the binaries ADS 4,974. Calculated positions are compared with observations and ephemerides are given for each system.

D. J. Zulević: *Orbites nouvelles (ADS 2446)*, Circ. Inf., No. 93, UAI, Comm. des Etoiles Doubles, (1984).

G. M. Popović: *Micrometer measures of double stars (series 37)*, Bull. Obs. Astron. Belgrade **134** (1984), 60.

D. Olević, V. Erceg: *Orbite nouvelle de 8926 = A 1789*, Circ. Inf., No. 95, UAI, Comm. des Etoiles Doubles, (Feb. 1985).

V. Erceg, D. Olević: *Orbite nouvelle de SLR 19 = IDS 14012S4924*, Circ. Inf., No. 96, UAI, Comm. des Etoiles Doubles, (Juin 1985).

V. Erceg: *Les orbites de trois étoiles doubles visuelles. (ADS 3686, IDS 05312S5108, ADS 5707AB)*, Bull. Obs. Astron. Belgrade **135** (1985), 45–46.

The author presents: the orbital elements, the Thiele-Innes constants, the dynamical parallaxes, the masses and the ephemerides.

D. J. Zulević: *Étoiles doubles nouvelles (Lunette de 65 cm Belgrade)*, Circ. Inf., No. 96. UAI, Comm. des Etoiles Doubles, (1985).

G. M. Popović: *IDS triple systems*, Publ. Obs. Astron. Belgrade **33** (1985), 88.

G. Djurašević: *Critical equipotential surfaces in close binary systems*, Astrophys. Space Sci. **124** (1986), 5–25.

The well-known problem of reckoning the critical surfaces (equipotential zero-velocity surfaces) in the close binary systems is approached by an independent method. The formulation of the problem is based on the assumptions of the binary's matter consisting of ionized hydrogen, the system possessing black-body radiation, a potential magnetic field, being in adiabatic equilibrium. Total pressure and total internal energy are examined. The model, implying synchronous rotation of the components, is described by hydromagnetic equations. For a statical case, however, it is representable by the equation of motion alone. Next, the temperature field is reproduced whereby the ratio $P_r/P_g = \alpha$ is playing part of a free parameter. The resulting potential functions, applied to particular binaries, furnish the Lagrangian collinear points, critical surfaces and potentials over them in terms of α. The families of surfaces thus obtained, compared with those originating from the Roche model, differ qualitatively in their geometry, position of the collinear equilibrium points, number of possible equilibrium states and the values of critical potentials. At identifying the allowed and forbidden regions of the gas motion new areas have been disclosed across which the gas outflow can take place and more possibilities of shell forming both around the individual components and the system as a whole. As the gas enthalpy and radiation are increased, the surface geometry is undergoing changes. The method enables the intensity of gas velocity to be ascertained at any point in the system. The results of the method outlined here complement the picture of possible equilibrium states in the close binary systems in the presence of radiation and magnetic field.

V. Erceg and D. Olević: *Orbits of four visual double stras ADS 8718, ADS 8926, IDS 14012S4924, IDS 14571S4012)*, Bull. Obs. Astron. Belgrade **136** (1986), 78–81.

Presented are preliminary orbital elements, dynamical parallaxes, absolute magnitudes, masses, ephemeris and residuals of four visual double stars.

V. Erceg, D. Olević: *Orbite nouvelle de I 1262 = IDS 14571S4012*, Circ. Inf., No. 98, UAI, Comm. des Etoiles Doubles, (Feb. 1986).

V. Erceg, D. Olević: *Orbites nouvelles de HU 657 = ADS 9711*, Circ. Inf., No. 100, UAI, Comm. des Etoiles Doubles, (Oct. 1986).

D. J. Zulević: *Orbites nouvelles (ADS 8242, 10459)*, Circ. Inf., No. 98, UAI, Comm. des Etoiles Doubles, (1986).

D. J. Zulević: *Orbites nouvelles (ADS 10385)*, Circ. Inf., No. 99, UAI, Comm. des Etoiles Doubles, (1986).

D. J. Zulević: *Micrometer measures of double stars (Ser. 40)*, Bull. Obs. Astron. Belgrade **136** (1986), 91–99.

Presented here are 289 measures of 103 double stras made with 65/1055 cm refractor of Belgrade Observatory.

G. M. Popović: *Orbite nouvelle: ADS 15007*, Circ. Inf., No. 98, UAI, Comm. des Etoiles Doubles, (1986).

G. M. Popović: *Étoiles doubles nouvelles (GP 192, 193, 191, 188, 190)*, Circ. Inf., No. 98, UAI, Comm. des Etoiles Doubles, (1986).

G. M. Popović: *Orbite nouvelle: ADS 9595*, Circ. Inf., No. 100, UAI, Comm. des Etoiles Doubles, (1986).

G. M. Popović: *New double stars discovered at Belgrade observatory with the Zeiss refractor 65/1055 cm. Supp. VII*, Bull. Obs. Astron. Belgrade **136** (1986), 49–52.

G. M. Popović: *Micrometer measures of double stars (Series 39)*, Bull. Obs. Astron. Belgrade **136** (1986), 84–90.

D. Olević, V. Erceg: *Orbits of two visual double stars. (IDS 15428N5059 and IDS 16358S3653)*, Bull. Obs. Astron. de Belgrade **137** (1987), 80–81.

The autors present: the orbital elements, the Thiele-Innes constants, the dynamical parallaxes, the masses and the ephemerides.

V. Erceg, D. Olević: *Orbites nouvelles de SEE 318 = IDS 16594S3829*, Circ. Inf., No. 103, UAI, Comm. des Etoiles Doubles, (Oct. 1987).

V. Erceg, D. Olević: *Orbites nouvelles de I 600 = IDS 17225S6022*, Circ. Inf., No. 103, UAI, Comm. des Etoiles Doubles, (Oct. 1987).

G. Djurašević: *Light curve variabilities of close binaries*, Publ. Astron. Institute of Czechosl. Acad. Sciences **70** (1987).

In the paper is considered a possibility of the determination of the parameters of close binaries of the type RS CVn by means of the comparison of the light

curve derived from photoelectric measurements to a synthetic curve obtained on the basis of a model of a binary system. The inverse problem method based on the nonlinear least square method is used. A few test examples and a shorter analysis of the proposed method are given.

D. J. Zulević: *Orbites nouvelles (IDS 16594S3829)*, Circ. Inf., No. 102, UAI, Comm. des Etoiles Doubles, (1987).

S. Ninković, G. M. Popović: *Unseen Companions to Stars*, Bull. Obs. Astron. Belgrade, **137** (1987), 44.

The existing data concerning 32 unseen companions are compiled and presented in Table I of the paper. The contribution of unseen companions to the local mass density is estimated. A value of 0.0044 $\mathfrak{M}_\odot$ pc^{-3} is found. Only one of the stars listed in Table I (Barnard's star) seems to be a strong candidate to possess a planetary system, according to the accepted criteria.

G. M. Popović: *Étoiles doubles nouvelles (GP 194, 197)*, Circ. Inf., No. 103, UAI, Comm. des Etoiles Doubles, (1987).

G. M. Popović: *The binary star Σ 2799 = ADS 15007*, Bull. Obs. Astron. Belgrade **137** (1987), 82–84.

D. J. Zulević: *Micrometer measurements of double stars (Ser. 42)*, Bull. Obs. Astron. Belgrade **138** (1988), 63–75.

Presented here are 420 measurements of 154 double stars made with 65/1055 cm refractor of Belgrade Observatory.

D. J. Zulević: *Orbites nouvelles (ADS 15988)*, Circ. Inf., No. 106, UAI, Comm. des Etoiles Doubles, (1988).

G. M. Popović, V. Trajkovska: *Relative motion of the components of the system GP 34 AB*, Bull. Obs. Astron. Belgrade **139** (1988), 65.

The rectilinear trajectory and ephemeris of the GP 34 AB to the 2020.0 are given. Relative proper motion of the component B, i.e. BD +34°3568 star, of 0″.116/year in the direction 341°.5 results from the trajectory elements.

G. M. Popović: *Micrometer measurements of double stars (Series 41)*, Bull. Obs. Astron. Belgrade **138** (1988), 55–62.

D. J. Zulević: *Orbites nouvelles (ADS 12631)*, Circ. Inf., No. 107, UAI, Comm. des Etoiles Doubles, (1989).

G. M. Popović, D. J. Zulević: *Micrometer measurements of triple stars (Ser. 43)*, Bull. Obs. Astron. Belgrade **140** (1989), 83.

326 measurements of triple systems from the Belgrade Survey of triple Systems, IDS Catalogne (up to 200 pc) and from the Leningrad Programme of Nearby Triple Stars are communicated.

D. J. Zulević: *Micrometer measurements of double stars (Ser. 44)*, Bull. Obs. Astron. Belgrade **140** (1989), 99.

Presented here are 156 measurements of 74 double stars made with 65/1055 cm refractor of Belgrade observatory.

G. M. Popović, Z. Ćatović: *Orbite nouvelle: ADS 10838*, Circ. Inf., No. 107, UAI, Comm. des Etoiles Doubles, (1989).

G. M. Popović, Z. Ćatović: *Orbite nouvelle: ADS 10429*, Circ. Inf., No. 109, UAI, Comm. des Etoiles Doubles, (1989).

G. M. Popović, D. J. Zulević: *Micrometer measurements of triple star systems — Series No. 43*, Bull. Obs. Astron. Belgrade **140** (1989), 83–97.

G. M. Popović, V. Trajkovska: *Relative proper motions of components of 16 triple star systems*, Bull. Obs. Astron. Belgrade **140** (1989), 43–46.

By comparing the proper motions determined from meridian measurements with the relative proper motions obtained from rectilinear trajectories it is concluded that out of 16 examined triple systems 11 systems have at least one optical component.

D. J. Zulević: *Orbites nouvelles (ADS 6582)*, Circ. Inf., No. 111, UAI, Comm. des Etoiles Doubles, (1990).

D. J. Zulević: *Orbites nouvelles (ADS 9425)*, Circ. Inf., No. 112, UAI, Comm. des Etoiles Doubles, (1990).

G. M. Popović, Z. Ćatović: *Orbite nouvelle: ADS 16242*, Circ. Inf., No. 112, UAI, Comm. des Etoiles Doubles, (1990).

Ž. P. Anosova, G. M. Popović: *Programma izucheniya trojnykh zvezd. Vydelenie sistem s fizicheski svyazanimi komponentami*, Kinematika i fizika nebesnykh tel, VINITI, No. 5694-B89, (1990).

Ž. P. Anosova, G. M. Popović: *Discovery of triple stars with physically connected components*, Kinematika i fizika nebesnykh tel, 1990/1.

9.2. Variable Stars
9.2. Promenljive zvezde

J. Arsenijević, A. Kubičela, I. Vince: *Surprisingly high optical polarization of μ Cephei*, Inf. Bull. Var. Stars, 1859, (1980).

J. Arsenijević: *Optical polarization of some cool supergiants*, Publ. Obs. Astron. Belgrade **28** (1980), 1.

Mathematical description of linearly polarized light is briefly presented in this paper. Also, some mechanisms of the origin of polarized radiation in stars

are described. In the case of six late spectral type supergiants the optical polarization has been measured. The analysis of the measured polarization of all observed stars has led to the positive conculsion about the existence of the intrinsic polarization changes originating in the circumstellar envelopes.

J. Arsenijević: *Polarimetry in astronomy*, Proc. IV National Conf. Yugoslav Astronomers, Sarajevo, (1981), 181.

Polarization as one of the fundamental properties of radiation and polarimetry as a method capable of giving important informations in astronomy has been presented. The complementary character of polarimetric and photometric methods is stressed. Some results of variable stars polarimetry are shown.

J. Arsenijević: *Synchronous changes of polarization, brightness and radial velocities of o Andromedae*, Bull. Obs. Astron. Belgrade **131** (1981), 13.

The complex event on the star o And in the interval of time JD 2442700-800 is analysed. It seems likely that synchronous changes of linear optical polarization, brightness and radial velocities were observed.

J. Horn, P. Koubský, J. Arsenijević, J. Grygar, P. Harmanec, J. Krpata, S. Kříž, and K. Pavlovski: *Radial-velocity and photometric variations of o And: Critical evaluation of possible periods*, Be stars, Proc. IAU Simp. 98, eds. M. Jacshek, H. G. Groth, (1982), 315.

All available data on radial velocities and, photometric measurements in the visible region are collected and evaluated periodicities are reported.

J. Arsenijević: *A possible eruptive event on M-supergiant μ Cephei*, Astron. Astrophys. **145** (1985), 430.

A sudden fast brightening of μ Cep amounting to 0.034 magnitude in V spectral region has been observed on August 3, 1981 at $0^h31^m.9$ UT. The observation was done with the Belgrade polarimeter using 4^s integration intervals. Standard deviation of the measurements was ± 0.011 mag. The shape and duration of the disturbed portion of the light curve of the observed event evokes those of an ordinary M-dwarf flare. New complex observations of μ Cep are necessary.

J. Arsenijević, S. Jankov, G. Djurašević, I. Vince: *Promene optičke polarizacije nekih Be zvezda*, Saopštenja, VIII Kongres fiz. mat. astronoma Jugoslavije, (1985), 341.

M. Vukićević-Karabin, J. Arsenijević: *Aktivni fenomeni na Suncu i zvezdama*, Saopštenja, VIII Kongres fiz. mat. i astron. Jugoslavije, (1985), 342.

G. Djurašević, J. Arsenijević, Z. Knežević: *Short-term variations of o And?*, Bull. Obs. Astron. Belgrade **135** (1985), 32-39.

Photoelectrical observations of o And revealed this object probably having short-term variations (on a time scale of 0.1 days) of low amplitude (about

0.01 magnitude), superimposed on the variations of longer (on the time scale of 1 day) priods. These short-term variations, if assumed to be a consequence of a pulsating mechanism in the star and treated as such, furnish a period consistent with the obeserved one.

J. Arsenijević, S. Jankov, G. Djurašević, I. Vince: *Variations of the liner optical polarization of κ Draconis*, Bull. Obs. Astron. Belgrade **136** (1986), 6–11.

It is demonstrated that the slow going variations in the linear intrinsic polarization of the star κ Dra in the spectral band V were present in the period 1979 to 1984.

The variations were within approximately 0.13 and 0.61 polarization percent, the minimum having taken place during 1980. The position angle varied between 5° and 22°. As of 1981 the polarization percent is continuously increasing while the position polarization percent has been occasioned by the emission from the shell which is largely unpolarized.

J. Arsenijević, S. Jankov, I. Vince and G. Djurašević: *Optical polarization changes of 88 Her in the period 1974–1985*, Bull. Obs. Astron. Belgrade **137** (1987), 49.

Linear optical intrinsic polarization of 88 He (HD 16273) measured with the Belgrade polarimeter in the period 1974–1985 has been presented. The polarization percentage changed from 0.15% (1976) to 0.56% (1979). Small values of polarization percentage corresponded to the period with negligible envelope effects. The maximum polarization has been found during the early period of a strong shell phase, about one year after brightness minimum. The polarization positon angle varies between 58 and 83 degres. An indication of the correlation between polarization percentage and H-alfa emission line intensities is demonstrated.

J. Arsenijević, A. Kubičela, I. Vince: *Be stars-challenge to the observers and theoreticians*, II Workshop Astrophysics in Yugoslavia, Abstracts, Beograd, Ed. M. Dimitrijević, (1987), 1.

J. Arsenijević, S. Jankov, G. Djurašević: *Long-term polarization changes of 88 Her*, Proc. IAU Coll. 92, Physics of Be Stars, (Eds. A. Slettebak, T. P. Snow), (1987), 200.

Linear optical polarization of 88 Her has been measured in V spectral region during the period 1974–1985. The mean annual values of the intrinsic polarization parameters are presented. The polarization percentage changes from 0.15% (1976) to 0.56% (1979). Small values of the polarization percentage correspond to the period when the envelope effect is negligible. The maximum of polarization percentage has been found during the early period of strong shell phase. The polarization position angle varies between 53 and 83 degress.

S. Jankov, B. Foing: *Indirect imaging of active RS CVn stars*, Proc Cambridge Workshop: Cool Stars, Stellar Systems and the Sun, (eds. J. L. Linsky and R. E.

Stencel), Springer-Verlag, Berlin-Heidelberg (1987), 528.

The RS CVn system HR 1099 has heen monitored over the orbital period to study spectroscopic variabilhty in photospheric lines and in Hα. The information provided by the variability of profiles, together with the limits of the Doppler imaging method are also presented. Different inversion algorithms were applied to test the image reconstruction of HR 1099, showing the role of such constraints as chi-square adjustment of the spectra and maximum entropy of the input image.

B. Foing, S. Jankov: *Doppler imaging, MUSICOS (Multi Site Continous Spectroscopy)*, Proc. Meudon Workshop, eds. C. Catala and B. Foing, (1987).

R. Duemmler, A. Kubičela, V. Doazan, B. Bourdonnau and J. Arsenijević: *The development and weakening of the shell spectrum of 88 Herculis (1977–1987). I. A radial velocity study*, Astron. Astrophys. Suppl. Ser. **75** (1988), 311.

We present new radial velocity measurements of 88 Her during 1977–1987, when the shell spectrum first developed and subsequently weakened. The data show that: (i) the radial velocity variations of the blue Balmer shell lines continued without any detectable change of the 86.72 day period; (ii) the radial velocity of the Hα shell line of the new set of data seems to follow the same behaviour as the blue Balmer shell lines; (iii) the V/R at Hα shows a clear trend toward values < 1 when the blue Balmer lines are more negative than the gamma velocity, and conversely; (iv) the FeII shell lines follow the same periodic behaviour as the Balmer shell lines, with a suggestion of slightly more negative values; (v) the radial velocities of the CaII (K) and NaI (D1 and D2) lines are variable, but they do not follow the periodic radial velocity curve of the blue Balmer shell lines. Their mean values are significantly more negative than that of all the other shell lines studied in this paper.

J. Arsenijević, A. Kubičela and I. Vince: *Be stars — a challenge to the observers and theoreticians*, Bull. Obs. Astron. Belgrade **138** (1988), 31.

The main historical steps in the investigation of the B stars with emission lines, starting with the year 1922 when IAU Commission 29 introduced the name "Be stars" at the first General Assembly of the Union in Rome and closing with the IAU Colloquium No. 92 "Physics of Be Stars" organized in Augst 1986 in Boulder, are briefly reviewed. The enormous quantity of the existing observational data and their significant characteristics over broad spectral region from X-ray to radio wavelengths are discussed. One of the main characteristics — photometric and spectral time variablity — is analysed with a special attention to long-term changes. The correlation of long-term photometric and spectral changes with the polarimetric ones for some stars has been mentioned. Obeservational results in confrontation with the theoretical interpretations from Struve's hypothesis to the contemporary empirical Be stars models are presented.

J. Arsenijević, S. Jankov, G. Djurašević, I. Vince: *Long-term changes of linear optical polarization of Be stars*, Bull. Obs. Astron. Belgrade **140** (1989), 1.

As a part of a more extensive research program at Belgrade Astronomical

Observatory, the first results of ten-year optical polarization measurements of o And, 88 Her, κ Dra and γ Cas have been shown. The existence of slow changes of polarization parameters has been established in all four stars. For two of them, 88 Her and κ Dra, the intrinsic polarization has been determined. A further analysis of these results is in preparation.

J. Arsenijević, A. M. Hubert, S. Jankov, I. Vince: *Common properties of some Be stars observational parameters*, Abstracts, Treći seminar Astrofizika u Jugoslaviji, Zagreb, ed. V. Vujnović, (1989).

J. E. Neff, F. M. Walter, S. L. Skinner, A. Brown, K. G. Strassmeier, M. Rodono, G. Cutispoto, S. Jankov, S. Char: *Ultraviolet, visible and radio observaton EI Eri*, Proc. IAU Coll. 106, Evolution of Peculiar Red Giant Stars, eds. H. R. Johnson and Zuckerman, (1989).

B. Foing, S. Jankov: *Imagerie Doppler d'étoilles active de types RS CVn*, Proc. MUSICOS Workshop, Meudon, (1989), 6.

J. Arsenijević, S. Jankov, G. Djurašević: *Changes of some envelope characteristics of Be star gamma Cas*, Contributed papers, XV SPIG, Dubrovnik, ed. D. Veža, (1990), 374.

J. Arsenijević, S. Jankov: *Long-term polarimetric activity of cold supergiant μ Cep*, Abstracts, IAU Coll. 130, The Sun and cool Stars, (1990), 104.

S. Jankov, B. Foing: *ESO remote control observations from Garching for MUSICOS'89 campaign*, Proc. II MUSICOS Workshop, eds. C. Catala and B. Foing, Meudon, (1990), 65.

B. Foing, S. Char, S. Jankov, C. Catala, D. S. Zhai: *First results from MUSICOS'89 campaign: Active surface structure and flares on HR1099*, Proc. II MUSICOS workshop, eds. C. Catala, and B. Foing, Meudon, (1990), 117.

10. STAR CLUSTERS AND GALAXIES
10. ZVEZDANA JATA I GALAKSIJE

S. Ninković: *Disc-to-Halo Nonthermal Emissivity Ratio according to a Study of the Radio Background at 10 MHz*, Publ. Astron. Obs. Sarajevo **1** (1981), 219.

An analysis of the data of Caswell's (1976) map aimed at determining the disc-to-halo nonthermal emissivity ratio is undertaken. A comparison with Fenkart's (1977) results gives indications in favour of the existence of a correlation between disc-to-halo mass ratio and disc-to-halo nonthermal emissivity ratio.

S. Ninković: *On the Study of the Clobular Cluster ω Cen*, Bull. Appl. Math. **193** (1983), 53.

A short report on a study of the globular cluster ω Cen is given. Examinations on the basis of the virial theorem and a tidal radius determination show that

a large mass, like that obtained in a paper by Ogorodnikov et al. in 1976, is possible for this cluster. An empirical model of the cluster, indicating that the largest fraction of the total mass is present near the centre, is constructed, as well.

S. Ninković: *On Eccentricities of Globular Cluster Galactocentric orbits*, Astron. Nachr. **304** (1983), 305.

The House-Wiegandt method is modified and applied to a large sample of globular clusters belonging to our Galaxy. The results obtained indicate high orbital eccentricities for them, but clearly demonstarting the diffeerences among globular clusters of different chemical composition.

P. Brosche, M. Geffert, S. Ninković: *Lessons from the Globular Cluster NGC 5466*, Publ. of the Astron. Inst. of the Czechosl. Acad. Sciences **56** (1983), 145.

NGC 5466 is a "loose" globular cluster (large core radius) with low metallicity. Its absolute velocity has been measured and leads to perigalactic distances around 6 kpc. The value of the observed "tidal radius" is clearly too large in comparison with the theoretical value.

S. Ninković: *Opredelenie mass sharovykh skoplenij po sobstvennym dvizheniyam*, Astrofizika **20** (1984), 283.

A determination for globular cluster masses for M 15, M 92 and M 13 by use of the methods proposed by Naumova and Ogorodnikov and by applying the virial theorem is made. A discussion of obtained results is presented as well.

S. Ninković: *Results of the Galactocentric Orbit Calculation for a Globular Cluster NGC 5466*, Pub. Obs. Astron. Belgrade **33** (1985), 32.

In the calculation in addition to the other data, the proper motion of NGC 5466, recently determined at Bonn observatory, is also used. In spite of a large proper motion error the obtained results clearly indicate an orbit, highly inclined to the galactic plane ($80° \pm 10°$) and highly elongated (eccentricity 0.7).

S. Ninković: *On the Structure and Mass of the Galactic Halo*, Astrophys. Space Sci. **110** (1985), 379.

On the basis of a globular cluster study a crude estimate of the total mass of the galactic halo within 20 kpc from the centre is done. It gives a minimal halo mass of the order of $10^{10}\,\mathfrak{M}_\odot$, yielding possibilities for a mass as large as $10^{11}\,\mathfrak{M}_\odot$. The content of the interstellar matter in the halo is estimated too. It is found that the gas content is a few percents the minimal mass, the gas temperature is very high-about 1×10^6 K, the magnetic field weak-about 0.25 nT. A weak nonthermal radio emission might be expected from such a halo.

S. Ninković: *On Tidal Radius Determination for a Globular Cluster*, Astron. Nachr. **306** (1985), 237.

A tidal radius determination for a globular cluster based on its density minimum, which is caused by the galactic tidal forces and derivable from a model of the Galaxy, is proposed. Results obtained on the basis of the Schmidt model for two clusters are in a satisfactory agreement with those obtained earlier by means of other methods. A mass determination for the clusters through the tidal radius, when the latter one is identified with the cluster perigalactic distance, yields unusually large mass values. Probably, the tidal radius should be identified with the instantaneous galactocentric distance. Use of models more recent than the Schmidt one indicates that a globular cluster may contain a significant portion of an invisible interstellar matter.

P. Brosche, M. Geffert, A. R. Klemola, R. S. Ninković: *One more Space Motion of a Globular Cluster: NGC 147*, Astron. J. **90**, 2033 (1985), 126.

From measurements of 39 stars with respect to the extargalactic Lick reference system, we derived the absolute proper motion of NGC 4147 and-using in addition the radial velocity — the space velocity with respect to various standards. The membership of individual stars of special astrophysical interest is discussed. Parameters of the cluster's galactic orbit are presented together with those of the previously treated cluster NGC 5466. Among these, the relatively low angular momenta seem to be especially remarkable.

S. Ninković: *K otsenke orbital'nogo ékstsentrisiteta*, Astrofizika **24** (1986), 411.

A Criterion for orbital eccentricity evaluating for objects moving in a spherically symmetric force field with mass distribution $\mathfrak{M}\alpha r^{\beta}$, based on the radial component rate in total kinetic energy is proposed. The latter quantity preserves a nearly constant value over a sufficiently large fraction of the orbit, admitting thus its instantaneous value to be a measure of the eccentricity.

S. Ninković: *A Further Study of the Globular Cluster M 71*, Bull. of Astron. Inst. of Czech. **38** (1987), 147.

For the purpose of determining the galactocentric orbit and tidal radius of the globular cluster M 71 (NGC 6838) is used, inter alia, the most recent observational material: the proper motion and heliocentric distance, determined by Cudworth. An attempt aimed at mass determination is done, too, whereby, inter alia, the method proposed by Naumova and Ogorodnikov is used.

Main results:

i) The cluster moves almost in the galactic plane, along a low-eccentricity orbit. The orbital eccentricity is most likely equal to 0.2, with a possible uncertainty limit of 0.1; apo- and perigalactic distances are most likely equal to 7.7 kpc and 5.1 kpc, respectively.

ii) The tidal radius appears to be within the limits 19–46 pc depending on the assumed concept.

iii) The mass value of $3 \times 10^4 \mathfrak{M}_\odot$ expected on the basis of the luminosity, seems justified, though the possibility of a higher mass cannot be excluded.

S. Ninković: *Orbital Eccentricity Study for the Spherical Component of our Galaxy*, Astrophys. Space Sci. **136** (1987), 299.

An analysis of the data concerning high-velocity stars from Eggen's catalogue aimed at a determination of the approximate slope of the mass function for the spherical component of our Galaxy, and at estimating the local circular velocity, as well as the local rotation velocity, as by-products, has been performed. Our conculsions are that:

(i) a linear dependence of the mass on the radius is very likely;

(ii) the value of the limiting radius is most likely equal to $(40 \pm 10)\,\mathrm{kpc}$

(iii) the two local velocities are approximately equal to each other, being both equal to $(230 \pm 30)\,\mathrm{km\,s^{-1}}$.

(iv) the local escape velocity appears to be most likely equal to $(520 \pm 30)\,\mathrm{km\,s^{-1}}$;

(v) the total mass of a corona, obtained in this way, is $(5 \pm 1) \times 10^{11} \mathfrak{M}_\odot$.

S. Ninković: *Dynamical Constants for our Galaxy*, Publ. of the Astron. Inst. Czechosl. Acad. Sciences **69** (1987), 317.

According to the present author's results a following system of the galactic dynamical constants is proposed: local escape velocity $u_e = (520 \pm 30)\,\mathrm{km\,s^{-1}}$, local circular velocity, $u = (230 \pm 30)\,\mathrm{km\,s^{-1}}$, local angular velocity of rotation, $\omega = (25 \pm 5)\,\mathrm{km\,s^{-1}\,kpc^{-1}}$, local circular frequency of planar oscillations, $\kappa_p = (40 \pm 10)\,\mathrm{km\,s^{-1}\,kpc^{-1}}$, local circular frequency of vertical oscillations, $\kappa_z = (70 \pm 20)\,\mathrm{km\,s^{-1}\,kpc^{-1}}$. The value of $(9 \pm 1)\,\mathrm{kpc}$ is assumed for the galactocentric distance of the Sun. The latter three values yield $(0.09 \pm 0.03)\mathfrak{M}_\odot\,\mathrm{pc^{-3}}$ for the local matter density, a value very close to the density obtained by use of statistical methods. On the basis of the proposed value it is concluded that the dark matter should be present in the form of a large, rarefied, massive, spherical corona.

S. Ninković: *Galactocentric Orbit and Tidal Radius of M 22*, Bull. Obs. Astron. Belgrade **139** (1988), 21.

The globular cluster M 22 (6656) appears to be in a not very eccentric orbit — $e = 0.5 \pm 0.2$ — especially not highly inclined to the galactic plane — $i = 150° \pm 20°$, as predicted by the present author (Ninković, 1983) on the basis of a statistical study. The tidal radius is found to be within the limits 28–86 pc depending on the cluster's mass and tidal radius concept assumed.

S. Ninković, A. D. Chernin, M. B. Shakenov: *O raspredelenii skrytykh mass v Mestnoj gruppe galaktik*, Astron. Tsirk. **1541** (1989), 1.

Dynamical models of the Local Group of galaxies involving various types of distribution of dark matter have been studied with numerical simulation. The

results have proved to be in favour of models with individual massive coronae around the two major galaxies of the Group.

S. Ninković: *On the Flattening of the Galactic Corona*, Bull. Astron. Inst. Czech. **41** (1990), 236.

A possibile flattening of the galactic (dark) corona is examined. It was found that, if the corona makes an essential contribution to the local density of the galactic matter, it should be at least as flattened as 0.1.

11. THEORETICAL ASTROPHYSICS AND PLASMA PHYSICS
11. TEORIJSKA ASTROFIZIKA I FIZIKA PLAZME

11.1. Radiative Transfer
11.1. Prenos zračenja

O. Atanacković, E. Simonneau: *Effects of elastic collisions on the local frequency redistribution in the transfer of resonant line photons*, Annales de Physique, Colloque No. 3, Vol. **11** (1986), 137–138.

The effects of elastic collisions on the local frequency redistribution of resonant line photons are shown through the behaviour of the velocity distribution function of the excited atoms, emission profile coefficient and radiation intensity.

O. Atanacković: *Analiza nelokalnih efekata u ne-LTR prenosu zračenja u rezonantnim linijama zvezdanih atmosfera*, Magistarski rad, Beograd, Decembar 1986.

O. Atanacković-Vukmanović, E. Simonneau: *Kinetic effects in non-LTE line transfer in stellar atmospheric conditions*, Bull. Obs. Astron. Belgrade **137** (1987), 66–79.

A survey of the main stages in the development of radiative transfer theory is given. Special attention is dedicated to an analysis of kinetic (local and non-local) effects of the transport of the excited atoms in two approximations of the general, selfconsistent solution. In both cases, emission profile coefficient is coherently derived proceeding from the velocity distribution function of the excited atoms.

O.Atanacković-Vukmanović, E. Simonneau: *Parameters characterizing non-LTE line radiative transfer in some astrophysical conditions*, Bull. Obs. Astron. Belgrade **137** (1987), 58–65.

In this paper, the values of three dimensionless parameters: ε, ζ and η, characterizing non-LTE line formation, and measuring, respectively, the importance of inelastic collisions, elastic collisions and streaming of excited atoms, are estimated for different astrophysical conditions. The estimation is performed for the atmospheres of main sequence stars, those of white dwarfs and gaseous

nebulae and for the resonance lines formed therein. It is shown that in all cases except for the Lyman α line, for which kinetic non-local effects can be significant, local "classical" partial redistribution theory should be used.

O. Atanacković-Vukmanović, M. S. Dimitrijević, E. Simonneau: *Karakteristike prenosa zračenja u pražnjenjima visokog pritiska koja se koriste u svetlosnim izvorima*, Zbornik radova sa 29. Simpozijuma "Etan u pomorstvu", Zadar, (1987), 282–284.

O. Atanacković-Vukmanović, E. Simonneau: *An approximative solution in the frame of kinetic non-LTE approach of Lyman alpha line transfer in chromospheric conditions*, II Workshop "Astrophysics in Yugoslavia", Beograd, (1987), 21–22.

O. Atanacković, J. Borsenberger, J. Oxenius, E. Simonneau: *Resonance line transfer and transport of excited atoms — III. Self-consistent solutions (2)*, J. Quant. Spectrosc. Radiat. Transfer **38** (1987), 427–446.

In this last part of our study on non-LTE line transfer with convective transport of excited atoms, we present self-consistent solutions of the radiative transfer equation and the kinetic equation of the excited two-level atoms when the excited atoms undergo elastic velocity-changing collisions. We assume pure Doppler broadening of the spectral line and investigate reflecting and destroying boundaries for the excited atoms. Concerning elastic collisions of the excited atoms, our study covers all cases, from a collisionless gas (free particle streaming) discussed in Part II of this series of papers, to a collision — dominated gas with the limiting case of complete redistribution. We present arguments that the streaming pattern of the gas of excited atoms does not depend critically on the shape of the line profile. Therefore, our results for a pure Doppler profile may also be used for other line profiles (Voigt, Lorentz) in a first approximation, at least when the streaming parameter η is not too large.

O. Atanacković: *Non-LTE radiative transfer*, Bull. Obs. Astron. Belgrade **140** (1989), 127–130.

A brief review is given of some basic points in the development of non-LTE radiative transfer theory along with some remarks concerning the activity in this field at Belgrade Observatory.

E. Simonneau, O. Atanacković-Vukmanović: *Iteration factors in the solution of the NLTE line transfer problem*, in: Stellar atmospheres: Beyond classical models, NATO Advanced Research Workshop, Trieste, (1990); Pré-publication No. 333 (1990), Institut d'Astrophysique de Paris.

11.2. Spectral Line Shapes in Astrophysics and Plasma Physics
11.2. Profili spektralnih linija u astrofizici i fizici plazme

M. Dimitrijević: *Stark broadening and its astrophysical applications*, XI Int. School for Young Astronomers, Hvar, (1980), 22.

M. Dimitrijević, N. Konjević: *Modified semiempirical formula for the electron-impact width of ionized atom lines*, V. Int. Conf. on Spectral Line Shapes, Berlin, (1980), Program and Abstracts 53.

N. Konjević, M. S. Dimitrijević: *On the systematic trends of Stark broadening parameters of isolated ion lines*, V Int. Conf. on Spectral Line Shapes, Berlin, (1980), Program and Abstracts 55.

M. S. Dimitrijević, N. Konjević: *Uticaj oblika spektralne linije na interakciju zračenja sa plazmom*, 22 ETAN u pomorstvu, Zadar, (1980), Vol. 2, 365.

M. Dimitrijević, N. Konjević: *Semiempirical Stark line widths of alkali like ions*, X SPIG, Dubrovnik, (1980), 204.

M. S. Dimitrijević, N. Konjević: *Stark broadening of NII, NIII and NIV lines*, V ESCAMPIG, Dubrovnik, (1980), 88.

M. S. Dimitrijević, D. P. Grubor: *Stark line widths of some lithium isoelectronic sequence ions*, V ESCAMPIG, Dubrovnik, (1980), 89.

M. S. Dimitrijević: *Semiclassical calculations of the Stark widths of CIII and CIV*, V ESCAMPIG, Dubrovnik, (1980), 90.

M. S. Dimitrijević, N. Konjević: *Stark widths of doubly-and triply-ionized atom lines*, J. Quant. Spectrosc. Radiat. Transfer **24** (1980), 451–459.

In this paper, we report modifications of well known semiempirical and semiclassical approximation formulas for Stark line-width calculations. Comparisons with experiments for doubly ionized atoms yield, as an average ratio of measured to calculated widths 1.06 ± 0.31 for a modified semiempirical formula and 0.96 ± 0.24 for a modified semiclassical formula. For triply ionized atoms these ratios are 0.91 ± 0.42 and 1.08 ± 0.41, respectively. Comparison with other theoretical calculations have also been made.

M. S. Dimitrijević and N. Konjević: *Semiempirical Stark linewidths of alkali like ions*, Astron. Astrophys. **102** (1981), 93.

In this paper we have tested the applicability of modified semi-empirical formula with newly proposed Gaunt factors for evaluation of Stark linewidths of alkali like ions. The comparison with experiments and other, already tested theoretical approaches indicates that these new Gaunt factors can be used successfully for Stark linewidth calculations.

M. S. Dimitrijević and N. Konjević: *On the Stark broadening of ionized nitrogen lines*, J. Quant. Spectrosc. Radiat. Transfer **25** (1981), 387.

In this paper, we report an analysis of the experimental procedure and results obtained in a recently published paper on the Stark broadening of singly, doubly-, and triply-ionized nitrogen lines. The results of this analysis indicate that the influence of self-absorption on the line profiles is not taken into account properly and that therefore the results of Ref. 6 cannot be applied with confidence. Comparison of experimental results with numerous theoretical calculations have also been performed.

M. S. Dimitrijević, N. Feautrier and S. Sahal-Bréchot: *Comparison between quantum and semiclassical calculations of the electron impact broadening of the Li I resonance line*, J. Phys. B: At. Mol. Phys. **14** (1981), 2559.

We present quantum mechanical calculations of Stark broadening parameters for the Li I $2s^2S$-$2p^2P$ line. Semiclassical calculations have also been performed and both have been compared with other available results. A detailed analysis of Stark broadening parameters as functions of the impact electron angular momentum quantum number and of the temperature is carried out. The influence of the polarisation potential and of the completeness of the set of energy levels on the Stark broadening parameters is investigated. The low temperature behaviour of the half width is discussed too.

N. Konjević, M. S. Dimitrijević: *Širenje spektralnih linija u plazmi*, Savremena istraživanja u fizici, redaktor V. Urošević, Institut za fiziku i Naučna knjiga, Beograd, (1981), 191.

M. S. Dimitrijević, N. Konjević: *Modified semiempirical formula for the electron-impact width of ionized atom lines*, in: Spectral line shapes, ed. B. Wende, Walter de Gruyter, Berlin, (1981), 211.

N. Konjević, M. S. Dimitrijević: *On the systematic trends of Stark broadening parameters of isolated lines in plasmas*, in: Spectral line shapes, ed. B. Wende, Walter de Gruyter, Berlin, (1981), 241.

M. S. Dimitrijević, D. P. Grubor, N. Konjević: *Electron impact broadening of multiply charged ion lines*, 2 Colloque sur l'influence des processus collisionnels sur le profil des raies spectrales, Orleans, (1981), 9.

M. S. Dimitrijević, N. Feautrier, S. Sahal-Bréchot: *Quantum and semiclassical Stark width calculation for the Li I resonance line*, 2 Colloque sur l'influence des processus collisionnels sur le profil des raies spectrales, Orleans, (1981), 8.

M. S. Dimitrijević: *Electron impact broadened line widths in a supermultiplet*, IECAP, Heidelberg, (1981), 529.

M. S. Dimitrijević: *Štarkovo širenje jonskih linija u sudarnoj aproksimaciji*, II Jugoslovenski seminar o fizici atomskih sudara, Stubičke Toplice, (1981).

M. S. Dimitrijević: *Stark broadening of some OIII lines*, Proc. IV Nat. Conf. Yug. Astronomers, Sarajevo, Publ. of the Astronomical Observatory of Sarajevo **1**, Sarajevo, (1981), 215.

M. S. Dimitrijević: *Similarities of Stark line widths within a given spectrum and irregular energy level structure*, Hvar. Obs. Bull. **6** (1982), 185.

M. S. Dimitrijević: *Stark broadening of non hydrogenic ion lines within the impact approximation*, in: The Physics of Ionized Gases, Ed. G. Pichler, Institute of Physics of the University, Zagreb, (1982), 397.

In this talk various methods for Stark broadening parameter estimation will be examined and their limitations will be discussed. This will be done on the basis of comparison with experimental data for singly, doubly and triply ionized atoms.

M. S. Dimitrijević, N. Feautrier, S. Sahal-Bréchot: *Influence of different kinds of collisions on the Stark broadening of the Li I resonance line*, XI SPIG, Dubrovnik, (1982), 277.

M. Dimitrijević, M. Cornille, N. Feautrier, S. Sahal-Bréchot: *Resonant scattering (autoionization) contributions to Stark broadening of ion lines*, XI SPIG, Dubrovnik, (1982), 281.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening parametres for infrared lines of He I*, 6th Conf. on Spectral Line Shapes, Boulder, (1982), 281.

N. Konjević, M. S. Dimitrijević: *On the Stark broadening of non-hydrogenic spectral lines of heavy elements in plasmas*, 6th Conf. on Spectral Line Shapes, Boulder, (1982), 23.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of the He I resonance lines*, XI SPIG, Dubrovnik, (1982), 273.

M. S. Dimitrijević: *On the variation of Stark line widths within a supermultiplet*, Astron. Astrophys. **112** (1982), 231.

In order to find out if similarities among Stark broadening parameters within a supermultiplet are apparent to such a degree that accurate interpolation of new data and critical evaluation of experimental results are possible, the exceptions to this rule in the available theoretical data have been analysed and reasons for such situations have been discussed. The reasons may be divided into two categories: (i) irregular atomic energy level structure and (ii) inadequacy of the used model of the emitter structure. For the O II 3s-3p quartets, semi-classical calculations for Stark broadening parameters have been performed taking into account the emitter structure properly.

M. S. Dimitrijević: *Stark broadening of heavy ion solar lines*, in: Sun and Planetary System, eds. W. Fricke and G. Teleki, Astrophysics and Space Science Library **96**, D. Reidel PC, Dordrecht, (1982), 101.

M. S. Dimitrijević and N. Konjević: *Semiclassical calculations of electron impact Stark widths of S(III), Cl(III) and S(IV) isolated lines*, J. Quant. Spectrosc. Radiat. Transfer **27** (1982), 65.

In this paper we report results of semiclassical calculations of electron impact Stark widths of doubly-ionized sulfur and chlorine and of triply-ionized sulfur. Comparison with available experimental data yields an average ratio of measured to calculated line widths of 0.73 and 0.74 for S(III) and Cl(III), respectively, and of 0.50 for a single S(IV) line.

M. Dimitrijević: *Stark broadening of heavy solar lines*, VI ERMA, Dubrovnik, (1982), 32.

M. S. Dimitrijević, N. Konjević: *On the Stark broadening of heavy non-hydrogenic neutral atom lines in plasmas*, Int. Conf. on Plasma Physics, Göteborg, (1982), 343.

M. Dimitrijević, A. Mihajlov: *Istraživanje oblika kalijumovih linija u pražnjenjima srednjeg i visokog pritiska*, 25. ETAN u pomorstvu (1983), 530.

M. Dimitrijević, M. Cornille, J. Dubau, N. Feautrier, S. Sahal: *Diagnostic spectroscopique des plasmas denses: contribution des resonances d'autoionisation a l'élargissement Stark des raies emises par des ions*, Collisions et Rayonnement, Orleans, (1983), P27.

M. S. Dimitrijević, S. Sahal-Bréchot: *L'élargissement Stark des raies de l'helium neutre*, Collisions et Rayonnement, Orleans, (1983), P26.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening parameters for He II infrared lines*, in: Spectral Line Shapes, Vol. 2, ed. K. Burnett, Walter de Gruyter Co., Berlin-New York, (1983), 103.

N. Konjević, M. S. Dimitrijević: *On the Stark broadening of non-hydrogenic lines of heavy elements in plasmas*, Vol. 2, ed. in: Spectral line shapes, K. Burnet, Walter de Gruyter Co., Berlin – New York, (1983).

I. Vince, M. S. Dimitrijević: *Doprinos limb-efektu raznih mehanizama širenja spektralnih linija u seriji Na I* ($4s^2S - np^2P$), VI Nac. Konf. Astr. Jugoslavije, Hvar, (1983), 123.

M. S. Dimitrijević: *Astrofizičke primene izučavanja profila spektralnih linija*, VI Nac. Konf. Astr. Jugoslavije, Hvar, (1983), 13.

I. Vince: *On the telluric lines position instability*, Bull. Obs. Astron. Belgrade **133** (1983), 5–15.

On the ground of the observational data as well as the measurements of the relative positions of the telluric lines in the solar spectrum it has been established that these lines have an unstable position. To a position change during

a day corresponds a Doppler velocity of $100\,\mathrm{m\,s^{-1}}$. The existence is pointed out of the diurnal position variations of the telluric lines and there is some indication of the diurnal variation being superimposed by some long-periodical or irregular changes. The aerological factors are found to contribute to the position instability of the telluric lines, while the instabilities of the position differences of the investigated spectral lines of water vapor and molecular oxygen can practically completely be accounted for by the convective motion of air masses. The possibility of the position instability of telluric lines being only a consequence of the instrumental errors has also been examined.

M. S. Dimitrijević, N. Konjević: *Stark broadening of isolated spectral lines of heavy elements in plasmas*, J. Quant. Spectrosc. Radiat. Transfer **30** (1983), 45.

In this paper we present results of semiclassical calculations of Stark broadening parameters for some lines of heavy neutral atoms. Comparisons with experiment show large discrepancies previously undetected for lighter elements. Critical evaluation of experimental data indicate that in most cases the experiment must be blamed for these discrepancies.

M. S. Dimitrijević, N. Feautrier and S. Sahal-Bréchot: *Influence of different collisional processes on the Stark broadening*, Fizika **15** (1983), 205.

Using a semiclassical formalism, elastic, inelastic and strong collision's contributions to the electron impact width of the Li I ($2s^2S-2p^2P^0$; $\lambda = 670.78\,\mathrm{nm}$) resonance line have been computed for different angular momenta of the incoming perturbing electron and for $T = 2500$, 10000 and 20000 K. On the basis of the obtained results, the relative importance of elastic, inelastic and strong collision's contributions to the line width are discussed.

M. S. Dimitrijević: *Stark broadening of Si II and Si III spectral lines*, Astron. Astrophys. **127** (1983), 68.

Modified semiempirical and approximative semiclssical methods have been used for the calculation of recently measured Si II and Si III Strk line widths in order to test both methods, as well as the new experimental data (Kusch and Schröder, 1982).

V. Vujnović, Č. Vadla, V. Lokner and M. S. Dimitrijević: *Half-widths of neutral fluorine spectral lines*, Astron. Astrophys. **123** (1983), 249.

The profiles of 29 fluorine spectral lines from seven transitions, emitted by a wall-stabilized arc, were measured and the electron impact broadening half-widths of the transitions were calculated using the semiclassical perturbation appoach. The plasma conditions were given by $T = 14.000\,\mathrm{K}$ and $N_e = 10^{23}\,\mathrm{m^{-3}}$. A close agreement between the experimental results and the calculations was found, depending on the calibration of the electron concentration and on the evaluation approach.

M. S. Dimitrijević, N. Konjević: *On the dependence of Stark width and shift on the ionization potential*, Z. Naturforsch **39a** (1984), 553.

The simple relations between the Stark broadening parameters and the ionization potential derived by Purić et al. are discussed, and attention is drawn to the serious limitations for their application. The periodic dependence of the Stark width and shift on nuclear charge number obtained by the same authors is also explained.

N. Konjević, M. S. Dimitrijević and W. L. Wiese: *Experimental Stark widths and shifts for spectral lines of neutral atoms (a Critical Review of selected Data for the Period 1976 to 1982)*, J. Phys. Chem. Ref. Data **13** (1984), 619.

A critical review of all experimental data on Stark widths and shifts of spectral lines of neutral elements published during the period 1976–1982 has been carried out. This work represents an extension and update of an earlier review which covered the period before 1976. Data tables containing the selected experimental Stark broadening parameters are presented together with estimated accuracies. Comparisons with comprehensive calculations based on the semiclassical theory are made whenever possible.

N. Konjević, M. S. Dimitrijević and W. L. Wiese: *Experimental Stark widths and shifts for spectral lines of positive ions (a Critical Review and Tabulation of Selected Data for the Period 1976 to 1982)*, J. Phys. Chem. Ref. Data **13** (1984), 649.

A new critical review of the available experimental data on the Stark widths and shifts for lines of non-hydrogenic ionized spectra has been carried out which covers the period from 1976 to the present and represents a continuation of an earlier critical review. The relevant literature, compiled by the NBS Data Center on Atomic Lines Shapes and Shifts as well as by the present authors, was critically evaluated, and data tables containing the selected experimental Stark broadening parameters have been assembled. The data are arranged according to spectra and elements and these are presented in alphabetical order. The accuracy of the experimental data is estimated on the basis of guidelines developed during the previous review. Comparisons with theoretical results are made whenever possible since the comparison with theory has often been a principal motivation for the experiments.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of neutral helium lines*, J. Quant, Spectrosc. Radiat. Transfer **31** (1984), 301.

Using a semiclassical approach for the Stark broadening of atomic linea, we have calculated electron and proton impact line widths and shifts of 56 neutral He lines in the ultraviolet, visible and i.r. region of the spectrum. The comprehensive set of results obtained is used for investigation of Stark-broadening parameter regularities within the spectral series.

M. S. Dimitrijević: *Electron impact line widths of the resonance lines of Be-like ions*, Astron. Astrophys. **131** (1984), 327.

Analytical expressions recently obtained for the collisions strengths of reso-

nant transitions of Be-like ions are used for the calculation of Stark broadening parameters.

M. S. Dimitrijević: *The trajectory effect in calculations of the phaseshift for binary collisions and broadening of neutral atom lines*, J. Phys. B: At. Mol. Phys. **17** (1984), L283.

The trajectory effect for $C_n r^{-n}$ ($n = 2, 3$ and 4) potential is estimated and compared with the results obtained according to the approximate method of Valee et al. based on the use of effective rectilinear trajectories.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of neutral helium lines of astrophysical interest. Regularities within spectral series*, Astron. Astrophys. **136** (1984), 289.

Following our earlier work, and using a semiclassical perturbation formalism for the Stark broadening of atomic lines, we have calculated electron and proton impact line widths and shifts of 36 neutral He lines. Stark broadening parameters were calcualted for lines originating from upper energy levels with 4 to 10, and for an electron density of $10^{13}\,\mathrm{cm}^{-3}$. The comprehensive set of results obtained is used for the investigation of line-broadening parameter regularities within the spectral series.

M. S. Dimitrijević, S. Sahal-Bréchot: *Semiclassical calculation of the He I Stark broadening parameters*, XVI ICPIG, Düsseldorf (1983), 630.

M. S. Dimitrijević, S. Sahal-Bréchot: *Approximative electron and proton-impact line widths within a spectral series*, XVI ICPIG, Düsseldorf, (1983), 628.

M. S. Dimitrijević, S. Sahal-Bréchot: *Élargissement des raies spectrales par collisions avec les électrons et les protons: Formule asymptotique de la largeur lorsque le nombre quantique principal augmente*, Collisions et Rayonnement, Orleans (1983) p. 25.

M. S. Dimitrijević: *The trajectory effect and broadening of neutral atom lines*, XIIth SPIG, Šibenik (1984), 465.

I. Vince, M. S. Dimitrijević, V. Kršljanin: *Collisional broadening and solar limb effect: Na I $3p^2P^0 - ns^2S$ lines*, 7th Conf. on Spectral Line Shapes, Aussois (1984), F4.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of He I lines of astrophysical interest: Regularities within spectral series and influence of Debye shielding*, 7th Conf. on Spectral Line Shapes, Aussois (1984), A10.

M. Dimitrijević, N. Konjević: *Elektronnoe ushirenije spektral'nykh linij ionizirovannykh atomov*, Fotoprocessy, vozbuzhdeniya i jonizacii, Leningrad, (1984), 41.

M. Dimitrijević, N. Konjević: *O Shtarkovskom ushirenii linij nejtral'nykh atomov rubidiya, kadmiya i cinka*, Fotoprocessy, vozbuzhdeniya i jonizacii, Leningrad, (1984), 47.

M. S. Dimitrijević: *Dependence of Stark widths and shifts on the ionization potential: $np^{k-1}(n+1)s - np^4$ resonance transitions*, Astron. Astrophys. **145** (1985), 439–442.

Simple relations between the Stark broadening parameters and the ionization potential are derived for $np^{k-1}(n+1)s - np^4$ resonance transitions of singly ionized emitters, using the semiclassical approach. The relations obtained are compared with those derived by Purić et al. (1980).

M. S. Dimitrijević, N. Konjević: *A simple formula for estimating Stark broadening parameters of neutral atom lines*, Collisions et Rayonnement, Orleans, (1985), 21.

S. Jankov: *Instrumental profile of the Belgrade solar spectrograph*, Bull. Obs. Astron. Belgrade **135** (1985), 25.

The instrumental profile of the Belgrade solar spectrograph is determined using the O_2 telluric lines. The Fourier transform method is applied. A procedure of simultaneous use of several calibration curves has been developed for minimizing the errors, occasioned by the photographic calibration. The telluric line absorption coefficient is approximated by Voigt function. A procedure of normalisation of the natural profile, suitable for computer processing, has been developed. The actual resolving power of the spectrograph is 106 780 and 134 040 in the 4th and 5th order spectrum, which makes about 37% of its theoretical value.

M. S. Dimitrijević, S. Sahal-Bréchot: *Comparison of measured and calculated Stark broadening parameters for neutral-helium lines*, Physical Review A, **31** (1985), 316.

Stark broadening parameters for neutral helium lines obtained using a semiclassical pertubation formalism are compared with critically selected experimental data. Our data are also compared with the results of Benett and Griem as well as with the semiclassical convergent calculations of Bassalo, Cattani, and Walder.

I. Vince, M. S. Dimitrijević: *Influence of different line broadening mechanisms on the limb-effect within Na I ($4s^2S - np^2P^0$) series*, Publ. Obs. Astron. Belgrade **33** (1985), 15.

M. S. Dimitrijević: *Astrophysical significance of spectral line shapes investigation*, Publ. Obs. Astron. Belgrade **33** (1985), 11.

M. S. Dimitrijević, V. Kršljanin: *Semiempirical Stark shifts of ion lines*, XVII ICPIG, Budapest, (1985), 975.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of Na I lines: Regularities within a spectral series*, XVII ICPIG, Budapest, (1985), 978.

M. S. Dimitrijević, Truong-Bach: *Sur l'inégalite des largeurs Stark a l'interieur d'un multiplet ou supermultiplet de l'argon*, Collisions et Rayonnement, Orleans 1985, P 23.

V. Kršljanin, I. Vince: *Zastupljenost natrijuma u sunčevoj atmosferi*, VIII Congress of the Mathematicians, Physicists and Astronomers of Yugoslavia, ed. Dj. Teleki, SDMFAJ, Priština, (1985), 340.

I. Vince, V. Kršljanin: *Uticaj sudarnih procesa na limb efekt u pegama: linija Na I* $3p^2P^0 - 6s^2S$, VIII Congress of the Mathematicians, Physicists and Astronomers of Yugoslavia, ed. Dj. Teleki, SDMFAJ, Priština, (1985), 341.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of neutral sodium lines*, J. Quant. Spectrosc. Radial. Transfer **34** (1985), 149–161.

A semiclassical apporach has been used to evaluate. Stark broadening of atomic lines and also electron-and proton-impact line widths and shifs of 30 neutral sodium lines. The results are used to investigate Stark broadening-parameter regularities within the spectral series.

I. Vince, M. S. Dimitrijević, V. Kršljanin: *Pressure broadening and solar limb effect*, J. E. Beckman and L. Crivellari (eds.), Progres in Stellar Spectral Line Formation Theory (1985), 373–380.

The pressure broadening contribution to the solar limb effect has been discussed for the case of a spectral series using Na I 3p-ns and 4p-ns series as an exemple. We have found that the influence of the pressure broadening on the solar limb effect is reduced due to different signs of hydrogen and electron impact shifts in the case considered. We have discussed also the behaviour of pressure broadening contribution to the solar limb effect within a spectral series and we have compared our results with simple radial-current theory predictions.

M. S. Dimitrijević: *Electron impact broadening dependence on the ionization potential:* $np^{k-1}(n+1)s - np^k$ *resonance transitions*, II ECAMP, Amsterdam, (1985), 206.

M. S. Dimitrijević, S. Sahal-Bréchot: *L'élargissement Stark des raies du potassium neutre*, Collisions et Rayonnement, Orleans, (1985), P 22.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of He I lines of astrophysical interest: Regularities within spectral series and influence of Debye shielding*, Spectral Line Shapes III, W. de Gruyter, Berlin – New York, (1985), 53.

I. Vince, M. S. Dimitrijević, V. Kršljanin: *Collision broadening and solar limb effect: Na I* $3p^2P^0 - ns^2S$ *lines*, Spectral Line Shapes III, W. de Gruyter, Berlin – New York, (1985), 649.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical approach as a source for Stark broadening data in astrophysics: Li-like lines in stellar atmospheres*, Coll.

on Atomic Spectra and Oscillator Strengths for Astrophysics and Fusion Research, Toledo, (1986), 84.

M. S. Dimitrijević: *On the Stark broadening within a F I transition array*, Astron. Astrophys. Suppl. Ser. **64** (1986), 591–594.

Using a semiclassical formalism, electron impact widths and shifts within 3s-3p transition array of F I have been computed. A detailed analysis of Stark broadening parameters as functions of the impact electron angular momentum quantum number and the temperature is carried out. On the basis of the results obtained, the differences between the contribution of elastic, inelastic and strong collisions to the line widths within a transition array are discussed, as well as the Stark shift and width behaviour of the various components.

I. Vince, M. S. Dimitrijević: *Influence of spectral lines pressure shift on the convective layer diagnostic*, XIII SPIG, Šibenik, (1986), 325.

M. S. Dimitrijević, S. Sahal-Bréchot: *L'élargissement Stark des raies du potassium neutre*, Annales de Physique, Coll. No. 3, Suppl. au No. 3, Vol. 11 (1986), 181.

Nous avons calculé les largeurs et les déplacements de 50 raies spectrales de K I, dus aux collisions avec les électrons, les protons et Ar II, dans l'approximations des impacts. Les resultats obtenus sont utilisé pour étudier les comportements des parametres d'élargissement dans une série spectrale.

M. S. Dimitrijević, N. Konjević: *Simple formulae for estimating Stark broadening parameters of neutral atom lines*, Annales de Physique, Coll. No. 3, Suppl. au No. 3, Vol. 11 (1986), 197.

Simples formulae for estimating Stark width and shift of neutral atom lines are presented.

M. S. Dimitrijević, Truong-Bach: *Sur l'inégalité des largeurs Stark a l'intérieur d'un multiplet ou supermultiplet de l'argon II*, Annales de Physique, Coll. No. 3, Suppl. au No. 3, Vol. 11 (1986), 183.

Les paramètres Stark de divers composants à l'intérieur du multiplet $4s^2P - 4p'^2P$ et du supermultiplet $4p-4d$ ($^2P-^2P$, $^2P-^2D$, $^2D-^2D$) de l'Argon II sont calculés suivant un formalisme semi-classique. La possibilité de difference entre ces largeurs ou déplacements est discutée en fonction de l'effet d'écran Debye et des irrégularités dans le diagramme des nivaux d'énergie.

M. S. Dimitrijević, Truong-Bach: *On the Stark broadening of singly ionized argon lines*, Z. Naturforsch. **41a** (1986), 772–776.

Using a semi-classical formalism which includes Debye shielding, Stark broadening parameters of various components within the $4s^2P - 4p'^2P^0$ multiplet and the $4p - 4d$ ($^2P^0 - ^2P$, $^2D^0 - ^2P$, $^2D^0 - ^2D$) supermutiplet of Ar II are computed. We show that when various components of a multiplet (supermultiplet or transition array) are broadened inequally by an embedded close-lying

perturbing level, use of a perturber parameter cut-off at the Debye length can restrain the calculated differences between Stark widths within the multiplet.

M. S. Dimitrijević, V. Kršljanin: *Electron-impact shifts of ion lines: modified semiempirical approach*, Astron. Astrophys. **165** (1986), 269–274.

A simple method for calculation of ion line shifts produced by electron impacts, based on the modified (Dimitrijević and Konjević, 1980) semiempirical (Griem, 1968) approach is presented. Obtained relations have been applied to a number of Be II, Mg II, Al II, Ar II and Ca II lines and the results are compared with semiclassical and semiempirical values as well as with critically selected experiments.

M. S. Dimitrijević, N. Konjević: *Simple formulae for estimating Stark widths and shifts of neutral atom lines*, Astron. Astrophys. **163** (1986), 297–300.

Formulae for estimating Stark widths and shifts of neutral atom lines, based on the simple method of Freudenstein and Cooper and the GBKO semiclassical theory, are presented. For the calculations, most of the available personal computers are sufficient. Obtained formulae have been applied to He I and Mg I lines and results are compared with calculations of Benett and Griem and values obtained according to the method of Freudenstein and Cooper.

M. S. Dimitrijević, V. Kršljanin: *Modified semiempirical estimates of ion lines Stark shifts: spectra of hot DA white dwarfs*, XIII SPIG, Šibenik, (1986), 321.

M. S. Dimitrijević, M. C. Artru: *Stark broadening of Ga II and Ga III spectral lines*, XIII SPIG, Šibenik, (1986), 317.

M. S. Dimitrijević, N. Konjević: *Ion line Stark broadening in stellar plasmas*, XIII SPIG, Šibenik, (1986), 313.

M. S. Dimitrijević, N. Feautrier, S. Sahal-Bréchot: *Resonance structures in electron scattering cross sections and Stark broadening*, XIII SPIG, Šibenik, (1986), 303.

B. Grabowski, M. S. Dimitrijević: *Trajectory effects on the phase shift in the impact approximation*, XIII SPIG, Šibenik, (1986), 299.

M. S. Dimitrijević, A. A. Mihajlov, M. Popović: *On the electron-impact broadening for the resonance lines of the alkalis*, VIII ESCAMPIG, Greifswald, (1986), 89.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of KI: Regularities within spectral series*, VIII ICSLS, Williamsburg, (1986), A10.

M. S. Dimitrijević, N. Konjević, V. Kršljanin: *Modified semiempirical estimates of ion lines Stark broadening: I Theory*, VIII ICSLS, Williamsburg, (1986), A11.

M. S. Dimitrijević, N. Konjević, V. Kršljanin: *Modified semiempirical estimates of ion line Stark broadening: II Application*, VIII ICSLS, Williamsburg, (1986), A12.

A. Kubičela, I. Vince, M. S. Dimitrijević, R. Dümmler: *Differential Fe I limb effect around $\lambda = 630.2\,nm$*, VIII ICSLS, Williamsburg, (1986), DA1.

I. Vince, M. S. Dimitrijević: *Solar spectral line asymmetries and pressure broadening*, VIII ICSLS, Williamsburg, (1986), DA2.

M. S. Dimitrijević: *Stark broadening of spectral lines in the spectrum of Am 15 Vulpeculae*, IAU Colloq. No. **94**, Physics of Formation of Fe II Lines Outside LTE, ed. R. Viotti, Capri, (1986), 47.

S. Jankov: *Restauration des spectrogrammes astronomiques en application de la fonction de filtration selon Wiener dans les conditions du manque d'information a priori sur l'objet de recherche*, Master Science Thesis, Univ. Beograd, (1986) (in serbocr.).

I. Vince: *Uticaj sudarnih procesa na limb-efekt (Influence of Collisional Proceses on the Limb-effect)*, doktorska disertacija, (Ph. D. Thesis), Univ. Beograd, (1986).

I. Vince: *A részecskeütközések hatása a nap- és a csillagkonvekció diagnosztikájára*, Magyarok szerepe a világ természettudományos és müszaki haladásában (eds. Fodor O., Nagy F., Stefkoné Vermes J.), Budapest, (1986), 897.

V. Kršljanin, I. Vince: *Collision broadening and microturbulence sensitivity of some Na I non-resonant lines*, Bull. Obs. Astron. Belgrade **136** (1986), 12–19.

Profiles of six weak and moderate weak Na I lines in the centre and on the limb of the solar disk have been synthetized using the Smirnov-Roueff potential. The sensitivity has quantitatively been examined of a variety of parameters of the spectal line profiles (equivalent width, central intensity, half-width and line shape parameter) to microturbulent velocity variations. The results are displayed both numerically and graphically. Inadequate knowledge of the collision broadening can lead to the value of the microturbulence velocity, obtained from these spectral lines being significantly distorted.

V. Kršljanin: *Štarkov pomak jonskih linija kod toplih zvezda*, M. Sc. Thesis, Faculty of Sciences, Belgrade University, (1986), 1–151.

J. Arsenijević, M. Karabin, A. Kubičela, I. Vince: *Beginning of a study of long-term changes of selected Fraunhofer spectral lines*, Abstracts, II Workshop, Astrophysics in Yugoslavia, Beograd, Ed. M. Dimitrijević, 31, (1987).

J. Arsenijević, M. Karabin, A. Kubičela, I. Vince: *A Belgrade program for monitoring of activity-sensitive spectral lines of the Sun as a star*, Abstracts, Fifth Europ. Meeting on Solar Phys., Solar and Stellar Physics, Titisee, FRG, (1987), P5.

M. S. Dimitrijević, G. Peach: *Regularities in line widths due to neutral nonresonant collisions*, in: Radiative Excitation and Ionization Processes, ed. V. Vujnović, Institute of Physics, Zagreb, (1987), 19.

M. S. Dimitrijević, V. Kršljanin: *An aproximate method for electron impact shift calculation*, in: Radiative Excitation and Ionization Processes, ed. V. Vujnović, Institute of physics, Zagreb, (1988), 22–25.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of highly excited C IV lines*, in: Radiative Excitation and Ionization Processes, ed. V. Vujnović (Proc. of lectures given at a seminar held in Zagreb), Institute of Physics, Zagreb, (1987), 76.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of K I: Regularities within spectral series*, in: Spectral Line Shapes, Vol. 4, ed. R. J. Exton, A. Deepak Publ., Hampton, Virginia, (1987), 61.

S. Jankov: *Imagerie indirecte des étoiles à partir des obsérvations spéctroscopiques et photométriques*, DEA Astrophysique et Tehniques Spatiales, Université Paris VII (1987).

I. Vince, M. S. Dimitrijević: *Solar spectral line asymmetries and pressure broadening*, in: Spectral Line Shapes, Vol. 4, ed. R. J. Exton, Deepak Publ., Hampton, Virginia, USA, (1987), 621.

It is confirmed that the convection is the major cause of solar line asymmetries and wavelength shifts. However, the influence of pressure broadening on solar line shapes must be taken into account in some cases. E.g. convective motions of solar granulation are manifested in the spatially unresolved spectrum as slight asymmetries and wavelength shifts of photospheric spectral lines. For the investigation of this effect the line bisectors (medians), i.e. the loci of points midway between equal-intensity points on either side of the line are commonly usedi. Consequently, it is important to know the influence of pressure broadening on the bisector shape formation. Here, we investigate the influence of collisional processes on solar Na I 616.1 nm line bisector. Our results are compared also with observational data. We calculated line bisectors for different positions on the solar disk by solving the radiative transfer equation using HSRA solar atmosohera model. Shift produced by absorber-neutral atom collisions is calculated using Smirnof-Roueff exchange potential. For Stark broadening contribution semiclassical data are used.

M. S. Dimitrijević, A. A. Mihajlov, and M. M. Popović: *Stark broadening trends along homologous sequences*, Astron. Astrophys. Suppl. Ser. **70** (1987), 57–61.

Using a semiclassical formalism, a detailed analysis of Stark broadening parameters as a function of the impact electron angular momentum quantum number and the temperature is caried out for resonance lines of the alkalis. On the basis of the results obtained, the differences between the contribution of elastic, inelasstic and strong collisions to the line widths for analogous transitions in homologous atoms are discussed.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of neutral potassium lines*, J. Quant. Spectrosc. Radiat. Transfer **38** (1987), 37–45.

Using a semiclassical approach, we have calculated electron-proton and Ar II impact line widths and shifts of 50 neutral potassium lines. The compre-

hensive set of results obtained is used for investigation of Strak-broadening-parameter regularities within the spectral series.

M. S. Dimitrijević, N. Konjević: *Simple estimates for Stark broadening of ion lines in stellar plasmas*, Astron. Astrophys. **172** (1987), 345–349.

Simple analytical expressions for estimation of Stark widths and shifts of ionized atom lines have been derived from the low temperature limit of a modified semiempirical formula.

A. Kubičela, I. Vince, M. S. Dimitrijević, R. Dümmler: *Differential Fe I limb effect around* $\lambda = 630.2\,nm$, in: Spectral Line Shapes, Vol. 4, ed. R. J. Exton, Deepak Publ., Hampton, Virginia, USA, (1987), 619.

For heliocentric angles up to 52° a relative limb effect of Fe I 630.15 nm and 630.25 nm, amounting to $50\,m\,s^{-1}$ has been found. The differential pressure broadening shifts have been estimated as negligible. The observed differential limb effect is probably caused by some unresolved photospheric velocities.

M. S. Dimitrijević, N. Feautrier, S. Sahal-Bréchot: *On neutral oxygen lines formation in* γ *Cas*, II Workshop: Astrophysics in Yugoslavia, Beograd, (1987), 39.

Y. Vitel, M. Skowronek, M. S. Dimitrijević, M. M. Popović: *Electron-impact broadening along homologous sequences of noble gases*, II Workshop: Astrophysics in Yugoslavia, Beograd, (1987), 15.

I. Vince, M. S. Dimitrijević: *On the C IV line profiles in the white dwarfs*, II Workshop: Astrophysics in Yugoslavia, Beograd, (1987), 5.

T. Lanz, M. S. Dimitrijević, M.-C. Artru: *Influence of Stark broadening on equivalent widths of Si II visible lines in stellar atmospheres*, II Workshop: Astrophysics in Yugoslavia, Beograd, (1987), 33.

I. Vince, M. S. Dimitrijević: *Uticaj sudarnih procesa na profile linija natrijuma u sunčevim i zvezdanim spektrima*, V Jug. skup iz fizike atomskih sudara, Kopaonik, (1987), G1.

M. S. Dimitrijević: *Mehanizam formiranja linija neutralnog kiseonika u zvezdanim omotačima*, V Jug. skup iz fizike atomskih sudara, Kopaonik, (1987), G2.

M. S. Dimitrijević, N. Feautrier, S. Sahal-Bréchot: *On lines formation in stellar envelopes*, VII Gen. Conf. European Phys. Soc. "Trends in Physics", Helsinki, (1987), 165.

M. S. Dimitrijević, S. Sahal-Bréchot: *On the Stark broadening of C IV lines*, VII Gen. Conf. European Phys. Soc. "Trends in Physics", Helsinki 1987, 171.

M. S. Dimitrijević, N. Konjević, V. Kršljanin: *Modified semiempirical estimates of ion lines Stark broadening, I. Theory*, in: Spectral Line Shapes, Vol. 4, ed. R. J. Exton, A. Deepak Publ., Hampton, Virginia, (1987), 63.

M. S. Dimitrijević, N. Konjević, V. Kršljanin: *Modified semiemprical estimates of ion lines Stark broadening II. Application*, in: Spectral Line Shapes, Vol. 4, ed. R. J. Exton, A. Deepak Publ., Hampton, Virginia, (1987), 65.

I. Vince, M. S. Dimitrijević: *Influence of non-resonant collisions with neutral atom on the Na I lines in the solar spectrum*, in: Radiative Excitation and Ionization Processes, Inst. Phys. Univ., Zagreb, (1987), 84.

M. S. Dimitrijević, S. Sahal-Bréchot: *On the Stark broadening of Si IV lines: Regularities within spectral series*, IX Int. Conf. Spectr. Line Shapes, Toruń, (1988), A12.

M. S. Dimitrijević, G. Peach: *Line width regularities and systematic trends due to collisions with neutral perturbers*, IX Int. Conf. Spectr. Line Shapes, Toruń, (1988), D9.

M. S. Dimitrijević, M. M. Popović: *Stark broadening of noble gas ions as a function of the ionization potential*, XIV SPIG, Sarajevo, (1988), 289.

M. S. Dimitrijević, G. Peach: *Line widths due to neutral non-resonant collisions witin a homologue sequence: An investigation of the Van der Waals formula*, XIV SPIG, Sarajevo, (1988), 321.

M. S. Dimitrijević, A. A. Mihajlov, B. Grabowski: *The influence of Debye shielding on the Stark widths and shifts of ion lines in the adiabatic limit*, XIV SPIG, Sarajevo, (1988), 329.

M. S. Dimitrijević, S. Sahal-Bréchot: *Comparison between calculated, and measured Stark widths of C IV lines*, XIV SPIG, Sarajevo, (1988), 333.

M. S. Dimitrijević: *Classical trajectory method in line shapes investigations*, Int. Conf. on Classical Dynamics in Atomic and Molecular Physics (CDAMP), Brioni, (1988), 21.

M. S. Dimitrijević: *Stark broadening of the Fe II lines in the solar and stellar spectra*, R. Viotti et al. (eds.), Physics of Formation of Fe II Lines Outside LTE (1988), 211–216.

Recently developped modified semiempirical approach (Dimitrijević and Konjević, 1980, 1986; Dimitrijević and Kršljanin 1986) is applied to the Stark broadening calculation of Fe II lines in the Solar spectrum and the spectrum of Am 15 Vulpeculae.

M. S. Dimitrijević, Z. Djurić, A. A. Mihajlov: *Electron-impact broadening of Cu IV lines from an electrodynamic macroparticles accelerator arc plasma*, Int. Conf. on Phys. of Multiply Charged Ions, Grenoble, (1988), 2.16.

Y. Vitel, M. Skowronek, M. S. Dimitrijević, and M. M. Popović: *Stark broadening along a homologous sequence of noble gas atomic lines in dense plasmas*, Astron. Astrophys. **200** (1988), 285–290.

We present experimental results on the broadening and shift of some rare gas atomic lines emitted by high electron density plasmas created in linear flash-tubes. From a semiempirical formula, we find a theoretical dependence of the Stark broadening parameters on the ionisation potential for lines broadened by electron impacts. Experimentally, a non-linear dependence is found between the Stark width w and shift d, and the electron density. At the lowest electron density, our values of w and d agree with other experimental determinations. We have observed a regularity of w and d for analogous lines of homologous atoms.

M. S. Dimitrijević: *Comparison between different approximate approaches for the calculation of Stark widths of doubly- and triply-charged ion lines of astrophysical importance*, Bull. Obs. Astron. Belgrade **139** (1988), 31–58.

Stark widths of spectral lines from 127 astrophysically important multiplets of doubly- an triply-charged ions were calculated by means of the Griem's (1968) semiempirical method, Griem's simplified semiclassical method (1974), and a modified version of this latter method (Dimitrijević and Konjević, 1980). Obtained results were compared with those (Dimitrijević, 1988) derived by using the modified semiempirical method (Dimitrijević and Konjević, 1980).

M. S. Dimitrijević: *Electron-impact widths of doubly and triply charged ion lines of astrophysical impotance*, Astron. Astrophys. Suppl. Ser. **76** (1988), 53–59.

A recently developed modified semiempirical approach (Dimitrijević and Konjević, 1980, 1987: Dimitrijević and Kršljanin, 1986) is applied to the Stark boradening of spectral lines from 127 astrophysically important multiplets of doubly and triply charged ions.

T. Lanz, M. S. Dimitrijević, and M. C. Artru: *Stark broadening of visible Si II lines in stellar atmospheres*, Astron. Astrophys. **192** (1988), 249–254.

The Stark broadening of visble Si II lines is studied and its consequence on the intensity of the stellar absorption is analyzed. A complete set of atomic data concerning the Stark widths, is elaborated for 19 multiplets of Si II of astrophysical importance. Previous available determinations are reviewed and new Stark widths are calculated by means of the semi-classical impact theory. The accuracy of different theoretical and empirical methods are discussed. The new adopted Stark widths are applied, in several examples, to the analysis of stellar absorption lines. These widths are generally smaller than the previous theoretical estmates for the low-excitation transitions of Si II. But it leads to reduce only slightly (less than 10%) the equivalent widths, even with enhanced silicon. The only exception is the multiplet 1, whose equivalent width could be reduced from 10% to 35%. On the other hand, the influence of the large Stark widths obtaind for the high-excitation multiplets, is shown

to be critical for the abundance analysis. The example of the 4d-8f transition, at 4201 Å, is detailed.

Radiative widths are also given for these 19 multiplets and could be as large as 40 times the classical damping. Such widths affect particularly the low-excitation transitions and increase the equivalent widths up to 30% with respect to those calculated with the classical value.

M. S. Dimitrijević: *Classical trajectory method in line shapes investigations*, Proc. of the International Conference on Classical Dynamics in Atomic and Molucular Physics CDAMP'88, Eds. T. Grozdanov, P. Grujić, P. Krstić, (1988), 403.

The use of classical perturber trajectories within semiclassical and classical approaches to the line shapes and frequency shift calculations is briefly reviewed and discussed with special emphasis on the deviation of the perturber motion from the uniform one.

V. Kršljanin: *Ion lines Stark shifts in spectra of hot stars*, (M. Sc. Thesis Paper), IX National Conference of Yugoslav Astronomers Abstract Book, Sarajevo (1988), 3.

V. Kršljanin: *Stark broadening of resonance lines for the lithium isoelectronic sequence and some astrophysical applications*, in: Radiative Excitation and Ionization Processes, ed. V. Vujnović, Inst. Phys. Univ. Zagreb, (1988), 80–83.

M. S. Dimitrijević: *On the Stark broadening of C IV lines*, Bull. Obs. Astron. Belgrade **139** (1988), 70–71.

In this paper, results of semiclassical calculations of electron impact Stark widths within C IV multiplets are reported. A comparison with available experimental and theoretical data is performed too.

M. S. Dimitrijević, G. Peach: *An investigation of Van der Waals formula within a homologous sequence*, IX Nat. Conf. Yug. Astr., Sarajevo, (1988), 7.

M. S. Dimitrijević: *Critical selection of line broadening data for astrophysicists*, IX Nat. Conf. Astr. Yug., Sarajevo, (1988), 8.

J. Arsenijević, A. Kubičela, I. Vince and S. Jankov: *Belgrade program for monitoring of activity-sensitive spectral lines of the Sun as a star I. An analog solar scanning monochromator*, Bull. Obs. Astron. Belgrade **138** (1988), 1.

A scanning attachment for the Belgrade equatorial solar spectrograph based on a tipping glass rotation in front of the focal plane is described. An analog position encoder and an X-Y recorder complete the system of a solar scanning monochromator. The reduction procedure is reviewed and some instrumental parameters estimated, e.g. the flexure, the expected temperature influence, the range of flat field factors, the distortion of the wavelength scale, and certain components of the instrumental scattered light.

J. Skuljan, S. Erkapić, I. Vince, A. Kubičela: *Beogradski program za praćenje spektralnih linija osetljivih na aktivnost kod Sunca kao zvezde, III. Prvi spektrofotometrijski rezultati*, Saopšteno na IX Nacionalnoj konferenciji jugoslovenskih astronoma, Sarajevo, oktobar, 1988.

I. Vince, A. Kubičela, J. Arsenijević: *Belgrade program for monitoring of activity-sensitive spectral lines of the Sun as a star, II. Selection of Fraunhofer lines and beginning of a study of their long-term changes*, Bull. Obs. Astron. Belgrade **139** (1988), 25.

The selection of program spectral lines, preceeded by a short review of some earlier results, and progress report on their Belgrade observations are given. The lines are selected according to their various responses to the physical conditions in the photosphere and listed in Table I. Eight series of observations were done during 1987 covering the period of minimal solar activity. The first spectrophotometric errors have been estimated and research aims for the near future have been pointed out.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical Stark shifs of arII lines*, Z. Phys. D – Atoms, Molecules and Clusters **14** (1989), 273–280.

Stark shifts for 47 multiplets of ArII are calculated according to modified semiempirical approach, and compared with critically selected experimental data, as well as with semiclassical values of Jones et al. (1971) when available. Mean experimental to theoretical (modified semiempirical) shift ratio 1.38 ± 0.60 is obtained.

M. S. Dimitrijević, A. A. Mihajlov, Z. Djurić, B. Grabowski: *On the influence of Debye shielding on the Stark broadening of ion lines within the classical model*, J. Phys. B: At. Mol. Opt. Phys. **22** (1989), 3845–3850.

The influence of Debye shielding on the Stark line shift to width ratio is demonstrated in the case of ion lines. The Coulomb cut-off potential, especially suitable for a non-ideal plasma and for highest densites, has been used.

I. Vince: *Investigation of the collisional limb effect and shape of solar spectral lines at the Astronomical observatory in Belgrade*, Bull. Obs. Astron. Belgrade **140** (1989), 117–121.

Besides other research programs, at the Belgrade Astronomical Observatory we investigate the absorber-perturber collision effects on solar limb effect and on spectral line profile. A short review of our method of calculation and some examples of our results of the work on effect of atomic collision processes on the solar limb effect and solar spectral line bisectors are given here.

M. S. Dimitrijević, S. Sahal-Bréchot: *On the Stark broadening parameters for Li-like ions*, Collisions et Rayonnement, Orleans, (1989).

M. S. Dimitrijević, O. Atanacković-Vukmanović: *Plasma screening effects on Stark broadening of ion lines at the adiabatic limit*, Collisions et Rayonnement, Orleans, (1989).

I. Vince: *A Nap sugarának változásai*, A Magyarok szerepe a világ természettudományos és müszaki haladásában (eds. Fodor O., Füzeseri A., Stefokné Vermes J.), II. Tudományos talalkozó, Országos müszaki információs központ és könyvtár, (1989), 753–756.

M. S. Dimitrijević: *Stark broadening in astrophysics*, Bull. Obs. Astron. Belgrade **140** (1989), 111–116.

The importance of Stark broadening in astrophysics is briefly reviewed. A short review of results of Yugoslav research workers on this field is also presented.

M. S. Dimitrijević, M. M. Popović: *Estimates of Stark width along a homologous sequence*, Astron. Astrophys. **217** (1989), 201–203.

A simple analytical expression for Stark widths as a function of the ionization potential suitable for critical evaluation of existing experiments and interpolation of new data along homologous ion sequences at low temperature limit, has been derived.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical Stark widths and shifts of Ar II lines*, Bull. Obs. Astron. Belgrade **140** (1989), 7–14.

The modified semiempirical aproach (Dimitrijević and Konjević, 1980; Dimitrijević and Kršljanin, 1986) was used for calculation of Stark widths and shifts for Ar II lines. Comparison has been made with semiclassical results of Jones et al., (1971) as well as with critically selected experimental data. Since the good average accuracy of the present results has been achieved, tabulation of modified semiempirical Stark broadening parameters for 50 Ar II multiplets is also given.

I. Vince, M. S. Dimitrijević: *Pressure broadening and solar spectral line bisectors*, R. J. Rutten and G. Severino (eds.), in: Solar and Stellar Granulation (1989), 93–97.

In order to show that pressure broadening (atomic collisional processes) may have an important contribution to the spectral line asymmetries in some cases, what is of interest especially for the solar granulation studies, bisectors for Na I $3s^2S - np^2P^0$ solar lines have been calculated for different positions on the solar disk. Our numerical results clearly demonstrate that in the case of the examined spectral series the influence of pressure broadening has not a negligible role for the convective layer diagnostic.

M. S. Dimitrijević, Z. Djurić, A. A. Mihajlov: *Electron-impact broadening of Cu IV lines for the diagnostic of the arc plasma of electrodynamic macro-particle ac-*

celerator, Journal de Physique, Coll. C1, Suppl. au No. 1, Tome **50** (1989), C1-623.

Using a model method of loss energy simulation on the boundary surfaces, temperature and composition of an electrodynamic macroparticle accelerator arc plasma created by the evaporation of a Cu foil, have been calculated. Stark widths for Cu IV lines of interest for the arc plasma diagnostic have been calculated also, by using the modified semiempirical method.

V. Kršljanin: *On pressure shifts of Fe I lines in stellar atmospheres*, in: Solar and Stellar Granulation, eds. R. J. Rutten and G. Severino, Kluwer, Dordrecht, (1989), 91.

Calculated pressure shifts (with hydrogen- and electron-impact contributions taken into account) of two Fe I lines in spectra of A-G main sequence stars are presented and their importance in diagnostics of dynamical processes, particularly in hot stellar atmospheres is emphasized.

V. Kršljanin: *The spectral line synthesis study in Belgrade*, Bull. Obs. Astron. Belgrade **140** (1989), 123–125.

Investigation of both solar and stellar atmospheres using the spectral line synthesis method in the Astrophysical group of the Belgrade Astronomical Observatory started in 1983. The study of the pressure broadening in the astrophysical plasma and related topics are the main research orientation. Corresponding computer programs are developed. A review of the first results and the current investigations concerning line asymmetries and shifts caused by pressure, abundance determinations and microturbulence is given here.

V. Kršljanin: *Inversion of solar absorption lines*, 3rd Workshop: Astrophysics in Yugoslavia, ed. V. Vujnović, Inst. Phys. Univ. Zagreb, (1989), 9.

V. Kršljanin: *Ion lines Stark shifts in spectra of hot stars*, Publ. Obs. Astron. Belgrade **37** (1989), 1–114.

High-resolution UV spectroscopy from spacecrafts reveals different stellar spectral line features connected with line shifts and asymmetries. These features are mainly caused by dynamics of stellar envelopes, mass loss, convective motions and gravitation. Purpose of this work is to determine the contribution of pressure (i.e. Stark) broadening to such effects in spectra of hot ($T_{\rm eff} \geq 20000\,{\rm K}$) main sequence and high gravity stars ($4.5 \leq \log g \leq 9.0$). In that order, modified semiempirical theory for calculation of ion lines electron-impact shifts is developed. The method is tested via comparison with results of the semiclassical and semiempirical theories as well as with critically selected experiments. Stark shifts of astrophysically important Si, C, N, O, ion lines in spectra of hot stars are calculated. Simple analytical expressions for resonance lines Stark shifts in lithium isoelectronic sequence are obtained. Contribution of the Stark shifts to the stellar spectral line shifts mainly by mass loss, gravitation and stellar atmospheric motions is estimated and importance of this contribution is discussed.

M. S. Dimitrijević, M. M. Popović: *Štarkovo širenje duž homolognog niza alkalnih metala*, VI Jug. Skup. iz Fizike Atomskih Sudara, Brioni, (1989), 36.

M. S. Dimitrijević: *Približni metodi za dobijanje parametara Štarkovog širenja*, (Uvodno predavanje), VI Jug. Skup iz Fizike Atomskih Sudara, Brioni, (1989), 35.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical Stark shift examination: Ar II Stark line shifts*, XIX IGPIG, Beograd, (1989), 330.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical Stark shift examination: II. Alkali-like singly charged ion lines Stark shifts*, XIX ICPIG, Beograd, (1989), 332.

M. S. Dimitrijević, S. Sahal-Bréchot: *On the semiclassical Stark widths of C IV lines*, XIX IGPIG, Beograd, (1989), 334.

M. S. Dimitrijević, S. Sahal-Bréchot: *On the Stark broadening of Si IV lines: influence of different collisional processes*, XIX ICPIG, Beograd, (1989), 336.

M. S. Dimitrijević, M. M. Popović: *Stark broadening data along a homologous sequence of earth alkali metal ion lines*, XIX ICPIG Beograd, (1989), 338.

M. S. Dimitrijević, V. Vujnović: *Stark broadening of Cu I lines — New calculation and a review of old results*, XIX ICPIG, Beograd, (1989), 340.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical theory of Stark broadening in astrophysics: Ar II line shifts in spectra of B stars*, III Seminar Astrofizika u Jugoslaviji, Zagreb, (1989), 11.

M. S. Dimitrijević, S. Sahal-Bréchot: *Semiclassical calculations of astrophysically important Stark broadening parameters*, III Seminar Astrofizika u Jugoslaviji, Zagreb, (1989), 10.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of He I lines*, Astron. Astrophys. Suppl. Ser. **82** (1990), 519–529.

Using a semiclassical approach for the Stark broadening of atomic lines, we calculated electron-, proton and ionized helium-impact line widths and shifts for 77 neutral helium multiplets in the ultraviolet, visible and infrared regions of the spectrum.

S. Djurović, N. Konjević, and M. S. Dimitrijević: *Stark broadening of halogen atom lines from* $(^1D)np$ *levels*, Z. Phys. D — Atoms, Molecules and Clusters **16** (1990), 255–260.

We report results of a study of the Stark broadening of halogen atom lines from $(^1D)np$ levels. Wall stabilized arc is used as a plasma source. Electron densities $2.2\text{–}3.2 \times 10^{22}\,\mathrm{m}^{-3}$ are determined from the width of H_β line and electron temperature 9300–10000 K from plasma composition data. The agreement with the results of simple semclassical calculations is within the

limits of the estimated errors of both experiment and theory. And explanation for the large discrepancy between theory and experiment detected for three Br I lines is offered.

M. S. Dimitrijević: *Line shapes investigations in Yugoslavia 1962–1985 (Bibliography and citation index)*, Publ. Obs. Astron. Belgrade **39** (1990), 1–214.

First part of the publication contains review and analysis of the results of spectral line shapes investigations in Yugoslavia in the period 1962–1985, with special emphasis on the importance of such investigations. In the second part, the bibliography of the contributions of Yugoslav scientists is given, together with the citation index.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of Li(I) lines: Regularities within a spectral series*, 22 EGAS, Uppsala, (1990), 478.

M. S. Dimitrijević: *Approximate methods for line broadening calculations*, IAU Symposium 145, "Evolution of stars: the photospheric abundance connection", Zlatni Pjasci (Družba), (1990), 16.

V. Kršljanin, M. S. Dimitrijević: *Stark broadening of C IV λ 1549 lines and carbon abundance in hot DA white dwarfs*, IAU Symposium 145, "Evolution of stars: the photospheric abundance connection", Zlatni Pjasci (Družba), (1990), 82.

M. S. Dimitrijević, G. Peach: *An examination of regularities in neutral atom broadening*, 10th ICSLS, Austin, (1990), 57.

M. S. Dimitrijević, N. Ben-Nessib: *Simple convergent formulae for estimating Stark widths of neutral atom lines*, 10th ICSLS, Austin, (1990), 161.

S. Djurović, N. Konjević, M. S. Dimitrijević: *Plasma broadening of Br I and II lines from* $(^1D_2)np$ *levels*, 10th ICSLS, Austin, (1990), 26.

M. S. Dimitrijević, S. Sahal-Bréchot: *Profiles of neutral lithium lines: broadening by charged particles*, 12th European Regional Astronomy Meeting of IAU, Davos, (1990), III 6.

M. S. Dimitrijević, Vladimir Kršljanin: *On the use of the modified semiempirical approach: the case of close perturbing levels*, XV SPIG, Dubrovnik, (1990), 201.

M. S. Dimitrijević, V. Vujnović: *On the Stark broadening of Cu I lines — the influence of the oscillator strength values*, XV SPIG, Dubrovnik, (1990), 241.

M. Karabin, A. Kubičela, J. Skuljan, I. Vince: *Activity cycle variation of some photospheric lines*, Proc. of the E.P.S. 6th European Solar Meeting *The Dynamic Sun*, Publ. of Debrecen Heliophysical Obs. **7** (1990), 104.

The equivalent widths, W, of 10 Fraunhofer lines, observed at Belgrade Astronomical Observatory, have been studied from 1987 till 1990. Four lines

show no change. The lines MnI 539.47 nm, ScII 552.68 nm and FeI 557.61 nm steadily decrease in W from 2.4% to 4.4% per year. The other three, TiII 533.68 nm, CaI 560.13 nm and NaI 568.82 nm slowly increase in W from 2.2% to 6.2.% per year. It is assumed that these changes are correlated to the solar activity.

I. Vince: *Contribution of atomic collisions to the solar limb effect*, XV Summer School and International Symposium on the Physics of Ionized Gases (ed. Veža D.), (1990), 128.

M. S. Dimitrijević: *Semiclassical and approximate methods for Stark broadening investigations of astrophysical and laboratory spectra*, XV SPIG, Dubrovnik, (1990), 322.

V. Kršljanin: *Broadening of NaI lines due to collisions with atomic hydrogen*, in: 22nd EGAS, ed. A. Wannstrom, Univ. Uppsala, (1990), 760–762.

V. Kršljanin: *Simple estimates for Stark widths and shifts of neutral atom lines*, in: 22nd EGAS, ed. A. Wannstrom, Univ. Uppsala, (1990), 757–759.

V. Kršljanin, I. Vince and S. Erkapić: *FeI line asymmetries and shifts caused by pressure broadening and diagnostics of solar convective motions*, in IAU Colloquium 130, The Sun and Cool Stars: Activity, Magnetism, Dynamos; Programme and Abstracts, Helsinki, (1990), 68.

V. Kršljanin, S. Marković-Kršljanin: *On Stark line shifts in spectra of hot main sequence stars*, in: XV SPIG Contributed Papers, ed. D. Veža, Inst. Phys. Univ. Zagreb, (1990), 370–371.

V. Kršljanin: *Hydrogen-impact broadening and solar abundance of sodium*, in: IAU Symposium 145, Evolution of Stars: The Photospheric Abundance Connection, Abstracts of Presented Papers, Golden Sands, Bulgaria, (1990), 26.

V. Kršljanin: *Hydrogen-impact broadening of NaI Fraunhofer lines and solar photospheric abundance of sodium*, Ph. D. Thesis Paper, in: 12th ERAM of the IAU Abstract Book, Davos, Switzerland, (1990), p. PD-2.

M. S. Dimitrijević: *Accuracy of line broadening data*, in: Accuracy of Element Abundances from Stellar Atmospheres, (ed. R. Wehrse), Lecture Notes in Physics **356** (1990), 31–44.

The line broadening calculations for spectral lines broadened by collisions with charged and neutral particles has been reviewed. The accuracy of existing calculations and the possibilities of theoretical approaches suitables for acquisition of new data useful in astrophysics has been discussed.

11.3. Atoms and Atomic Collisional Processes
11.3. Atomi i atomski sudarni procesi

M. S. Dimitrijević, P. Grujić: *An investigation of e-He double ionization near the threshold. The classical trajectories method*, X SPIG, Dubrovnik, (1980), 22.

M. S. Dimitrijević, P. Grujić: *Electron-hydrogen collisions in a homogeneous magnetic field: classical calculations*, ECAP Heidelberg, (1981), 735.

M. S. Dimitrijević, P. Grujić, S. Vučić: *Elastic e-He* $(2S^2)$ *scattering: classical treatment*, ECAP Heidelberg, (1981), 764.

M. S. Dimitrijević, P. Grujić: *Classical investigations of* $e^+ + H \rightarrow H^+ + e^- + e^+$ *reaction near the threshold*, 5th Gen. Conf. EPS, Istanbul, (1981), 84.

M. S. Dimitrijević, P. Grujić: *Electron-helium double ionisation near the threshold: numerical investigations*, J. Phys. B: At. Mol. Phys. **14**, (1981), 1663.

The classical trajectory method is applied to the investigation of low-energy e+He $\rightarrow$ He^{2+}+3e collisions. In contrast to the hydrogenic case numerical calculations appear unable to derive the ionisation threshold law by varying one or two initial parameters. Final electron energies appear as linear functions, of the initial time parameter and it is conjectured that the energy distribution should be uniform within the total energy interval: $0.544 \leq E \leq 6.75\,\mathrm{eV}$. Calculated angular correlations between the three escaping electrons conform to the full central symmetry at very small energies, but go over to axially symmetric configurations as the energy rises. The final angular momenta acquire large values, with dramatic enhancement at the edges of an ionisation interval, where momentum exchange becomes particularly strong. Finally, the applicability of the classical model to non-hydrogenics is discussed, as well as some stochastic effects encountered.

M. S. Dimitrijević, P. Grujić and S. Vučić: *A classical model for e-He* $(2s^2)$ *elastic scattering*, Fizika **13** (1981), 321.

Two variants of the free fall model for helium in the first autoionizational site have been proposed for calculating differential cross section for e-He $(2s^2)$ elastic scattering. At $E = 7\,\mathrm{eV}$ impact energy the cross sections are evaluated numerically, making use of the classical trajectory method and are found sistematically higher for the case of the asynchronous atomic electrons motion than for the synchronous one.

M. S. Dimitrijević, P. Grujić: *The classical trajectory study of* $e^+ + A \rightarrow A^+ + e^- + e^+$ *reaction near the threshold*, J. Phys. B: At. Mol. Phys. **16** (1983), 297.

Numerical investigations of the positron-atom ionisational collisions near the threshold have been carried out within the classical trajectory method. It is found that for an infinitely heavy target the threshold law reads: $I \sim E^{2.49}$, whereas recent analytical calculations predict a value of 2.65 for the exponent. However, in the case of a hydrogen-atom target, the value 1.64 has been

obtained, indicating that the resting target mass assumption, as employed in all previous analytical investigations of $e^{\pm} - A$ processes near the ionisation threshold, breaks down in the case of the positron-light-atom collisions. The energy distribution of the outgoing particles appears non-zero and uniform in larger parts of available energy regions: $e^{+}[E/2, E]$, $e^{-}[0, E/2]$, but turns out, surprisingly, to be zero around $E/2$. The calculated energy dependence of the mutual angle is consistent with the analytically predicted $\theta_{+-} \sim E^{1/4}$ behaviour.

M. S. Dimitrijević: *Energy distribution in the near-treshold positron impact ionization of atoms*, XII SPIG, Šibenik, (1984), 109.

M. S. Dimitrijević, P. Grujić: *Langmuir's helium-like models revisited*, Z. Naturforsch **39A** (1984), 930.

Classical two-electron configurations, proposed by Langmuir in the days of Old Quantum Theory as models for heliumlike atoms, have been examined making use of modern semiclasical theory for the periodic orbits quantization. Combining both analytical and numerical investigations, energy spectra for the rotor-like and oscillator-like models have been evaluated for the nuclear charges $Z = 1, 2, 3, 6$. No essential improvement of the original result (for $Z = 2$) is obtained, signifying that either configuration turns out to be inferior to the simple Bohr's planetary model. Stability of these systems with respect to small perturbations has been examined and a general criterion for selection classical models as candidates for atomic orbitals within the semiclassical theory is discussed.

M. S. Dimitrijević, P. Grujić: *An old two-electron-system model revisited*, SPIG, Šibenik (1984), 112.

A. Mihajlov, M. Dimitrijević: *Determination of the cross section for elastic scattering of the electrons on cut off Coulomb potential in quasi classical method*, XII SPIG, Šibenik (1984), 416.

M. S. Dimitrijević, P. Grujić: *Classical spectrum of an oscillatory helium model*, Fizika **17** (1985), 1.

A generalization of an oscillatory two-electron atomic system, first proposed by Langmuir, has been studied numerically, by calculating electron classical orbits. By applying semiclassical quantization procedure, energy spectrum of the system is evaluated.

A. A. Mihajlov, M. S. Dimitrijević: *Uticaj jon-atomskih sudara na apsorpciju zračenja u atmosferama zvezda A tipa*, VIII Kongres MFAJ, Priština, (1985), 344.

A. Mihajlov, M. Dimitrijević, D. Djordjević: *Kvaziklasično i klasično određivanje preseka za rasejanje čestica na odsečenom Kulonovom potencijalu*, IV, JS FASP, Plitvice, (1985).

A. A. Mihajlov, M. S. Dimitrijević: *Influence of ion-atom collisions on the absorption of radiation*, Astron. Astrophys. **155** (1986), 319–322.

It is shown that for the interpretation of the continuum absorption spectra, of A type stars, the processes $H_2^+ + \hbar\omega \rightarrow H + H^+$ and $H + H^+ + \hbar\omega \rightarrow H + H^+$ must be considered together since their contribution is comparable. The corresponding absorption coefficients are also determined.

N. Simonović, P. Grujić, M. Dimitrijević: *Triatom fragmentation near the break up threshold*, Collision dynamics of clusters and long-lived states, Brioni, (1986).

A. A. Mihajlov, M. S. Dimitrijević, D. Djordjević, M. Luft, W. D. Kraeft; *Quasi-classical and classical cross sections for the scattering of electrons on the Coulomb cut-off potential*, Contrib. Plasma Phys. **27**, 1 (1987), 1–13.

The elastic scattering of electrons on the cut-off Coulomb potential $U_c(r) = -1/r + 1/r_c$, for $r \geq r_c$ and $U_c(r) = 0$, for $r < r_c$. has been considered. It has been shown that for $\varepsilon > 0.5/r_c$ (ε is the energy of free electrons in atomic units) the analytical quasi-elassical expressions describe quite well the behaviour of transport, differential and total cross sections for elastic scattering. It has been shown moreover, that in the energy range considered, transport cross sections could be determined with practically the same accuracy already by means of classical, analytical expressions. Born approximations show larger deviations form exact quantum calculations.

M. S. Dimitrijević, P. Grujić, G. Peach, N. Simonović: *Near-threshold CID processes: numerical studies*, I CDAMP, Brioni, (1988), 48.

A. A. Mihajlov, M. S. Dimitrijević: *Coulomb cut-off potential and modeling of radiation and collision processes in dense plasmas*, I CDAMP, Brioni, (1988), 25.

M. S. Dimitrijević, P. Grujić: *Threshold laws for the fourfold ionization by electrons*, I CDAMP, Brioni, (1988), 47.

Lj. M. Ignjatović, A. A. Mihajlov, M. S. Dimitrijević: *Electron elastic scattering on the cut-off Coulomb and Debye potential*, XV SPIG, Dubrovnik, (1990), 37.

A. A. Mihajlov, M. S. Dimitrijević: *Influence of $H - H^-$ collisions on the continuum absorption spectra of cool stars*, 12th European Regional Astronomy Meeting of IAU, Davos, (1990), III 17.

M. S. Dimitrijević, A. A. Mihajlov: *Influence of ion-atom collisions on the stellar continum absorption spectra*, XV SPIG, Dubrovnik, (1990), 368.

M. S. Dimitrijević, P. Grujić, G. Peach and N Simonović: *Small-energy three-body systems: IV. Classical trajectory calculations for the near-threshold behaviour of collision-induced dissociation*, J. Phys. B: At. Mol. Opt. Phys. **23** (1990), 1641–1653.

Near-threshold collision induced dissociation is simulated numerically for the process $Xe + Xe_2 \rightarrow 3Xe$ by carrying out detailed classical trajectory calculations. A static model of the target is chosen and the system is assumed to

have zero total angular momentum. Then by varying a single parameter, the threshold law $\sigma \sim E^{1.6}$ for the cross section is derived, and this is consistent with analytical results obtained previously. We also consider the distributions of energy, mutual angles and individual angular momenta in the final channel.

M. S. Dimitrijević, P. Grujić, and N. Simonović: *Fourfold ionization by electrons near the threshold*, Z. Phys. D — Atoms, Molecules and Clusters **15** (1990), 203–209.

Threshold law for the process $e + A^{q+} \rightarrow A^{(q+4)+} + 5e$ has been derived within the classical theory. For neutral targets ($q = 0$) the threshold exponent asumes value 5.08 consistent with previous calculations for ionizations of lower orders. The method fails for $q < -4$. The results are compared with recent experimental measurements, which considerably underestimate theoretical findings. An empirical formula for n-fold ionization is provided, which predicts values for the threshold exponent $k = 7.8$ and 12.5 for $n = 5, 6$ respectively.

11.4. Laser Produced and Laboratory Plasmas
11.4. Laserski proizvedene i laboratorijske plazme

M. S. Dimitrijević, N. Konjević: *Uticaj predimpulsa na oštećenje prozračne mete laserskim zračenjem*, 22 ETAN u pomorstvu, Zadar, (1980), Vol. 2, 371.

M. S. Dimitrijević, N. Konjević: *The importance of the pulse shape for the laser-beam target interaction*, Optics and Laser Technology **12** (1980), 145.

Theoretical analysis of a pulsed CO_2 laser beam aluminium target interaction demonstrates increased efficiency if the main laser pulse is preceded by a pulse of enough power to induce breakdown in air and create plasma in front of the metal target surface.

M. S. Dimitrijević, N. Konjević: *O proceni optičke prozračnosti plazme koja nastaje prilikom obrade metala snažnim laserskim zračenjem*, 23 ETAN u pomorstvu, Zadar, (1981), 323.

M. S. Dimitrijević, N. Konjević: *Uticaj oblika laserskog impulsa na profil plazme ispred metalnih meta*, 23 ETAN u pomorstvu, Zadar, (1981), 330.

B. Lončarević, S. Jovićević, M. S. Dimitrijević, N. Konjević: *Apsorpcija laserskog zračenja na metalnoj meti u prisustvu proboja ispred mete*, 23 ETAN u pomorstvu, Zadar, (1981), 335.

S. Jovićević, B. Lončarević, V. Knežević, S. Manola, M. S. Dimitrijević, N. Konjević: *Spektroskopsko proučavanje laserski proizvedene plazme*, 23 ETAN u pomorstvu, Zadar, (1981), 348.

S. Jovićević, M. S. Dimitrijević, N. Konjević: *Uticaj talasne dužine lasera na apsorpciju zračenja na metalu u prisustvu plazme*, 24 ETAN u pomorstvu, Zadar, (1982), 374.

M. S. Dimitrijević, N. Konjević: *Uloga predimpulsa kod praga za oštećenje metalne mete laserskim zračenjem*, 24 ETAN u pomorstvu, Zadar, (1982), 367.

P. K. Cibin, M. S. Dimitrijević: *Influence of electron colisions on the propagation of guided electron plasma waves along the cylindrical interface between two plasmas*, Int. Conf. Plasma Physics, Göteborg, (1982), 319.

N. Konjević, M. S. Dimitrijević: *On the Stark broadening of non-hydrogenic lines of heavy elements in plasmas*, in: Spectral Line Shapes Vol. II, ed. K. Burnett, Walter de Gruyter, Berlin – New York, (1983), 137.

M. S. Dimitrijević: *Apsorpcija laserskog zračenja na metalima u prisustvu plazme ispred mete*, 25 ETAN u pomorstvu, Zadar 1983, 522.

A. Mihajlov, M. Dimitrijević, M. M. Popović: *Determination of electrical conductivity of plasma by the use of classical transport cross-sections calculated on the basis of the cut-off Coulomb potential model*, XII SPIG, Šibenik, (1984), 420.

A. Mihajlov, M. Dimitrijević, M. M. Popović: *Determination of electrical conductivity of plasma on the basis of the cut-off Coulomb potential model*, XVII ICPIG, Budapest, (1985), 357.

A. A. Mihajlov, M. S. Dimitrijević, D. Djordjević, M. M. Popović: *Absorption of electro-magnetic radiation during collisions between lithium atoms and ions in low temperature plasma*, IX Int. Conf. on Gas Discharges, Venezia, (1988), 587.

A. A. Mihajlov and M. S. Dimitrijević: *Cut-off Coulomb potential in atomic and plasma physics*, Proceedings of the International Conference on Classical Dynamics in Atomic and Molecular Physics, Brioni, Yugoslavia, eds. T. Grozdanov, P. Grujić, P. Krstić, (1988).

APPENDIX
DODATAK

LECTURES HELD AT THE ASTRONOMICAL OBSERVATORY IN THE PERIOD 1980–1990

PREDAVANJA I SEMINARI ODRŽANI NA ASTRONOMSKOJ OPSERVATORIJI U BEOGRADU U PERIODU 1980–1990

3.03.1980.
V. A. Fomin (GAO AN SSSR, Pulkovo, Lenjingrad)
RADIOTELESKOP RATAN – 600 I NJEGOVO KORIŠĆENJE ZA ODREĐIVANJE TAČNIH KOORDINATA UNUTRAŠNJIH PLANETA

19.03.1980.
D. Olević
a) RASPODELA MASA U ASTEROIDNOM PRSTENU
b) ANALIZA KIRKWOODOVIH PRAZNINA

4.06.1980.
Dj. Teleki
AKUMULACIJA ZNANJA O POLOŽAJIMA ZVEZDA

22.12.1980.
B. Kovačević (Elektrotehnički fakultet, Niš)
INTERNI VREMENSKI SISTEMI

26.02.1981.
S. Sadžakov, M. Dačić, D. Šaletić
REZULTATI ISPITIVANJA SISTEMATSKIH GREŠAKA ZVEZDA NPZT PROGRAMA BEOGRADA I BORDOA

30.03.1981.
L. Vušković (Institut za fiziku, Beograd)
PRIKAZ ISTRAŽIVAČKOG RADA U OKVIRU VASIONSKOG PROGRAMA U JPL (Pasadena)

9.11.1981.
J. Moczko (Direktor širinske astronomske opservatorije, Borowiec, Poljska)
O RADOVIMA OPSERVATORIJE U BOROWIEC-U

31.03.1982.
A. Kubičela, M. Vukičević-Karabin (Institut za astronomiju PMF-a, Beograd)
NOVI POGLED NA SINODIČKU ROTACIJU SUNCA

7.04.1982.
A. Kubičela, I. Vince
EFEKAT VANFOKUSNOG POSMATRANJA NA SUNČEVOM SPEKTROGRAFU ASTRONOMSKE OPSERVATORIJE U BEOGRADU

29.04.1982.
Z. Knežević
RANA I KASNA OTKRIĆA MALIH PLANETA

11.08.1982.
S. Sadžakov, V. Fomin (GAO AN SSSR, Pulkovo, Lenjingrad), M. Dačić
a) AN INVESTIGATION OF THE SYSTEMATIC ERRORS OF THE BELGRADE NPZT AND AGK3 CATALOGUES ON THE BASIS OF MODERN PZT OBSERVATIONS
b) SYSTEMATIC ERRORS IN LATITUDE OBSERVATIONS OF VARIOUS OBSERVATORIES

28.10.1982.
V. Zappala, M. DiMartino, F. Scaltriti (Astronomska opservatorija, Torino), Z. Knežević, G. Djurašević
PRIRODA ASTEROIDA 216 KLEOPATRA NA OSNOVU NOVIH FOTOMETRIJSKIH POSMATRANJA

17.11.1982.
V. Škodrov (Astronomski odsek Akademije nauka Bugarske)
ASTRONOMSKA ISTRAŽIVANJA U BUGARSKOJ

11.01.1983.
R. Grujić, Dj. Teleki
ISPITIVANJA UTICAJA VETRA NA MERENJA KOD BEOGRADSKIH ŠIRINSKIH POSMATRANJA

18.01.1983.
B. Kovačević, Lj. Golubović (Elektrotehnički fakultet, Niš)
a) PRENOS VREMENSKIH SIGNALA PREKO SATELITA I PRECIZNO ODREĐIVANJE NJIHOVOG MESTA
b) TEHNIČKA OPREMLJENOST ČASOVNE SLUŽBE ASTRONOMSKE OPSERVATORIJE I MOGUĆNOSTI NJENOG OSAVREMENJAVANJA

3.03.1983.
Dj. Božičković
KATALOG APSOLUTNIH DEKLINACIJA 213 FK4 ZVEZDA U ZONI OD −30° DO +90°

4.05.1983.
a) V. Kršljanin
SAVREMENA KOSMOLOGIJA I FILOZOFIJA
b) N. Čabrić, A. Tomić (Narodna opservatorija, Beograd)
OKULTACIJA JUPITERA 6. MARTA 1983.
c) A. Tomić, N. Čabrić (Narodna opservatorija, Beograd)
FIKTIVNI DNEVNI METEORSKI RADIJANTI
d) A. Tomić, N. Čabrić (Narodna opservatorija, Beograd)
DENSITOMETAR SA He Ne LASEROM I LDR
e) S. Ninković
REZULTATI IZRAČUNAVANJA GALAKTOCENTRIČNE ORBITE GLOBULARNOG JATA NGC 5466

7.09.1983.
a) I. Pakvor
IZVEŠTAJ O STANJU RADOVA NA VAKUUMSKIM MERIDIJANSKIM MIRAMA
b) S. Sadžakov, V. A. Fomin (GAO AN SSSR, Pulkovo, Lenjingrad), M. Dačić
SISTEMATSKE GREŠKE TIPA $\Delta\alpha_\alpha$ I $\Delta\delta_\alpha$ POTSDAMSKOG PZT KATALOGA ZVEZDA

17.11.1983.
I. Almár (Konkoly Opservatorija, Budimpešta)
INFORMACIJE O SATELITSKO-GEODETSKIM MERENJIMA I O NJIHOVOJ GEODINAMIČKOJ PRIMENI U MAĐARSKOJ

23.11.1983.
V. A. Fomin (GAO AN SSSR, Pulkovo, Lenjingrad)
ISPITIVANJE SISTEMATSKIH GREŠAKA $\Delta\alpha_\alpha$, $\Delta\delta_\alpha$ TOKIJSKIH KATALOGA FZT

9.12.1983.
L. Sehnal (Opservatorija Ondřejov, Čehoslovačka)
OTPOR ATMOSFERE KRETANJU VEŠTAČKIH SATELITA I NOVI MODELI ATMOSFERE

29.12.1983.
R. Grujić, R. Krga
ISPITIVANJE „GREŠKE NOĆI" KOD BEOGRADSKIH ŠIRINSKIH PODATAKA U PERIODU 1949—1960

10.02.1984.
A. Yu. Yatsenko (Opservatorija Engelhardt, Kazan, SSSR)
a) O TATARSKOJ SSR
b) O KAZANSKOJ OPSERVATORIJI

11.04.1984.
B. Kovačević (Elektrotehnički fakultet, Niš)
UNAPREĐENJE ČASOVNE SLUŽBE NA ASTRONOMSKOJ OPSERVATORIJI

17.05.1984.
J. Vondrak (Opservatorija Ondřejov, Čehoslovačka)
a) OPSERVATORIJA ONDŘEJOV
b) UTICAJ PLANETA NA PRECESIJU I NUTACIJU

22.05.1984.
a) I. Vince, M. Dimitrijević, V. Kršljanin
SUDARNO ŠIRENJE I LIMB EFEKAT NA SUNCU: LINIJE NaI $3p^2P^0 - ns^2S$
b) Dj. Božičković
ODREĐIVANJE NAGIBA MIKROSKOPA

14.06.1984.
A. Yu. Yatsenko (Opservatorija Engelhardt, Kazan, SSSR)
ISTRAŽIVANJA PAVILJONSKE REFRAKCIJE NA ASTRONOMSKOJ OPSERVATORIJI ENGELHARDT

21.06.1984.
V. Zappala (Astronomska opservatorija, Torino), P. Farinella (Univerzitet, Pisa)
ROTATIONAL PROPERTIES AND COLLISIONAL EVOLUTION OF ASTEROIDS

31.08.1984.
I. Vince, M. Dimitrijević, V. Kršljanin
ŠIRENJE PRITISKOM I LIMB EFEKAT NA SUNCU

12.10.1984.
A. Yu. Yatsenko (Opservatorija Engelhardt, Kazan, SSSR), Dj. Teleki
SAVREMENI POGLED NA HARZEROVE RADOVE O ASTRONOMSKOJ REFRAKCIJI

22.10.1984.
Y. Andrillat (Direktor Observatoire Haute-Provence, Francuska)
THE OBSERVATORY HAUTE-PROVENCE

24.10.1984.
H. Debehogne (Observatoire Royal de Belgique)
PLATE REDUCTIONS AND MODERN ALGEBRA. ACCURACY ON LA SILLA-ESO PLATES BY THE TEST-STARS METHOD

25.10.1984.
Y. Andrillat (Direktor Observatoire Haute-Provence, Francuska)
Be ZVEZDE

7.12.1984.
M. Dimitrijević
PARISKA OPSERVATORIJA

11.12.1984.
P. Paquet (Observatoire Royal de Belgique)
PROGRAM „MERIT": DOBIJENI REZULTATI I OČEKIVANJA

19.12.1984.
A. Lesage (Opservatorija Paris-Meudon, Francuska)
VEROVATNOĆE PRELAZA I NJIHOV ZNAČAJ U ASTROFIZICI

31.01.1985.
a) A. Kubičela, I. Vince, Z. Ivanović (IX gimnazija, Beograd)
EFFECTS OF EXTRAFOCAL OBSERVATION WITH THE SOLAR SPECTROGRAPH OF THE BELGRADE ASTRONOMICAL OBSERVATORY. III: INTEGRATION OF THE LIMB EFFECT
b) G. Djurašević, J. Arsenijević, Z. Knežević
OMIKRON ANDROMEDAE — BRZE PROMENE

28.02.1985.
D. Olević, S. Šegan (Institut za astronomiju PMF-a, Beograd)
PROCENA TAČNOSTI ASTROGRAFSKIH POLOŽAJA DOBIJENIH KRATKOFOKUSNIM ASTROGRAFOM BEOGRADSKE OPSERVATORIJE

7.03.1985.
S. Sadžakov, M. Dačić
a) REZULTATI POSMATRANJA ZVEZDA ZA KATALOG DS PROGRAMA I U OKOLINI RADIO-IZVORA
b) POSMATRANJA SUNCA I PLANETA NA MERIDIJANSKOM KRUGU U BEOGRADU

2.04.1985.
M. S. Dimitrijević
ZAVISNOST ŠTARKOVIH ŠIRINA I POMAKA OD JONIZACIONOG POTENCIJALA: $np^{k-1}(n+1)s - np^k$ REZONANTNI PRELAZ

15.04.1985.
J. Vondrak (Opservatorija Ondřejov, Čehoslovačka)
IMPROVEMENT OF POSITIONS AND PROPER MOTIONS OF THE STARS FROM THE PZT OBSERVATIONS AT ONDŘEJOV OBSERVATORY

18.04.1985.
V. Kršljanin, I. Vince
SUDARNO ŠIRENJE I OSETLJIVOST SINTETIZOVANIH PROFILA NEKIH NEREZONANTNIH LINIJA NEUTRALNOG NATRIJUMA NA PROMENE MIKROTURBULENTNE BRZINE

30.05.1985.
A. Čadež (Institut za fiziku, Ljubljana)
GRAVITACIONI TALASI OD PULSARA

3.07.1985.
M. S. Dimitrijević, V. Kršljanin
SEMIEMPIRIJSKA FORMULA ZA ŠTARKOV POMAK SPEKTRALNIH LINIJA JONA

28.08.1985.
M. S. Dimitrijević
a) JEDNOSTAVNA FORMULA ZA PRORAČUN PARAMETARA ŠTARKOVOG ŠIRENJA LINIJA NEUTRALNIH ATOMA
b) O NEJEDNAKOSTI ŠTARKOVIH PARAMETARA UNUTAR JEDNOG MULTIPLETA I SUPERMULTIPLETA ArII
c) ŠTARKOVO ŠIRENJE SPEKTRALNIH LINIJA NEUTRALNOG KALIJUMA

4.09.1985.
O. Atanacković
EFEKTI ELASTIČNIH SUDARA NA LOKALNU FREKVENTNU PRERASPODELU FOTONA U REZONANTNIM LINIJAMA

12.09.1985.
a) G. Roberti (Astronomska opservatorija, Napulj)
THE FORMATION OF THE KI 7699 RESONANCE LINE IN NON-LTE CONDITIONS
b) G. Severino (Astronomska opservatorija, Napulj)
THE EFFECTS OF WAVES ON THE KI 7699 RESONANCE LINE

17.09.1985.
Dj. Alpar (Direktor Kosmičke geodezijske opservatorije u Pencu, Mađarska)
O DOPLER TEHNICI

18.09.1985.
Dj. Alpar (Direktor Kosmičke geodezijske opservatorije u Pencu, Mađarska)
O ANALIZI VREMENSKIH SERIJA

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26.12.1985.
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1.04.1986.
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3.04.1986.
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OSNOVNI PRINCIPI POSTAVKE SFERNIH SISTEMA KOORDINATA U ASTROMETRIJI

21.05.1986.
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INFORMACIJA O RAČUNSKOM CENTRU PARISKOG UNIVERZITETA 11 — ORSAY

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ASTRONOMSKI PROGRAM „NAUTILUS"

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18.11.1987.
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ANALIZA RELATIVNOG KRETANJA PARA GP 34

21.03.1989.
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DYNAMICS IN THE 2 : 1 RESONANCE

22.03.1989.
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31.05.1989.
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4.10.1989.
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21.02.1990.
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IZUČAVANJE AKTIVNIH TESNIH DVOJNIH SISTEMA

7.03.1990.
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GALAKTIČKI RADIO-HALO

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TOPLE ZVEZDE SA EMISIONIM LINIJAMA

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PRENOS ZRAČENJA U ZVEZDANIM ATMOSFERAMA

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INVERZIJA PROFILA ZVEZDANIH SPEKTRALNIH LINIJA

2.07.1990.
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POSMATRAČKE MOGUĆNOSTI NACIONALNE OPSERVATORIJE ROZHEN (BUGARSKA)

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REŠAVANJE BOLTZMANNOVE JEDNAČINE ZA NAŠU GALAKSIJU

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7.11.1990.
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FOREWORD

The aim of the present Volume "Astronomical Observatory in Belgrade — Activities and Abstracts of Papers (1980–1990)" is to offer a more complete insight into the fields and the contents of the recent researches performed at this Observatory.

Although of great diversity the Observatory's activity may be classified into the following research entities:

— Fundamental Astrometry
— Earth's Rotation
— Dynamical and Statistical Investigations on Celestial Bodies
— Astrophysical Researches.

The bulk of the Observatory's research activity consists in the acquisition of its own observational data, their processing and analysis as well as the forwarding of the obtained results to the international centres. Further activity consists in the theoretical research in astrometry, astrophysics and related fields (plasma physics, theoretical mechanics) along with the treatment of the observational data obtained from other astronomical centres.

The importance of research at the Belgrade Observatory arises from the fact that it is the only one in this country pursuing on a permanent basis observations of celestial bodies, necessary for the elaboration of stellar catalogues and astronomical ephemeris, for defining the celestial quasi-inertial coordinate frame, time and geographic coordinates determination, for the study of the Earth's rotation and for application in geodesy and geophysics. Multidisciplinary study of the variations in the Belgrade mean geographic coordinates is carried out conjointly with several institutes for geomagnetism, geophysics and seismology. Fundamental research performed at the Observatory in the astronomical spectroscopy finds its application in the physics and technology of plasma and its laboratory sources as well as in the physics and technology of thermonuclear fusion and the light sources.

Considerable part of the Observatory's researches is achieved through fruitful international cooperation. This is evidenced by many joint papers of our and foreign authors. In addition to direct cooperation, realized with a large number of domestic and foreign institutions, the Observatory is a member of several international services while participating in many research programmes under the auspices of the International Astronomical Union.

Among its key supports in the scientific and research activity is the Observatory's library, possessing the richest holdings of astronomical literature in the country: over 4.000 periodicals and 10.000 books.

The Observatory is the editor of *Bulletin de l'Observatoire Astronomique de Belgrade* (founded in 1936), dedicated to publishing the scientific articles and professional papers, and of *Publications de l'Observatoire Astronomique de Belgrade* (founded in 1947) containing chiefly monographs or conference proceedings. The exchange of these editions is effected with about 400 scientific institutions, more than 350 of them from abroad.

To provide a broader insight into the Observatory's interest subjects and activities presented herein is also a list of lectures and seminars having been held at the Observatory in the period 1980–1990.

Considering the thematic and phenomenological diversity of the Observatory's scientific and research activity, which is in steady growth, we hope that the publication thus arranged will, on one hand, furnish useful information to those interested in the current research pursued at this Observatory and, on the other, secure the necessary information to those wishing to better comprehend the development of astronomy on this soil.

Readers interested in more detailed survey of the development and of scientific activity of the Observatory since its foundation in 1887 to our days may refer to the "Publications de l'Observatoire astronomique de Belgrade" No. 36 — "The Hundred Years of Astronomical Observatory in Belgrade".

Editors

PREDGOVOR

Publikacija „Astronomska opservatorija u Beogradu — Aktivnosti i kratki sadržaji radova (1980–1990)" ima za cilj da pruži potpuniji uvid u oblasti i sadržaje najnovijih istraživanja vršenih na ovoj opservatoriji.

Iako vrlo raznovrsna, aktivnost na Opservatoriji se može grupisati u sledeće istraživačke celine:

— fundamentalna astrometrija
— Zemljina rotacija
— dinamička i statistička istraživanja nebeskih tela
— astrofizička istraživanja.

Najveći deo naučno-istraživačke aktivnosti Opservatorije čini prikupljanje sopstvenih posmatračkih podataka, njihova stručna i naučna obrada, kao i dostavljanje dobijenih rezultata medjunarodnim centrima. Ostalu aktivnost čine teorijska istraživanja u astrometriji, astrofizici i srodnim naučnim oblastima (fizici plazme, teorijskoj mehanici), kao i obrada posmatračkih podataka dobijenih iz drugih astronomskih centara.

O značaju rada Astronomske opservatorije govori činjenica da ona jedina u zemlji vrši stalna posmatranja nebeskih tela neophodna za sastavljanje zvezdanih kataloga i astronomskih efemerida, za definisanje nebeskog kvazi-inercijalnog koordinatnog sistema, za odredjivanje vremena i geografskih koordinata, za izučavanje Zemljine rotacije i primene u geodeziji i geofizici. Multidisciplinarna istraživanja promena srednjih geografskih koordinata Beograda vrše se zajedno sa više instituta iz oblasti geomagnetizma, geofizike i seizmologije. Fundamentalna istraživanja koja se na Opservatoriji vrše u oblasti astronomske spektroskopije nalaze primenu u fizici i tehnologiji plazme i njenih laboratorijskih izvora, kao i u fizici i tehnologiji termonuklearne fuzije i izvora svetlosti.

Značajan deo astronomskih istraživanja na Opservatoriji ostvaruje se u okviru plodne medjunarodne saradnje. O tome svedoči veliki broj zajedničkih radova domaćih i stranih autora. Pored neposredne saradnje koju ostvaruje sa velikim brojem ustanova u zemlji i inostranstvu, Opservatorija je član nekoliko medjunarodnih službi, a u okviru Medjunarodne astronomske unije učestvuje u više istraživačkih programa.

Jedan od značajnih oslonaca naučno-istraživačke aktivnosti je biblioteka Opservatorije, koja poseduje najbogatiji fond astronomske literature u zemlji: preko 4.000 naslova periodike i 10.000 knjiga.

Opservatorija izdaje *Bulletin de l'Observatoire astronomique de Belgrade* (osnovan 1936. godine) u kome se štampaju naučni i stručni radovi, i *Publications de l'Observatoire astronomique de Belgrade* (osnovane 1947. godine) koje sadrže monografije ili zbornike radova. Razmenu svojih izdanja Opservatorija vrši sa oko 400 naučnih institucija, od kojih sa više od 350 u inostranstvu.

Da bi se stekao širi uvid u interesovanja i aktivnosti na Opservatoriji u ovoj Publikaciji je dat i pregled predavanja i seminara održanih na Astronomskoj opservatoriji u periodu 1980–1990. godine.

S obzirom na tematsku i pojavnu raznovrsnost naučno-istraživačke aktivnosti Astronomske opservatorije, koja je u stalnom porastu, nadamo se da će ovako priredjena publikacija, s jedne strane, pružiti korisne informacije zainteresovanima za savremena istraživanja koja se vrše na Opservatoriji u Beogradu, a sa druge, obezbediti potrebne podatke onima koji žele da bolje sagledaju razvoj astronomije na ovom tlu.

Čitaocima koji su zainteresovani za detaljniji pregled razvoja i naučne aktivnosti Opservatorije od njenog osnivanja 1887. godine do danas preporučujemo Publikaciju br. 36 „Sto godina Astronomske opsevatorije u Beogradu".

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1. BIBLIOGRAPHY OF STELLAR CATALOGUES AND MAPS
1. BIBLIOGRAFIJA ZVEZDANIH KATALOGA I KARATA

B. M. Ševarlić, G. Teleki: *Katalozi paralaksi, sopstvenih kretanja i radijalnih brzina*, VII Kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Budva-Bečići, (1980), III-12.

B. Ševarlić, G. Teleki, Z. Knežević: *Bibliography of the photographic catalogues of star positions*, in G. Teleki, B. Ševarlić (eds.), *Epitome fundamentorum astronomiae, Pars II, "Photographic catalogues and charts of star positions"*, Publ. Obs. Astron. Belgrade **29** (1982), 71–97.

B. Ševarlić, G. Teleki, Z. Knežević: *Bibliography of stellar atlases, maps and charts*, in G. Teleki, B. Ševarlić (eds.), *Epitome fundamentorum astronomiae, Pars II, "Photographic catalogues and charts of star positions"*, Publ. Obs. Astron. Belgrade **29** (1982), 99–124.

B. M. Ševarlić, G. Teleki: *Epitome fundamentorum astronomiae III — Catalogues of Stellar Parallaxes, Proper Motions and Radial Velocities*, Hvar Obs. Bull. Suppl. **6** (1982) 1, 123–125.

O. Atanacković: *Le troisième volume d'Epitome fundamentorum astronomiae.* Bull. Inform. CDS **28** (1985), 15–16.

The plans for the third volume of the "Epitome fundamentorum astronomiae" are described. The volume deals with catalogs on radial velocities, parallaxes and proper motions.

G. Teleki, I. Pakvor: *Digital designations of catalogues and surveys of star positions (Series 1)*, Publ. Astron. Obs. Belgrade **140** (1989), 131–140.

Digital designations for first 60 catalogues and surveys of star positions are given. The designations contain 16 information groups with a total of 50 digits for observational catalogues and 10 groups with a total of 36 digits for other catalogues (derived, fundamental) and surveys.

B. Ševarlić, G. Teleki, O. Atanacković-Vukmanović, I. Pakvor: *Bibliography of catalogues and papers on parallaxes*, Publ. Obs. Astron. Belgrade **40** (1990), 79–128.

A comprehensive list of catalogues and articles on parallaxes, containing 763 bibliographical entries is given.

B. Ševarlić, G. Teleki, I. Pakvor, O. Atanacković-Vukmanović: *Bibliography of catalogues and papers on proper motions*, Publ. Obs. Astron. Belgrade **40** (1990), 129–238.

Bibliography of catalogues and articles on proper motions containing 1617 entries is given.

B. Ševarlić, G. Teleki, O. Atanacković-Vukmanović, I. Pakvor: *Bibliography of catalogues and papers on radial velocities*, Publ. Obs. Astron. Belgrade **40** (1990), 239–285.

Bibliography of catalogues and articles on radial velocities containing 686 entries is given.

2. DEVELOPMENT AND HISTORY OF ASTRONOMY
2. RAZVOJ I ISTORIJA ASTRONOMIJE

S. Sadžakov: *Influence of the progress in science and technology in astrometry*, Bull. Applied Math. (BAM), Budapest, **54** (1980), 85–90.

The accuracy of astromeric measurements has achieved a high degree. Astrometry is used today for the purpose of studying the nonuniformities in the Earth's rotation and in the Universal Time, as well as the terrestrial polar motion; attempts are done in order to notice movements of the continents, to investigate fine effects of various motions of the Earth. New directions in technology make the field of astrometric application more extensive, so that a new era in astrometric development begins which lies in the field of fundamental astrometry.

M. S. Dimitrijević: *Milutin Milanković and an attempt for explaining Michelson-Morley's experiment*, Dijalektika **15** (3–4), Beograd, (1980).

Milutin Milanković, famous astronomer, mathematician and geophysicist, whose name bears a crater on the invisible side of the Moon, the first Serbian doctor of technical sciences, of same age as Einstein, the first lecturer of the Relativity theory at the University of Beograd, did not accept immediately some of the Einstein's ideas. He published two papers in which he tried to explain the negative result of the Michelson-Morley's experiment in the framework of the classical mechanics, considering that relativistic interpretation can be replaced "without a collision with the experience" starting with another set of assumptions. These two papers are presented and reviewed.

G. Teleki: *O astronomskoj aktivnosti u periodu 1660–1880*, VII kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Budva-Bečići, (1980), III-12.

G. Teleki: *Astronomija danas i sutra — u svetu i kod nas*, VII kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Budva-Bečići, (1980), III-12.

G. Teleki: *An outlook on future development of the fundamental astrometry*, Zbornik "Zadachi sovremennoj astrometrii v sozdanii inertsial'noj sistemy koordinat", Izd. "Fan", Tashkent, (1981), 362–367.

S. Sadžakov: *Organization of specialized education in our country and the position of astronomy in it*, Publ. Obs. Astron. Sarajevo, **1** (1981), 51–57.

The topic is the idea and the direction of changes in pedagogy and education in this country. Formation of an educational system as a unique system of permanent education which is in accordance with the necessities of our society is mentioned as well.

G. M. Popović: *Aktivnost astronomske opservatorije u Beogradu od 1972. godine do 1981. godine na projektu podizanja visinske astronomske stanice*, Publ. Obs. Astron. Belgrade **31** (1981), 7.

G. Teleki: *Csillagaszat az egyes délszláv területeken a XIX. Század végén és a XX. század elején*, Vasi Szemle, Szombathely, XXXV, évf. (1981), 550.

G. Teleki: *On the instrumentation-observational development of astrometry in Yugoslavia*, Hvar Obs. Bull. Suppl. **6** (1982) 1, 91–97.

Proceeding from the present-day tendencies in astrometry, prospective development trends of astrometry in Yugoslavia, bearings upon instrumentation and observation, are analysed. With regard to the material, technical and manpower capabilities, the continuations with the already existing instruments is suggested, with the proviso, however, their programmes are strictly selected. Yugoslavia should join, in the years ahead, the VLBI stations network and the Hipparcos programme.

G. Teleki: *Astrometrical activity in the period 1600 to 1880*, "Compendium in Astronomy", D. Reidel Publ. Comp., Dordrecht-Boston-London, (1982), 23.

M. Protić, V. Protić-Benišek: *Milutin Milanković i astronomska opservatorija u Beogradu (Milutin Milankovitch et l'Observatoire astronomique à Belgrade)*, Zbornik radova "Život i delo Milutina Milankovića 1879–1979", Naučni skupovi Srpske akademije nauka i umetnosti, knj. XII, Predsedništvo, knj. **3** (1982), 181–190.

Le nom du Prof. M. Milankovitch est très étroitement lié aux tentatives et aux efforts entrepris pour élever à Belgrade un Observatoire astronomique moderne, dont l'équipement coûteux a été commandé et déjà livré.

G. Teleki: *Kozmikus asztrometria: a Hipparcos és Tychotervek*, Csillagászati Evkönyv 1984, Gondolat, Budapest, (1983), 169.

G. Teleki: *Kozmikus asztrometria*, Letnja škola mađarskih astronoma, Višegrad, (1983), 15.

G. Teleki: *A fundamentalis rendszer problémái*, Letnja škola mađarskih astronoma, Višegrad (1983), 3.

M. S. Dimitrijević: *Milutin Milanković i pokušaj objašnjenja Majkelson-Morlijevog ogleda*, Matematičko-fizički list **140** (1) (1984/85), 5.

V. Protić-Benišek: *Astronomical Observatory in Belgrade during 1941–1945*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985).

M. S. Dimitrijević, A. Tomić: *Radovan Danić — popularizator astronomije: I — Štampani radovi*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 41.

A. Tomić, M. S. Dimitrijević: *Radovan Danić — popularizator astronomije: II — Predavanja i kursevi*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 47.

G. M. Popović: *Prilog pregledu astronomskih izraza s kraja 18. stoleća u slavenoserbskom jeziku*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 111.

V. Trajkovska: *A note on Copernicus from 1837*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 127.

This paper contains description of proposal dating from 1837 to build a monument to N. Copernicus.

Dj. Teleki, O. Atanacković: *Rast znanja o astronomskoj refrakciji*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 151–155.

S. Sadžakov, M. Dačić: *Istorijski razvoj zvezdanih kataloga u svetu i kod nas*, VII Nac. konf. jug. astr. Beograd 1984, Publ. Astr. društva Ruđer Bošković **4** (1985), 181.

V. Kršljanin: *Contemporary cosmology and philosophy (Some aspects of relationships and possibilities of overcoming the present difficulties)*, Publ. Obs. Astron. Belgrade **33** (1985), 107.

Experimentally proved and uncontrovertable part of contemporary cosmological theories is considered in the feed-back with the philosophical principles, especially with the principles of materialistic dialectics. A survey is presented of ideas and facts which are, according to the author, most relevant for this relation (definition of the subject of cosmology, relation of cosmology to other fundamental fields of physics; relation of the scientific cosmology to the old prejudiced ideas, especially in connection with infinity; vulgar-materialistic superficiality and creationistic speculations).

Most attention is paid to some latest theories and results (instability of proton; inapplicability of energodominacy to actual polarisation of vacuum, which resulted in de Sitter-Starobinsky solution without initial singularity)

which, together with heuristic philosophical principles, served as the basis for suggesting the solutions of some problems and for the possibility to consider relations of cosmology and philosophy more systematically.

S. Ninković: *On Astrophysics Teaching in the Secondary Schools*, Publ. Obs. Astron. Belgrade, **33** (1985), 116.

The author presents his own three-year-long experience in astrophysics teaching at a Belgrade secondary school. Special attention is paid to the interest expressed by pupils in this subject and, their, in recent time, increased interest in performing their professional praxis in the field of astrophysics.

G. Teleki: *Growth of the knowledge of stellar positions*, Bull. Obs. Astron. Belgrade **135** (1985), 40–44.

An analysis is performed of the growth of the number of catalogues of star positions, the number of the catalogue positions, as well as the accuracy of the observational and fundamental catalogues. One of the conclusions is that the accuracy has been increasing faster than the number of catalogue positions and also faster than the number of the stars in the fundamental catalogues (FC-NFK-FK3-FK4 series).

G. Teleki: *Bibliography of papers of the Belgrade Astronomical Observatory research associates published in the period 1980–1983*, Bull. Obs. Astron. Belgrade **135** (1985), 64–70.

In the four years period 1980–1983 the researching results of the present and retired associates of the Belgrade Astronomical Observatory were published under 205 titles (articles, notes, abstracts, observations data) in a number domestic and foreign periodicals and editions.

G. Teleki: *A Kozmikus Csillagászat Fejlődése*, Fizikai Szemle, Budapest, (1986), 129.

G. Teleki: *The need for better co-operation and intercomparison in fundamental astrometry*, in "Astrometric Techniques", H. K. Eichhorn and R. J. Leacock (eds.), (1986), 749–755.

The present status and practice in the fundamental astrometry are analysed, and relying upon the findings the author suggests the organization of an international action aimed at achieving better co-operation in the star position observations and celestial reference system determinations, as well as performing the intercomparison of the different techniques and methods.

M. Djokić: *How the Observatory of the High School in Beograd was founded*, "Vasiona", Revue d'Astronomie, **8** (1987), 3–7.

The history of the actions lead by Milan Nedeljković from 1887 to 1891 which resulted by the foundation of the Astronomical and Meteorological observatory in Beograd is presented.

M. Djokić: *How the instruments for the Observatory of the High School and the University of Belgrade were obtained*, "Vasiona", Revue d'Astronomie **8** (1987), 91–95.

It is described how the astronomical instruments of the Belgrade High School and University observatory were obtained from reparation after First world war.

V. Protitch-Benishek: *Centenary of the Astronomical observatory in Belgrade*, Vasiona, **3–4** (1987), 64–70.

The history of the Astronomical observatory in Belgrade is presented.

G. Teleki: *Bibliography of papers of the Belgrade Astronomical observatory research associates published in the period 1984–1986*, Bull. Obs. Astron. Belgrade **137** (1987), 91–98.

Bibliography of papers of the Belgrade astronomical observatory research associates published in the period 1984–1986 is presented and analyzed.

S. Tolchel'nikova-Murri, S. Sadžakov, M. Dačić, Z. Cvetković: *The present situation with absolute methods of observations in fundamental astronomy*, Colloq. **100** IAU, Beograd, (1987).

M. S. Dimitrijević: *II workshop: Astrophysics in Yugoslavia*, Bull. Obs. Astron. Belgrade **139** (1988), 72.

M. Djokić: *Belgrade University observatory between 1924 and 1926*, IX Nacionalna konferencija astronoma Jugoslavije, Zbornik rezimea, Sarajevo, (1988), 42.

The data concerning the Observatory of Belgrade University between 1924 and 1926 are presented. That time is characterised by the division of the Observatory between an astronomical and meteorological one as well as by the constituting of the Astronomical Observatory as a separate establishment.

M. B. Protitch, V. Protitch-Benishek: *Data revision of the Babylonian and some Arabian lunar and solar eclipses used in the Newcomb's researches*, IX Nacionalna konferencija astronoma Jugoslavije, Sarajevo, (1988).

On the basis of Ptolomy's original manuscripts concerning Babilonian-Hellenic observations of lunar eclipses and analysing some Arabian notes about solar and lunar eclipses — for which S. Newcomb determined considerable deviations from the appropriate theory — the re-analysis of his results and conclusions was undertaken. The results of ancient data revision are also based on Newcomb's alternative presumption that such discrepancies are caused by one or more unknown long-term inequalities in the motion of the Moon. A quantitative result of analyse of ancient eclipse observations unambiguously indicates that these observations are, by no means, to be rejected. Of course, if they are interpreted in an appropriate way.

M. Mitrović, J. Arsenijević, I. J. Pakvor: *1987 — the hundredth year of Belgrade astronomical observatory life time*, Publ. Astron. Obs. Beograd **36** (1989), 13–22, (srpskohrvatski).

The activities concerning hundred years anniversary celebration are presented.

B. Ševarlić, J. Arsenijević: *One hundred years of activity of Belgrade Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 25–37, (srpskohrvatski).

The short report about the foundation and scientific activity of Belgrade Astronomical Observatory during one hundred years of its life is presented.

R. Grujić: *Latitude group of Belgrade Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 41–44, (srpskohrvatski).

A short review on the work on the geographic latitude determination for Belgrade from the begining (in 1947) until nowadays is given. An information on the programme of latitude derivation resulted from the changes done in the framework of the service itself, as well as in the framework of the IAU (MERIT) is given. It is also given another information concerning the state in the service at the moment of introducing of the new technic in the world. Furthermore, we inform on the results of comparison programme observations aimed at the declination determination for zenith stars. The results are positive and in such a way they indicate that such instruments should be also used in the future for these purposes, both in Yugoslavia and throughout the world. A short rewiew on the development of the service viewed in the light of the accuracy of the latitude determination and of the declination determination for zenith stars, as well as one on the service direction in the course of time, is presented.

G. M. Popović, D. J. Zulević: *Double stars Group*, Publ. Astron. Obs. Belgrade **36** (1989), 51–62, (srpskohrvatski).

S. Sadžakov: *Work on Meridian Circle of the Belgrade Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 63–71, (srpskohrvatski).

The review of the activity on the Meridian Circle of the Belgrade Astronomical Observatory is presented. The instrument rectification, the results of the investigation of vital parts of the instrument, the first observations as well as the results of the observations during last twenty years are described. Also, some data about the members of the group and their scientific results are given. The future work is mentioned too.

M. Mijatov, V. Trajkovska: *Activity of the Absolute Declination Group*, Publ. Astron. Obs. Belgrade **36** (1989), 71–81, (srpskohrvatski).

In this paper is presented the activity of the Group of Absolute Declinations since its formation in 1960 until nowadays. The main task of the group has been observation with the Large Vertical Circle. This instrument was received

from Germany after the first World War as a result of the war reparations, but because of lack of money it was not mounted before 1960. However, the regular observations were initiated as late as in 1976 due to serious problems, at first with the pavilion, itself, and later on because of technical disadvantages of the instrument. The instrument was prepared for observations as late as after a detailed reconstruction done by the chief engineer of Pulkovo Observatory, D. S. Usanov in late 1974. The reconstruction comprised changes concerning the functioning of the vertical axis and of the horizontal one. During 1976–1980 an absolute catalogue comparising 308 northern stars (declination zone $+65°$–$+90°$) from FK4 and BS catalogues was compiled. All the stars were observed both in the upper and lower culminations. The average number of observations per star was 10. The analysis is still being done. During the period 1983–1985 213 stars from FK4 catalogue were observed (declination zone $-30°$–$+90°$) by use of the absolute method. A major part of the observations was carried out in the Küstner series. All the stars satisfying $\delta > +60°$ were observed in the lower culmination, too. The average number of observations per star was 8. The analysis is still being done. Since 1982 meridian observations of the major and minor planets have been done by use of the quasiabsolute method and of the relative one. In addition to the observations an extended refraction research has been done. This kind of research has been mostly done by Dr G. Teleki, who was Chairman of the Working Group for the Study of Astronomical Refraction of Commission 8 of the IAU since its foundation in 1971 until his death in early 1987. Two parts of a multivolume edition of the bibliography of star catalogues "Epitome fundamentorum astronomiae" have been published and the third part is in preparation. In addition to the mentioned work the members of the group have dealt with testing of the instruments and equipment, with the problems of latitude and climatology, as well as with history, development and teaching astronomy. In the future the observations will be continued and in addition to the already existing ones other actual programmes of international importance, which can be done with the instrument, will be accepted.

I. J. Pakvor: *Activity of absolute right ascensions division*, Publ. Astron. Obs. Beograd **36** (1989), 83–87, (srpskohrvatski).

A complete history of the activity of Absolute Right Ascensions Division is given. Development of the Division is very close to the development of the Large Transit Instrument and its investigations. One of the most important point of this development is the foundation of vacuum meridian marks, an international recognized contribution.

V. Protić-Benišek: *Fifty years of activity: minor planets, comets and sattelites department of Belgrade Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 89–96, (srpskohrvatski).

This paper presents a review of the scientific and observational work in the Department of minor planets, comets and sattelites since 1935 till today at the Astronomical Observatory of Belgrade.

J. Arsenijević: *Astrophysical Group of the Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 97–101, (srpskohrvatski).

The activity of Astrophysical Group since its foundation in 1960. is briefly presented. Its scientific work has been covering three topics: physics of variable stars, solar physics and spectroscopy of astrophysical plasma. Short note about the future development has been given.

D. Petrović, J. Arsenijević: *The Observatory library*, Publ. Obs. Astron. Belgrade **36** (1989), 103–106, (srpskohrvatski).

The main data about the Observatory libary, the richest astronomical library in Yugoslavia, are presented.

M. Djokić: *How the Observatory of the High School in Belgrade was founded*, Publ. Obs. Astron. Belgrade **36** (1986), 143–151, (srpskohrvatski).

The foundation of the Belgrade High School Observatory is described and some characteristic archives' documents are presented.

V. Protić-Benišek, M. Djokić: *Dr V. V. Michkovitch and his election at the Belgrade faculty of philosophy in 1925*, Publ. Obs. Astron. Belgrade **36** (1989), 153–158.

Professor and Academician Dr. Vojislav V. Michkovitch was born in Fužine, Croatia, on 18th January 1892. The following year his parents moved to Serbia, where he graduated from high school in 1910 (Novi Sad) and took up his studies in Budapest and Göttingen. At the end of World War I, as one of the survived wariors of famous Serbian "students battalion", was sent to France where he graduated studies in astronomy in 1919 and obtained the position of an assistant of the Observatory in Marseille. Than, in 1922 he joined the staff of the Nice Observatory. He got Doctor's degree in 1924 on the thesis "Etudes de Statistique stellaire" (Study on Stellar Statistics). In 1926 he came back to Yugoslavia and was appointed professor of Practical Astronomy at the University of Belgrade. By his initiative a modern Astronomical observatory was erected in Belgrade in 1932. In 1939 he became elected regular member of the Serbian Academy of Sciences (from 1929 he was corresponding member), and soon, the General Secretary of this institution. He had become the member of International Astronomical Union in 1935. During World War II professor Mishkovitch was imprisoned by Gestapo.

His principal concerns were minor planets, especially the identifications of those unsufficient observed. In that scope he published a good number of studies and articles. He was a founder of the Astronumerical Institute of Serbian Academy of Sciences, Also, he initiated and was editor-in-chief for a lot of scientific publications. Among them worth to mention are: "Annuaire", which cover ephemeris of 240 stars for International Time Service, "Bulletin de l'Observatoire Astronomique de Belgrade", and others. In his final years he turned his attention to the history of astronomy and his several studies in this field were published by Serbian Academy of Sciences. He died on 25 November 1976 at the age of 85.

I. J. Pakvor: *An episode from the history of the foundation of modern astronomical observatory in Belgrade*, Publ. Astron. Obs. Beograd **36** (1989), 159–165, (srpskohrvatski).

Sixty years ago an attempt was done to build modern Astronomical Observatory outside of urban locality, on the mountain Fruška gora, 70 kms north-west form Belgrade, at place called Zmajevac. A group of eminent professors from Belgrade University entered into negotiations with local authorites, unfortunately without positive solution.

G. M. Popović: *From the observer's notebook of P. Djurković*, Publ. Obs. Astron. Belgrade **36** (1989), 165–176, (srpskohrvatski).

M. Djokić: *The archives' documents about Belgrade High School and University Observatory in the period 1887–1924*, Publ. Obs. Astron. Belgrade **36** (1989), 177–326, (srpskohrvatski).

The selection of archives documents about Belgrade High School and University Observatory from time of its foundation in the 1887 until 1924 — the year of dividing the Observatory into Astronomical Observatory and Meteorological Observatory — were presented.

G. Ivanišević, N. Djokić: *Bibliography of the papers published by Belgrade Astronomical Observatory*, Publ. Obs. Astron. Belgrade **36** (1989), 333–397, (srpskohrvatski).

M. S. Dimitrijević, A. Kubičela, J. Arsenijević, V. Kršljanin: *Position of astrophysics at the Astronomical observatory in Belgrade*, III Seminar „Astrofizika u Jugoslaviji", Zagreb, (1989), 17.

S. Sadžakov, S. A. Tolchel'nikova-Murri: *A contribution to the problem of the choice of observational methodics and international cooperation in fundamental astrometry*, Problemy postroeniya koordinatniykh sistem v astronomii, GAO AN SSSR, Leningrad, (1989), 79–87.

In order to make the international cooperation in fundamental astrometry efficient it is necessary to solve the two following problems:

1. To explain the role of absolute methods of reference frame formation as means to divide the observed relative motions of celestial bodies into the owen ones, existing for various observed bodies, and parallactic ones due to the displacements of terrestrial reference objects and of the Earth. This will enable an essential simplification in solving the problem of relationship among various reference frames including also the new ones based on space and radio observations. 2. To extend the compilation methodics of the fundamental catalogue on the basis of a suitable planning of observations for the following epoch. Observations of such kind can be organised on the basis of optical services of terrestrial rotation.

V. Protitch-Benishek: *Astronomical photography in Serbia*, Publ. SANU, No. 69, (1990).

3. INSTRUMENTS AND DATA REDUCTION METHODS
3. INSTRUMENTI I METODI OBRADE PODATAKA

T. Sotirović, M. S. Dimitrijević: *Problem analize i sinteze trakastih vodova*, 23 ETAN u pomorstvu, Zadar 1981, 272.

Lj. Varga, V. Protić-Benišek: *Transistorised servo-regulator of the Askania astrograph drive mechanism of the Belgrade Observatory*, Proceedings of the National Conference of Yugoslav astronomers, Publ. Obs. Astron. Sarajevo **1** (1981), 153–155.

After one serious defect of the centrifugal servo-regulator in 1977, it was decided to remove it and to equip the instrument with DC electromotor drive with a transistorized control system. During 1977 an experimental drive was constructed. It was found that this drive system had a satisfactory stability over long time intervals. This is important in view of the instrument having constructive deficiencies, especially concerning its balance system.

L. A. Mitić: *Investigation of the level division inequalities with an extrafocally adjusted collimator*, Bull. Obs. Astron. Belgrade **131** (1981), 9–12.

Graduation of two astronomical 1″ levels has been investigated from close distance (4.7 m) with a collimator (8/100 cm) whose micrometer was adjusted extrafocally by 32 cm. High precision of settings of the level graduation lines (mean error of settings ranged from ±0.″0020 to ±0.″0014) permitted the inequalities in the division values to be firmly established. These inequalities, however, rarely exceed ±0.″02.

V. Trajkovska: *An analysis of the division errors of the Belgrade Large Meridian instrument*, Publ. Astron. Obs. Sarajevo **1** (1981), 85.

An account is given of the results of investigation of the circle division errors of the Belgrade Observatory Large Meridian instrument. By the linear correlation method, interrelation of the circle corrections, found from the investigations carried out in 1966, 1968 and 1977, is established. In employing the spectral analysis method (Blackman-Tukey method) a periodic component with 2° period has been identified, supposed to be a consequence of the way of circle manufacturing.

A. Kubičela, M. Rakić: *Fotodioda PS-100-30 kao senzor položaja u astronomiji*, Saopšteno na VI Nacionalnoj konferenciji jugoslovenskih astronoma, Hvar, 1983.

Z. Stančić, M. Mijatov: *Nova određivanja kolimacije i savijanja na VMK AO u Beogradu*, VIII Kongres MFAJ i VIII Nacionalna Konf., Priština, (1985).

Dj. Bozhichkovich: *An Efficient Method of Determining and Removing the Inclination of the Microscope-Micrometers*, Astron. Tsirk. No. **1395** (1985), 4–5.

The use of plane-parallel glass is suggested for determining and removing the inclination of the microscope-micrometers.

A. Kubičela, M. Rakić: *Photodiode PS-100-30 as a position sensor in astronomy*, Publ. Obs. Astron. Belgrade **33** (1985), 23.

Position-sensing photodiode PS-100-30 has been preliminarily tested as the position encoder at a spectrogram measuring machine. It has been found that it would be necessary to keep determing the calibration constants as well as some systematic corrections depending on the position. Only taking care of such precautions the micrometer accuracy might be achieved.

V. Trajkovska: *Investigation of the graduation error of the Belgrade Meridian Circle*, Bull. Obs. Astron. Belgrade **136** (1986), 126.

Account is given of the organization and analysis of investigation of the graduation of the Belgrade Meridian Circle performed in 1977. Measurements are made at half-degree spacing, Bruns' method having been applied. Inquiry is made for possible temperature effects on the measurements.

D. Olević, S. Šegan and R. Pavlović: *Accuracy of the astrographic positions obtained with the Belgrade short-focus astrograph*, Bull. Obs. Astron. Belgrade **136** (1986), 36–39.

By analyzing astrographic position obtained with the Belgrade short-focus astrograph (Zeiss, $D = 16\,\mathrm{cm}$, $F = 80\,\mathrm{cm}$) the following has been estabilshed: a) Higher accuracy is reached by making reduction according to Terner's method involving 3 coefficients ($T(3)$) than the one associated with the reduction of Terner's equations involving 6 coefficients ($T(6)$); b) Considerably higher accuracy is reached in declination $|\Delta\delta| = 0''.3 \pm 0''.3$ in comparison with the one in right ascension $|\Delta\alpha| = 0''.7 \pm 0''.7$, attributable, in the authors' opinion, to defects in the measuring engine; c) Chief prerequisite for expecting optimum results lies in such a selection of reference stars that the object is placed not beyond 43 arc minute from their gravity centre, and d) The plate ought to be measured in two positions differing by 180°.

Z. Stančić, M. Mijatov: *Variations of collimation and flexure of the Belgrade Large Meridian Circle under the daytime conditions*, Bull. Obs. Astron. Belgrade **137** (1987), 85–90.

Results of the laboratory examination of the collimation and flexure constants of the Belgrade Large Meridian Circle (LMC) in the periods 1977–1980 and 1984–1985 are presented. Thereby are established: significant effects of the medium in which the instrument is placed; significant systematic differences in the measurements made at different hours of the day; significant seasonal variations; a difference between the laboratory evaluations of these quantities and their values resulting from the regular star observations; and a difference between the values obtained in the two periods. The measuring accuracy in the second period was twice better than the one in the first period.

B. Jovanović: *An approximation of tabulated function*, Publications de l'Institut Mathématique, Nouvelle série, tome **41** (**55**) (1987), 143–148.

Using a recurrent approach a method for approximate analytical representation of tabulated function as the sum of linear function, harmonics and

pairs of exponential functions is derived. The method is demonstrated by two examples.

B. Jovanović: *An analytical representation of ephemeris data*, Celestial Mechanics **45** (1989), 317–320, Kluwer Academic Publishers.

An algebraic method for the resolution of tabulated function into a class of elementary functions is examined on the high precision ephemeris data from the JPL DE 200.

S. Sadžakov: *Behaviour of second levels in the field of horizontal temperature gradients*, Bull. Obs. Astron. Belgrade **140** (1989), 31–36.

On the basis of level examinations, done in a laboratory and during star observations, a nonnegligible temperature influence on the measuring results is found. For practical purposes, such as reductions of observational materials, expressions are proposed which should be taken into account in coordinate derivations of observed celestial bodies and, in our case, in the derivation of the geographic latitude.

S. Sadžakov: *Behaviour of levels in the conditions of asymmetrical heating*, Bull. Obs. Astron. Belgrade **142** (1990), 79–81.

The subject of the paper is the earlier and present importance of second level examinations. The data of a general analysis are presented. They indicate net only some problems of second levels, but also give informations on level triers whose properties are weakly known at present.

4. ASTROMETRY
4. ASTROMETRIJA

4.1. Large Meridian Circle
4.1. Veliki meridijanski krug

4.1.1. *Determination of Star Positions and Proper Motions*
4.1.1. *Određivanje položaja i sopstvenih kretanja zvezda*

M. Dačić, K. G. Gnevisheva: *Preliminary results of an investigation of the declination system of the Belgrade Observatory Meridian Circle*, Izv. GAO AN SSSR Pulkove **197** (1980), 40–42.

The declination system of the meridian circle in Belgrade was obtained from twenty two series of observations of fundamental stars with declinations from $-25°$ to $+90°$ and including lower culminations to 65°. The systematic errors $\Delta\delta_\delta$ are due mainly to the horizontal flexure of the instrument which during some rights is as large as $2''$–$3''$. Residuals of the observed declinations from those of the fundamental catalogue on the average have a total amplitude of about $0''.5$. The position of the instrument (circle-east, circle-west) does not significantly affect the system of the instrument.

S. Sadžakov. G. Kosin, V. A. Fomin: *An estimation of proper motions of stars of the compiled catalogue of latitude stars and AGK3*, Izv. GAO AN SSSR Pulkove **197** (1980), 12–16.

On the basis of a comparison with ILS data (observations made during 1899–1972) the $\Delta\mu_\alpha$ systematic errors (Table 3) were derived for proper motions of the compiled catalogue of latitude stars and AGK3. The data in the table are given as 10 year proper motions in $0''.001$.

S. Sadžakov, D. Šaletić, M. Dačić: *Properties of the NPZT star catalogue*, VII Kongres MFAJ i V Nacionalna Konf., Bečići, (1980).

S. Sadžakov, M. Dačić, D. Šaletić: *Programme of observations of the catalogue of double and Pulkovo stars with the Belgrade Large Meridian Circle*, VII Kongres MFAJ i V Nacionalna Konf., Bečići, (1980).

S. Sadžakov, D. Šaletić, M. Dačić: *An examination of $\Delta\delta_\alpha$ type systematic errors for the preliminary Belgrade catalogue of NPZT programme stars*, Trudy 21 Astrometr. Konf. SSSR, Tashkent, (1981), 157–160.

The Preliminary Star Position Catalogue has resulted from observations performed with the Large Meridian Circle of Belgrade Observatory during 1972–1978. It is compared with KŠZ, SKŠZ, AGK3 and with Yasuda's preliminary catalogue. On the basis of the obtained results existence of systematic errors in the preliminary Belgrade catalogue, as well as in the PZT latitude observations of various observatories in the northern hemisphere, is apparent.

S. Sadžakov, V. A. Fomin: *On the Belgrade catalogue of the NPZT stars*, Astr. Cirk. AN SSSR, Moskva, **1194** (1981), 7–8.

A survey of the works performed for the NPZT Catalogue is given. The root-mean-square error of a single observation is $\varepsilon_\alpha \cos\delta = \pm 0^s.038$ and $\varepsilon_\delta = \pm 0''.26$. The root-mean-square error of position is $\pm 0^s.015$ and $\pm 0''.10$. The mean observational epoch is 1977.0 and 1976.8.

S. Sadžakov, D. Šaletić, M. Dačić: *Catalogue of NPZT programme stars*, Publ. Obs. Astron. Belgrade **30** (1981), 1–88.

The catalogue of NPZT stars is obtained on the basis of the observational material compiled by use of the Meridian Circle of Belgrade Astronomical Observatory during 1973–1980. It contains 1838 stars with magnitudes $6.5 \leq m \leq 8.5$. The mean epoch of observations is 1977.02 in α and 1978.78 in δ. The rms-error of the right ascension $\varepsilon_\alpha \cos\delta$ is $\pm 0^s.030$ and of declination ε_δ is $\pm 0''.26$. Comparison with the FK4 of about 340 stars yields an error in α of $\pm 0^s.015$ and in δ of $\pm 0''.14$.

S. Sadžakov, D. Šaletić, M. Dačić, V. Trajkovska: *Characteristics of the preliminary results obtained in elaborating the catalogue of NPZT stars*, Publ. Obs. Astron. Sarajevo **1** (1981), 167–172.

Results of the comparison are given of the right ascension and declination of fundamental stars, as obtained from observations undertaken within the elab-

oration of the catalogue of NPZT stars, with the corresponding coordinates in the FK4.

In addition the comparison is accomplished of the coordinates of the programme stars, obtained in the preliminary catalogue of NPZT stars, with those obtained at Moscow, Hamburg and Richmond latitude stations.

The results obtained reveal that the systematic difference of coordinates are affected by the "instrument's system" and there could be discerned the existence of the systematic errors of the $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ types.

S. Sadžakov, V. A. Fomin: *A comparison of the AGK3 star catalogue declinations with the results of latitude observations with Zenith-Telescopes and Photographic Zenith Tubes*, Izv. GAO AN SSSR Pulkove **199** (1982), 36–40.

A comparison of the AGK3 catalogue declinations with the declinations obtained from 27 northern sky latitude programs observations during the last 15–20 years is made. The results of the comparison show that the $\Delta\delta_\alpha$ systematic errors may be present both in the declination system of the AGK3 catalogue and in the declinations deduced from latitude observations.

S. Sadžakov, M. Dačić, V. A. Fomin: *An investigation of the systematic errors of the Belgrade NPZT and AGK3 catalogues on the basis of modern PZT observations*, 18 IAU General Assembly, Patras, (1982).

S. Sadžakov, M. Dačić, D. Šaletić, B. Ševarlić: *Results of comparison of the Belgrade and the Bordeaux catalogs of the northern PZT stars*, Bull. Obs. Astron. Belgrade **132** (1982), 7–13.

Results are presented of comparison the NPZT star catalogs compiled in Belgrade and Bordeaux, systematic differences between them derived and analysed with respect to the right ascension, declination, apparent magnitudes and spectral classes.

S. Sadžakov, D. Šaletić, M. Dačić: *Properties of the north PZT star catalogue*, Hvar Obs. Bull. Suppl., Vol. 6, **1** (1982), 99.

Observations of the north PZT stars with the Belgrade Large Meridian Circle have been carried out in the period from June 1973 to May 1980. There were in all 283 observing tours about 16000 recorded transits. The determination of both coordinates, that is, right ascensions and declinations, proceeded simultaneously.

An observing tour lasted at least three hours and at the most five hours. The number of the programme stars observed within the scope of one tour varied from about 60 to about 100, while that of the reference stars amounted to at least 12. The stars of this programme were observed within five zones: $(+10, +25)$, $(+35, +38)$, $(+39, +45)$, $(+47, +52)$ and $(+53, +59)$. The reference stars (owing to their scarcity within the corresponding zones) had to be taken from wider zones then those just indicated.

From the results obtained it follows that the error of a single determination of right ascension is $\varepsilon_\alpha \cos\delta = \pm 0^s.038$ and that of declination $\varepsilon_\delta = \pm 0''.26$.

The catalogue, with the corresponding discussion, is due to appear as Volume N. 30 of the Publications of the Belgrade Observatory.

S. Sadžakov, M. Dačić, D. Šaletić: *Programme of observations of the catalogue of double and Pulkovo stars with the Belgrade Large Meridian Circle*, Hvar Obs. Bull. Suppl., Vol. 6, **1** (1982), 101–105.

Criterions are presented of the selection of a double and Pulkovo stars programme, composed in Pulkovo and U.S. Naval Observatory, along wiht their distribution according to zones. The programme will be observed by relative method with the Belgrade Large Meridian Circle in the period 1981 to 1985. Each star will be observed four times.

S. Sadžakov, M. Dačić: *Variation in time of the parameters* $(u + m)$ *and* M_0 *of the Belgrade Meridian Circle*, Bull. Applied Math. (BAM), Budapest, **190** (1983), 13–17.

Dependence of the parameters $(u + m)$ and M_0 on the time of observation has been investigated using the methods of the correlation analysis.

The hypothesis of absence of a linear correlation between the Bessel constant $(u + m)$ and the time of observation, as well as the same hypothesis relating to M_0 (equator point) and the time of observation, has been confirmed in the most of the observed series. The absence of a non-linear correlation has been confirmed with the for lesser number of star series, an indication of how necessary it is to find out the variation in time, as reliable as possible of the quantities $(u + m)$ and M_0 for each individual observing night.

S. Sadžakov, M. Dačić, V. A. Fomin: *A comparison of star positions in the Belgrade catalogue with those in the AGK3 on latitude measurements*, Bull. Applied Math. (BAM), Budapest, **151** (1983), 119–126.

The results obtained on the basis of the comparison indicate existence of the systematic errors of $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ types which may have a seasonal character in the Belgrade Catalogue of NPZT stars. Systematic errors in the proper motions of the AGK3 stars are also apparent on high declinations.

S. Sadžakov, M. Dačić: *Systematic errors of Belgrade NPZT programme star catalogue*, Bull. Applied Math. (BAM), Budapest, **197** (1983), 121–126.

Results of a comparison — Belgrade NPZT programme star catalogue to six other catalogues, compiled by use of meridian circles of the same, or similar properties are given. Existence of small systematic errors of $\Delta\alpha_\alpha$ and $\Delta\delta_{\rm sp}$ type is found.

S. Sadžakov, M. Dačić, D. Šaletić: *On the catalogue of the stars positions in the NPZT programme*, Astrometr. Astrophys. Kiev **48** (1983), 58–59.

The paper deals with compilation of the catalogue of the NPZT stars in Belgrade. Some characteristics of this catalogue are given. The catalogue has

been already used in compiling the general catalogue of the NPZT stars by Yasuda.

S. Sadžakov, M. Dačić: *Primena korelacione analize na ispitivanje tačaka ekvatora i $(u+m)$ fundamentalnih zvezda merenih sa meridijanskim krugom u Beogradu*, VI Nacionalna Konf., Hvar, (1983).

M. Dačić: *Sistem meridijanskog kruga u Beogradu*, VI Nacionalna Konf., Hvar, (1983).

S. Sadžakov, M. Dačić: *Sistematske greške beogradskog kataloga zvezda programa SFZT*, VI Nacionalna Konf., Hvar, (1983).

S. Sadžakov, M. Dačić, V. A. Fomin: *Investigation of the systematic errors of the Belgrade NPZT and AGK3 catalogues*, Astron. Astrophys. Suppl. Ser. **52** (1983), 455–462.

Systematic errors of the $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ types are derived by comparing star positions in the NPZT and AGK3 catalogues with those deduced from the observations made with the PZTs at ten latitude stations.

S. Sadžakov, M. Dačić, V. A. Fomin: *Comparison of the Potsdam PZT catalogue with four NPZT catalogues*, VI Intern. Lohrmann Colloq., Dresden, (1983).

M. Dačić: *Instrument system of the Belgrade Meridian Circle*, Bull. Obs. Astron. Belgrade **134** (1984), 1–8.

Investigation has been executed of the sysematic difference "FK4 system minus instrument system" of the Belgrade meridian circle. The data, used in the present analysis, were acquired during two periods — 1973/75 and 1977/78 — by the observation of Küstner series, with a total of about 1000 transits. The data processing was accomplished in two stages. The first stage consisted in the instrument parameters being calculated by the method of least squares. In the second stage $(O-C)$ deviations in both coordinates have been determined. The instrument system is presented in the form $\Delta\alpha_\delta \cos\delta$ and $\Delta\delta_\delta$. Thus it was established that the instrument systems at both clamps were close to each other and that the mean instrument system kept steady over several years.

S. Sadžakov, V. A. Fomin, M. Dačić: *Comparison of Tokyo PZT catalogues with AGK3 and with three other independent catalogues*, Sympos. 109 IAU "Astronomic Techniques" Gainsville, Florida, (1984).

S. Sadžakov, M. Dačić: *Značaj određivanja položaja zvezda u okolini radio izvora*, VII Nacionalna Konf., Beograd, (1984).

S. Sadžakov, M. Dačić: *Preliminary results of observations of double stars and the stars near radio sources with the Belgrade Meridian Circle*, 19 IAU General Assembly, New Delhi, (1985).

S. Sadžakov: *Analysis of systematic $\Delta\delta_\alpha$ deviations of GCLS and AGK3 catalogues from 20 catalogues obtained from latitude observations*, 19 IAU General Assembly, New Delhi, (1985).

S. Sadžakov, M. Dačić: *Position determination of stars in the neighbourhood of radio sources*, Bull. Applied Math. (BAM), Budapest, **296** (1985), 149–152.

The forming of the inertial coordinate system implied, at the present-day status of astrometry two stages. In the first stage one achieves what called fundamental system of the mean equator coordinates while in the second stage its absolute rotation is ascertained up to an anticipated accuracy. As a result, an inertial coordinate system is aproximated.

S. Sadžakov, M. Dačić, Z. Stančić: *Ocena tačnosti položaja zvezda u katalogu dobijenom pomoću automatskog meridijanskog kruga u Brorfeldu*, VIII Kongres MFAJ i VIII Nacionalna Konf., Priština, (1985).

S. Sadžakov, M. Dačić: *Sistematske greške sopstvenih kretanja u katalozima GC, IKŠZ i AGK3*, VIII Kongres MFAJ i VIII Nacionalna Konf., Priština, (1985).

S. Sadžakov, V. A. Fomin, M. Dačić: *Issledovanie sistematicheskikh oshibok belgradskogo kataloga SFZT*, XXIII Astrom. Konf., Leningrad, (1985).

S. Sadžakov, M. Dačić: *Predvaritel'nye rezul'taty meridiannykh nablyudenij po programmam "dvojnye zvezdy" i "opornye zvezdy v okrestnostyakh radioistochnikov"*, XXIII Astrom. Konf., Leningrad, (1985).

S. Sadžakov: *Analysis of sistematic $\Delta\delta_\alpha$ deviations of GCLS and AGK3 catalogues from 20 catalogues obtained from latitude observations*, Bull. Applied Math. (BAM), Budapest, **426** (1986), 1–10.

To enable as dependable an estimate as possible of the quality of positions and proper motions of stars contained in GCLS (IKSZ, Sadzakov, 1978) and AGK3 (1975) catalogues we compared them with their homologues in 20 latitude stars catalogues listed in the enclosed Tables.

S. Sadžakov, M. Dačić, V. A. Fomin: *Investigation of systematic $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ type errors of Bucharest NPZT catalogue*, in: Bucharest Catalogue of NPZT Stars, Declination Zone +49° to +50°, Equinox 2000.0 (E. Toma, M. Tudor, M. Liculescu), Central institute of physics, Bucharest astronomical observatory, Center for astronomy and space science, Bucharest, (1986), 73–78.

Results are presented of the comparison of Bucharest NPZT Catalogue in the zone +41° to +63° declination with the catalogues obtained from latitude observations with PZTs and meridian circles. Systematic $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ errors are stated in both PZT and meridian circle observations. Seasonal effects are prominent in all the cited catalogues, some of the catalogues (Herstmonceux) even having their coordinate origins shifted in reference to the origins of the majority of other catalogues.

Z. Stančić: *Instrumental systems of the Belgrade Large Meridian Circle in the period 1981–84*, Bull. Obs. Astron. Belgrade **136** (1986), 119–125.

Results are exposed of determination of the Belgrade Large Meridian Circle's instrumental systems in right ascension and declination from the Küstner series observations performed in the period 1981–1984. Comparison is also made of the collimation error and of the flexure values as furnished by the Küstner series observations during 1984 to those resulting from the laboratory measurements.

S. Sadžakov, M. Dačić, V. A. Fomin: *Comparison of the Potsdam PZT catalogue with four NPZT catalogues*, Astron. Astrophys. Suppl. Ser. **65** (1986), 379–381.

Comparison is made of the Potsdam PZT star catalogue with four NPZT star catalogues. A clear systematic deviation of the Potsdam catalogue positions with respect to all four catalogues, in addition to the random differences, has been established.

S. Sadžakov, M. Dačić: *Comparison of Tokyo PZT catalogues with AGK3 and with three other independent catalogues*, Astrometric Techniques by the IAU, (1986), 571–580.

Results are presented of the comparison of five Tokyo PZT catalogues with the AGK3 and three independent catalogues obtained with meridian circles.

S. Sadžakov: *Systematic errors in visual and photographic latitude star catalogues*, Astron. Nachr. **308** (1987), 363–374.

The point discussed is the importance of investigation of the systematic errors of $\Delta\delta_\alpha$ and $\Delta\mu_\alpha$ types and their effects on stellar positions as obtained from visual and photographic observations.

S. Sadžakov, M. Dačić, Z. Cvetković: *A catalogue of double stars compiled from observations with the Belgrade Meridian Circle*, Colloq. 100 IAU, Beograd, (1987).

S. Sadžakov: *Investigation of the systematic errors in the Belgrade General Catalogue of Latitude Stars (IKŠZ)*, Sympos. 133 IAU, Prag, (1987).

S. Sadžakov, M. Dačić, Z. Cvetković: *Characteristics of the catalogue containing stars situated in the vicinity of radio sources*, Colloq. 100 IAU, Beograd, (1987).

S. Sadžakov, M. Dačić: *Preliminary results of meridian observations in the framework of the programmes "Double Stars" and "Reference Stars in the Vicinity of Radio Sources"*, Sovremennaya astrometriya, AN SSSR, Leningrade, (1987), 64–66.

The topics is observational programmes of Double stars and stars in the vicinity of radio sources. The distribution of stars in right ascension (every six hours) and declination (every 30°) is presented in a table. The values of the mean errors of star coordinates in FK4, as well as of the quantities $u + m$

and M_0 obtained from observations of double stars and those in the vicinity of radio sources, are presented.

S. Sadžakov, M. Dačić, V. A. Fomin: *An investigation of systematic errors of the Belgrade NPZT stars catalogue within the declination zone* 35°–40°, Izv. GAO AN SSSR, Pulkove **204** (1987), 41–47.

The results of comparison of the Belgrade NPZT Stars catalogue and the AGK3 catalogue with 5 Tokyo PZT stars lists compiled in 1959–1978 reveal some significant systematic $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ errors of the Belgrade NPZT stars catalogue within the declination zone 35°–40°.

S. Sadžakov, D. Šaletić: *Systematic differences in positions and proper motions between ILS catalogues and the main astrometric catalogues*, Astron. Astrophys. Suppl. Ser. **74** (1988), 53–61.

Using the results of many authors (see Refs.), we carried out direct comparison of the declination of star pair centres of the IKŠZ (AGK3) catalogue with the declination of star pairs centres obtained by latitude observations on ILS stations.

S. Sadžakov: *Characteristics of the General Latitude Star Catalogue*, Bull. Acad. Serbe Sci. Arts **30** (1988), 11–22.

The values of declinations and proper motions in General Catalogue were derived on the basis of about 36000 star positios, the rms error of their determination from 0.″20 to 0.″62 with the average being ±0.″35. The rms error of the determination of a single position is $\varepsilon_\delta = \pm 0.''08$ and the proper motion $\varepsilon_\mu = \pm 0.''005$ with a mean epoch of 1954.44. The systematic differences for the errors in proper motions exist in the AGK3, GC, N30, FK4. The error of determination of $\Delta\delta_\delta$, $\Delta\delta_\alpha$, $\Delta\mu_\alpha$ indicate existence positions and proper motion. Existence of small $\Delta\delta_\alpha$ type systematic errors for the catalogue of the order up to ±0.″2 and $\Delta\mu$ of the order up to ±0.″01 is seen.

S. Sadžakov, M. Dačić: *Preliminary results of observations of double stars and the stars near radio sources with the Belgrade Meridian Circle*, Bull. Acad. Serbe Sci. Arts **16** (1988), 17–22.

Some particulars on the double stars (DS) programme and of the one stars surrounding the radio sources (RS) are presented. Preliminary results of the relevant observations, currently under way, with the Belgrade Meridian Circle, are given.

S. Sadžakov: *Tačnost određivanja položaja zvezda dobijenih posmatranjima sa VMK u Beogradu*, IX Nacionalna Konf., Sarajevo, (1988).

S. Sadžakov, M. Dačić: *Estimate of proper motions for 453 double stars of Belgrade catalogue*, 20 IAU General Assembly, Baltimore, (1988).

S. Sadžakov, M. Dačić, Z. Cvetković, G. Damljanović: *Karakteristike beogradskog kataloga rektascenzija i deklinacija fundamentalnih zvezda (FK4)*, IX Nacionalna Konf., Sarajevo, (1988).

S. Sadžakov, M. Dačić, Z. Stančić: *Accuracy of the corrections determined for FK4 stars*, Bull. Obs. Astron. Belgrade **139** (1988), 7–14.

The results of observations of fundamental stars in series (zones) at the corresponding MC position are presented. The errors are $\varepsilon_\alpha \cos\delta = \pm 0^s.022$, $\varepsilon_{u+m} \cos\delta = \pm 0^s.005$ in the right ascension, $\varepsilon_\delta = \pm 0''.32$, $\varepsilon_{M_0} = \pm 0''.08$ in the declination.

S. Sadžakov: *Application of Brosche's method to examinations of coordinate differences for stars of two catalogues*, Bull. Obs. Astron. Belgrade **139** (1988), 14–21.

A short review concerning the method, itself, is presented, as well as the results obtained from the comparison of the IKŠZ Catalogue with the FK4, N30 and AGK3 ones.

S. Sadžakov, M. Dačić, Z. Stančić: *Analysis of results obtained from observations with meridian circles in Belgrade and Brorfelde*, Bull. Obs. Astron. Belgrade **138** (1988), 9–13.

Characteristics of the instruments used for the purpose of compilation of the here analysed observational material are given. The systematic errors of $\Delta\alpha$ and $\Delta\delta$ types in the right ascension, declination, magnitude and spectrum are determined.

S. Sadžakov, M. Dačić, Z. Cvetković, Z. Ćatović: *Characteristics of the Belgrade double stars catalogue*, Sympos. 141 IAU, Leningrad, (1989).

S. Sadžakov, M. Dačić, Z. Cvetković: *A presentation of the work performed with the Belgrade Large Meridian Circle during the period 1968–1988*, Sympos. 141 IAU, Leningrad, (1989).

R. S. Izmailov, N. G. Litkevich, S. Sadžakov, V. D. Simonenko, T. I. Suchkova, S. A. Tolchel'nikova-Murri, V. L. Turenko: *The comparison of the accuracy of the determination of right ascension by means of transit instruments of different types*, Sympos. 141 IAU, Leningrad, (1989).

S. Sadžakov, S. R. Izmailov, N. T. Litkevich, V. D. Simonenko, S. A. Tolchel'nikova-Murri: *A comparison of the accuracy of the right ascension determination with transit instruments of different types*, Inertial coord. system on the sky, Reidel Publ., (1990), 456.

A special series of observations of the groups of stars performed in Pulkovo, Chile, Kharkov and Belgrade were used to compare the mean errors of the right ascension by means of the method eliminating the influence of the errors

of the source catalogue. The results show the advantage of the small transit instruments over transit circle of the classical type.

S. Sadžakov, M. Dačić: *A catalogue of right ascension and declination of FK4 stars*, Astron. Astrophys. Suppl. Ser. **77** (1989), 411.

This catalogue contains the positions of 576 FK4 stars observed 1981–87. The mean epoch is 1983.90 for α and 1983.84 for δ with mean errors for a single observation of $\pm 0^{s}.022$ in α and $\pm 0''.32$ in δ.

S. Sadžakov, M. Dačić, Z. Cvetković, Z. Ćatović: *Characteristics of the Belgrade double star catalogue*, Bull. Obs. Astron. Belgrade **141** (1989), 1–5.

The results of the comparison of the Belgrade catalogue to a few others, as well as the systematic errors of the types $\Delta\alpha$, $\Delta\delta$, are presented.

S. Sadžakov, M. Dačić: *Belgrade catalogue of double stars*, Publ. Obs. Astron. Belgrade **38** (1990), 1–110.

In the period between March 1981 and April 1987, 1576 stars were observed in Belgrade during the Double Star Programme. The measurements and the treatment of the observational material were performed by use of the relative method. Both coordinates α and δ were observed simultaneously, on the average every three minutes. The rms error of a single observation of double stars between $-30°$ to $+60°$ is $\varepsilon_\alpha \cos\delta = \pm 0^{s}.026$ and $\varepsilon_\delta = \pm 0''.32$.

S. Sadžakov, Z. Cvetković, M. Dačić: *A presentation of the work performed with the Belgrade Large Meridian Circle during the period 1968–1988*, Inertial coord. system on the sky, Reidel Publ., (1990), 489–491.

The work performed with the Belgrade Large Meridian Circle and the results obtained during the last twenty years are presented.

S. Sadžakov, M. Dačić, Z. Cvetković: *A catalog of positions of 290 stars situated in the vicinity of radio sources*, Astron. Journal **101** (1991), 713–733.

With the Large Meridian Circle of the Belgrade Observatory we carried out in the period 1982–1987 visual measurements by using the relative method of the coordinates of 290 stars from 78 parts of the sky situated in the vicinity of radio sources. Each program star was observed on the average 5.5 in α and 5.8 times in δ. The rms-error of a single observation in right ascension is $\varepsilon_\alpha \cos\delta = \pm 0^{s}.024$ and in declination $\varepsilon_\delta = \pm 0''.30$. A comparison between the fundamental stars observed and those from the FK4 yields a position error of $\pm 0^{s}.010$ in α and $\pm 0''.13$ in δ.

4.1.2. *Observations of the Sun and Planets*
4.1.2. *Posmatranja Sunca i planeta*

S. Sadžakov, M. Dačić, D. Šaletić: *Results of observation of the Sun, Mercury and Venus 1974 to 1979*, Publ. Obs. Astron. Sarajevo **1** (1981), 69–79.

Description is given of the equipment and the procedure of observation, along with the mean $(O-C)$ values of the right ascensions and declinations, according to years, and computed corrections to the orbital elements. It is inferred that the quality of the observations is satisfactory.

S. Sadžakov, M. Dačić, D. Šaletić: *Positions of the Sun and inner planets obtained with the Meridian Circle of the Belgrade Observatory*, European Regional Meeting in Astronomy, VI ERMA, Dubrovnik, (1981).

The results of observations of the Sun, Mercury and Venus during the eight years period (1973–1981) are given. The corrections ΔA, $\Delta\delta_0$, ΔL_0, $\Delta\pi$ and $\Delta\varepsilon$ with respective mean square errors are derived.

The mean square error of a single observation, calculated for the equinox, ranges from: $\pm 0''.16$ to $\pm 0''.40$ and $\pm 0^s.015$ to $\pm 0^s.028$ for the Sun, $\pm 0''.16$ to $\pm 0''.50$ and $\pm 0^s.026$ to $\pm 0^s.040$ for Mercury and $\pm 0''.24$ to $\pm 0''.43$ and $\pm 0^s.012$ to $\pm 0^s.036$ for Venus.

S. Sadžakov, M. Dačić, D. Šaletić: *Results of observations of the Sun, Mercury and Venus with the Belgrade Large Meridian Instrument*, Bull. Obs. Astron. Belgrade **132** (1982), 45–53.

The apparent right ascensions and declinations of the Sun and two planets obtained from our observations are compared with the ephemeris positions and the results are given in Tables 1, 2, 3.

S. Sadžakov, M. Dačić, D. Šaletić, B. Ševarlić: *Observations of the Sun and inner planets with the Large Meridian Circle in Belgrade*, Sun and Planetary System, Reidel Publ., (1982), 445–446.

Observed apparent right ascensions and declinations of the Sun and the planets; the corrections of the orbital elements Sun, Mercury, Venus and the errors (σ) of their determination, based on the observations in the period 1975–1981.

S. Sadžakov, M. Dačić, D. Šaletić: *Observations of the Sun, Mercury and Venus with the Belgrade Meridian Circle in the period 1979 to 1981*, Bull. Obs. Astron. Belgrade **133** (1983), 45–50.

The results of observations of the Sun, Mercury and Venus with the Belgrade large meridian instrument in the period from 1979 to 1981, are presented.

S. Sadžakov, M. Dačić: *Observations of the Sun and planets with the Belgrade Large Meridian Circle*, Bull. Obs. Astron. Belgrade **135** (1985), 47–54.

Results are presented of the Sun, Mercury, Venus and Mars observations made with Large Meridian Circle of the Belgrade Observatory in the period September 1981 – November 1983.

S. Sadžakov, M. Dačić: *Nablyudeniya Solntsa i bol'schikh planet na meridiannom kruge v Belgrade*, XXIII Astron. Konf., Leningrad, (1985).

S. Sadžakov, M. Dačić: *Observations of the Sun and inner planets with the Large Meridian Circle Belgrade*, Colloq. 100 IAU, Beograd, (1987).

S. Sadžakov, M. Dačić: *Observations of the Sun and of planets with the Belgrade Meridian Circle*, Sovremennaya astrometriya, AN SSSR, Leningrade, (1987), 325–329.

On the basis of the differences $(O-C)_\alpha$ and $(O-C)_\delta$ we determined the corrections of the equinox and equator, as well as some of the corrections of orbital elements for the Earth, Mercury and Venus.

S. Sadžakov, M. Dačić, Z. Stančić: *Results of diurnal measurements for the Sun, Mercury, Venus and Mars obtained in the period 1984–1986*, Bull. Obs. Astron. Belgrade **138** (1988), 78–85.

In the paper we present the results $(O-C)_\alpha$ and $(O-C)_\delta$ obtained in the period 1984–1986 in Belgrade from diurnal observations of the Sun, Mercury, Venus and Mars with the large meridian circle "Askania" No 88077, $2r = 190\,\text{mm}$, $f = 2578\,\text{mm}$.

M. Dačić, S. Sadžakov, Z. Cvetković: *Observations of the Sun and planets with the Belgrade Large Meridian Circle*, Bull. Obs. Astron. Belgrade **140** (1989), 49–53.

Results are presented of the Sun, Mercury, Venus and Mars observations made with Large Meridian Circle of the Belgrade Observatory in the period March 1987 – Sept. 1988.

4.2. Large Vertical Circle: Determination of Absolute Declinations of Stars and Planets

4.2. Veliki vertikalni krug: Određivanje apsolutnih deklinacija zvezda i planeta

Dj. Bozhichkovich: *New method of measurement for the corrections determination of the totality of circle diametres*, Publ. Astron. Obs. Sarajevo **1** (1981), 93.

Instead of the classical procedure of measurements for the determination of the circle division corrections it is proposed that a uniform rotation be imparted to the circle under investigation. From the registered times of transit of the individual division lines in front of the photoelectrical gadgets, the division lines corrections would be determined by some of the currently existing methods. The efficiency of the method of measurements propsed may be judged from this author's estimate that all the measurements, requisite for the correction determination by Bruns' method of 5400 diameters, assotiated with $2'$ circle division, would require only 105 hours of actual measurements.

Dj. Bozhichkovich: *Determination of declinations with a uniformly rotating vertical or meridian circle*, Publ. Astron. Obs. Sarajevo **1**, No. 1 (1981), 103.

Instead of the standard method of declination determination, implying a *static* instrument (the vertical or meridian circle), it is proposed that the necessary measurements be performed with the instrument (the tube and the circle as a whole) uniformly *rotating* about its horizontal axis during the star's passage over the field of view. It is estimated that the mean error of a single declination determination, using the method suggestd, would be less than $\pm 0''.10$.

M. Mijatov, Dj. Bozhichkovich, G. Teleki: *Preliminary results of Determinations of 308 Bright Stars Declinations in the Zone from $+65°$ to $-90°$ obtained with the Vertical Circle of the Belgrade observatory*, Zbornik Zadachi savremenoj astrometri v sazdani inertsial'noj sistemy koordinat, Izd. Fan, Tashkent, (1981), 154.

M. Mijatov, Dj. Bozhichkovich: *Preliminary results of the flexure investigation of the Belgrade Large Vertical Circle in the period 1976–1979*, Bull. Obs. Astron. Belgrade **132** (1982), 3.

An account is given of the preliminary results of the flexure determinations of the Large Vertical Circle of the Belgrade observatory, carried out regularly under the observing program of bright strs in the period 1976–1979. A satisfactory accuracy of the measurements is stated, except for the year 1976, namely $\pm 0''.20$. Of particular importance is the finding that the flexure of our LVC keeps its properties over longer time intervals. More intense investigations of this parameter is recomended.

Dj. Bozhichkovich, M. Mijatov: *Investigation of the divided circle of the Belgrade Large Vertical Circle*, Bull. Obs. Astron. Belgrade **134** (1984), 16.

Corrections for 1080 dimeters at $10'$ spacing of the $2'$ divided circle of the Belgrade Large Vertical Circle are determined according to Nikolić's method. All the diameter corrections are within $\pm 1''.5$ limits, the accuracy being ± 0.11. The values of the corrections are tabulated and illustrated graphically.

M. Mijatov, V. Trajkovska: *Analysis of some characteristics of the levels of the Belgrade Vertical Circle*, Bull. Obs. Astron. Belgrade **134** (1984), 9.

On the basis of laboratory examinations of the levels of the Belgrade Vertical Circle, executed in the period 1963 to 1981, mean division values, as well as their dependence on time, air temperature and bubble length, are derived. The formulae (4) and (5) are proposed for use in the reduction of astronomical observations. The level division values, as derived by laboratory measurements, proved to fit in the regular astronomical observations made with our Vertical Circle.

V. Trajkovska: *Preliminary results of planet observations with the Belgrade Vertical Circle*, Bull. Obs. Astron. Belgrade **136** (1986), 100.

Account is given of the method, organization and results of obseervations of outer planets with the Belgrade Vertical Circle, carried out in the period

April 1983 to November 1984. The $O - C$ differences for all the observed planets, as well as the mean errors of observations are given.

Dj. Bozhichkovich: *Investigation of levels of the Belgrade Vertical Circle*, Bull. Obs. Astron. Belgrade **136** (1986), 40.

Two levels attached to the Belgrade Vertical Cirle have been investigated both on the examinator and on the instrument itslf. Data obtained by both methods are analysed. It could be found that the results provided by the measurements on the instrument itself, using the mercury horizon, were notably more realistic than those obtained with the examminator under laboratory conditions. In addition to the accounting for the temperature and the buble length effect on the level division value determination and accounting for the systematic effects of the irregulatries in the inner sliding surface and its graduation is suggested.

B. Jovanović, Dj. Bozhichkovich: *On division errors of the Belgrade Vertical and Meridian Circles*, Bull. Obs. Astron. Belgrade **137** (1987), 41.

By using the spectral analysis method the corrections of the division for the Meridian Circle and for the Vertical Circle of Belgrade Observatory are treated. A prominent term of a period of two degrees has been found for the former instrument, but not for the latter one. Both instruments were produced by "Askania".

V. Trajkovska: *Results of planet observations with the Belgrade Vertical Circle (Supplement I)*, Bull. Obs. Astron. Belgrade **138** (1988), 85.

Results of observations of five major planets with the Belgrade Vertical Circle, carried out in the period April 1985 to December 1986, are presented. The $O - C$ differences for the observed planets, as well as the mean errors of observations are given. Differences of the observed apparent and the ephemeris apparent semi-diameters of the planets Mars, Jupiter and Saturn are given, too.

M. Mijatov, V. Trajkovska: *Flexure of the Belgrade Large Vertical Circle in the period 1976–1980*, Bull. Obs. Astron. Belgrade **140** (1989), 37–42.

In the present paper an analysis of the variations in the flexure of the Large Vertical Circle of Belgrade Observatory between 1976 and 1980 is given. The examinations show a very prominent temperature dependence a significant variation during an observation night, and a dependence on observers and on quality of measurements; no dependence on meteorological parameters such as the pressure and humidity, as well as on weather conditions under which the measurements were made (cloudiness, wind, etc.) was found. Seasonal variations, being most prominent during the autumn season, are found. The most important systematic influences are collimator displacement and the tube refraction. The accuracy of the flexure determination is $\varepsilon_b = \pm 0''.22$.

4.3. Large Transit Instrument: Determination of Absolute Right Ascensions

4.3. Veliki pasažni instrument: Određivanje apsolutnih rektascenzija

I. Pakvor: *On the Observations of the Bright Polar Stars with the Large Transit Instrument at the Belgrade Observatory*, Publ. Astron. Obs. Sarajevo **1** (1981), 79–85.

The first regular observation program which is being carried out at the LTI of the Belgrade Observatory contains the determination of absolute right ascension of stars in the northern declination zone 70°–90°. The application of the vacuum meridian marks gives special interest to this program. The analysis of the instrument's constants is shown.

I. Pakvor: *Progress Report on Vacuum Meridian Marks*, Mitt. Lohrmann Obs. Tech. Univ. Dresden **6**, 51 (1984), 127–130.

I. Pakvor: *Progress report on the Belgrade catalog of absolute R.A.s of bright polar stars*, Trans. IAU, Proc. XIX IAU GA 1985, New Delhi.

A progress report on the *Belgrade Catalog of Absolute RA's of Bright Polar Stars* was given by I. Pakvor, Belgrade Observatory, Yugoslavia. He indicated that the observations of absolute RA's of bright polar stars from the list of 308 stars in the declination zone +65° to +90° with the Large Transit Instrument (LTI) of the Belgrade observatory were finished early in 1983. This is the first absolute RA catalog observed by the LTI of Belgrade observatory. These observations involve the first use of vacuum meridian marks for determining the values of differential azimuth and collimation errors. The annual variations of these constants were given. Reductions are in progress and the chain method is in use.

I. Pakvor: *The stability analysis of the vacuum meridian marks of the Large Transit Instrument at Belgrade Observatory*, Bull. Obs. Astron. Belgrade **136** (1986), 75–78.

The stability analysis of the vacuum meridian marks of the Large Transit Instrument at Belgrade Observatory is shown using the variation of the angle between the southern and northern meridian mark. The review of similar examinations at some other observatiories and the comparison of the results are given. For Belgrade meridian marks a significant annual variation is determined.

L. Mitić, I. Pakvor: *Vacuum meridian marks at Belgrade Observatory*, Proc. IAU Symp. 109, "Astrometric Techniques", Gainesville, Florida, D. Reidel Publ. Comp. (1986), 525–527.

More than a dozen years ago vacuum meridian marks were built for the Belgrade Large Transit Instrument with the purpose of completely keeping the air from interfering with the meridian mark readings. Information is presented on the favorable results achieved as regards both accidental and systematic accuracy.

5. EARTH ROTATION
5. ZEMLJINA ROTACIJA

5.1. Small Transit Instrument: Time Determination
5.1. Mali pasažni instrument: Astronomsko određivanje vremena

M. Jovanović, L. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzhba vremeni BL (Belgrad)*, Vsemirnoe Vremya, Byulleten' E 21–E 24, Moskva, 1980.

(M. Jovanović), (L. Djurović), *Daily values of UTO-UTC. transit instrument — Belgrade*, Monthly Notes of the Int. Polar Motion Service, Mizusawa, Nos. 1–12. 1980.

M. Jovanović: *Analiza vremenskih serija posmatranja na pasažnom instrumentu u Beogradu*, VII Kongres matem., fiz. i astronoma Jugoslavije, Budva-Bečići, (1980), III-6.

M. Jovanović, L. Djurović: *Svodka astronomicheskih nablydenij sluzhb vremeni. Sluzhba vremeni BL (Beograd)*, Vsemirnoe Vremya, Byulleten' E 25–E 28, Moskva, 1981.

(M. Jovanović), (L. Djurović), *Daily values of UTO-UTC. transit instrument — Belgrade*, Monthly Notes of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1981.

M. Jovanović, L. Djurović: *Détérmination astronomique de l'heure*, Bull. Obs. Astron. Belgrade **131** (1981), 45–48.

M. Jovanović, L. Djurović: *Sistematske greške rezidua pri određivanju geografskih koordinata dužine i širine astronomskim promatranjima*, in: M. Muminović (ed.), Proceedings of the IV Nat. Conf. of Yugoslav Astronomers, Sarajevo, 1979 = Publ. Astron. Obs. Sarajevo **1** (1981).

M. Jovanović, L. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzhba vremeni BL (Belgrad)*, Vsemirnoe Vremya, Byulleten' E 29–E 32, Moskva, 1982.

(M. Jovanović), (L. Djurović): *Daily values of UTO-UTC transit instrument — Belgrade*, Monthly Notes of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1982.

M. Jovanović, L. Djurović, B. Jovanović, D. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzhba vremeni BL (Belgrad)*, Vsemirnoe Vremya, Byulleten' E 33–E 36, Moskva, 1983.

(M. Jovanović), (L. Djurović), (B. Jovanović), (D. Djurović): *Daily values of UTO-UTC. Transit instrument — Belgrade*, Monthly Notes of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1983.

M. Jovanović: *Selenografija i selenologija*, Vojna enciklopedija, Beograd, (1983).

U radu je data savremeno shvatanje naučnog dostignuća najbližeg Zemljinog suseda Meseca. Takođe je dat osvrt na sastav i oblik zemljinog suseda.

(M.Jovanović), (B. Jovanović), (L. Djurović): *Daily values of UTO-UTC. Transit intrument — Belgrade*, Monthly Not. of the Int. Polar Motion Service, Mizusawa Nos. 1–12, 1984.

M. Jovanović, B. Jovanović, L. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzhba vremeni BL (Belgrad)*, Vsemirnoe vremya, Byulleten' E 37–E 40, Moskva, 1984.

M. Jovanović, B. Jovanović: *Služba vremena Astronomske opservatorije u Beogradu — polje rada, problemi, perspektive*, in: Proc. VIII Gen. Assembly, Union of Societes of Mathematicians. Physicists and Astronomers of Yugoslavia (VIII Kongres matematičara, fizičara i astronoma Jugoslavije — Saopštenja), Priština, (1985), 351.

M. Jovanović, L. Djurović: *A survey of meridian observations carried out with the transit instrument of the Belgrade Observatory in the period 1952 to 1983*, Bull. Obs. Astron. Belgrade **136** (1986), 130–132.

M. Jovanović, B. Jovanović, L. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni, Sluzhba vremeni BL (Belgrad)*, Vsemirnoe vremya, Bulleten' E 41–E 44, 1985.

(M. Jovanović), (B. Jovanović), (L. Djurović), *Daily values of UTO-UTC, Transit instrument — Belgrade*, Monthly Not. of the Int. Polar Motion. Service, Mizusawa, Nos. 1–12, 1985.

M. Jovanović, B. Jovanović, L. Djurović: *Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzba vremeni BL (Belgrade)*, Vsemirnoe vremya, Bulleten' E 45–E 48, 1986.

(M. Jovanović), (B. Jovanović), (L. Djurović): *Daily values of UTO-UTC, Transit instrument — Belgrade*, Monthly Not. of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1986.

5.2. Zenith Telescope: Latitude Determination
5.2. Zenit teleskop: Određivanje geografske širine

Dj. Teleki, R. Grujić: *O EW-WE efektu kod Beogradskih širinskih posmatranja*, VII Kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Budva-Bečići, (1980), III-5.

R. Grujić, Dj. Teleki: *Analiza karakteristika Talkotovih libela Beogradskog zenit-teleskopa*, VII Kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Budva-Bečići, (1980), III-5.

B. Kolaczek, G. Teleki: *On reference coordinate systems used in polar motion determinations*, E. M. Gaposchkin and B. Kalaczek (eds.), Reference Coordinate Systems for Earth Dynamics, (1981), 165–173.

A short review of the reference pole presently used in polar motion determinations by classical astrometric methods is followed by a discussion of the systematic differences between systems of polar coordinates and the influence of the mean latitude of stations on pole position. The importance of homogenous processing astrometric data is stressed.

V. Milovanović, G. Teleki, R. Grujić: *On the influence of the external factors on the accuracy of determination of latitude variations*, Publ. Obs. Astron. Sarajevo **1** (1981), 131–141.

In the period 1968–1970 certain alterations have been implemented in the Latitude Service of the Belgrade Observatory, aimed at reducing, to maximum possible degree, the influence of the external factors on the latitude determinations. These alterations are related to: thermal insulation of the zenith-telescope, improving the construction of its pavilion and the modification of the observing procedure and the data processing. Explanation is given as to what necessitated these changes and why a wider astrometric significance is attached to them. The anlysis of the observational data, acquired with this instrument, showed that the effects of the external factors can successfully be reduced, resulting in a considerably increased accuracy of the determination of the latitude varations. To that purpose comparisons were made with the observational results of other zenith-telescopes (with those obtained at Interntional Latitude Service stations in particular).

M. Djokić: *Comparison of the micrometer screw corrections of the Belgrade zenith telescope in the different systems*, Pub. Obs. Astron. Sarajevo **1** (1981), 163–166.

For estimating the validity of the different observation programs used the micrometer screw correction of the Belgrade zenith telescope were analysed in the catalog system AGK3 and SAO.

R. Grujić, M. Djokić: *Observations à la lunette zenithale (de 110 mm) du Service de la latitude de l'Observatoire de Beograd en 1979*, Bull. Obs. Astron. Belgrade **131** (1981), 43–44.

The results of latitude observations under new Belgrade latitude program for 1979 are presented.

R. Grujić, M. Djokić: *Observations à la lunette zenithale (du 110 mm) du Service de latitude de l'Observatoire de Belgrade en 1980*, Bull. Obs. Astron. Belgrade **132** (1982), 53–54.

On présente les valeurs de latitude ansi que quelques données météorologiques prises au cours d'observations.

B. Kolaczek, G. Teleki: *On investigations of mean latitude variations*, Sun and Planetary System, D. Reidel Publ. Comp. Dordrecht, Holland – Boston, U.S.A. – London, England, (1982), 191.

S. Sadžakov, V. Fomin, M. Dačić, D. Šaletić: *Systematic errors in latitude observations of various observatories*, 18 IAU General Assembly, Patras, (1982).

G. Teleki, R. Grujić: *Investigations of the EW-WE effect in the latitude determinations with the Belgrade zenith-telescope*, Hvar Obs. Bull. Suppl., Vol. 6, **1** (1982), 61–69.

Belgrade latitude data have been analysed with regard to the possible sources of the EW-WE effect whereby the equation (1) has been utilized. The strongest source proved to be the instrument itself, especially its levels, but other sources are not negligible either: the observer, declination system, seasonal changes.

R. Grujić, G. Teleki: *An analysis of the characteristics of the Talcott levels of the Belgrade zenith-telescope*, Hvar Obs. Bull. Suppl., Vol. 6, **1** (1982), 71–80.

It has been established by laboratory investigations that the mean division angular values of the Belgrade zenith-telescope levels are systematically undergoing changes with time. The reality of these changes has been confirmed by using the inclination values as determined in the course of latitude observations with this zenith-telescope.

M. Djokić: *Analysis of the latitude differences obtained from the subgroups of the new Belgrade's latitude program*, Suppl. Obs. Bull. Hvar **6** (1982), 81–90.

Temperature induced differences in the latitudes obtained from the subgroups of the new Belgrade latitude program are considered.

M. Djokić: *Closing errors of the Belgrade latitude observations and temperature influences*, Astrophysics and Space Science Library **96** (1982), 195–196.

The correlations between temperature differences and closing errors of latitudes under old Belgrade's observation program were demonstrated.

R. Grujić, M. Djokić: 1982, *Observations à la lunette zenithale (de 110 mm) du Service de latitude de l'Observatoire de Belgrade en 1980*, Bull. Obs. Astron. Belgrade **132** (1982), 53–54.

The results of latitude observations under new Belgrade latitude program for 1980 are presented.

R. Grujić, R. Krga, Z. Stančić: *Ispitivanje „greške noći" kod beogradskih širinskih posmatranja u periodu 1960–1980*, VI Nacionalna Konf., Hvar, (1983).

R. Grujić, G. Teleki: *Investigation of wind effects on the Belgrade latitude observations*, Bull. Obs. Astron. Belgrade **134** (1984), 26–31.

It is demonstrated that the alterations (thermal insulation of the zenith telescope, rebuilding of the pavilion improvements in the observational procedure and data processing) effected in the period 1968–1970 (Milovanović et al., 1981) resulted in a notable reduction of the wind effects on the Belgrade latitude observations and a general enhancement of the accuracy of observation. It is found that in the period 1976–1981 the systematic effects of winds from N-W quadrant are stronger than those produced by winds from S-E quadrant (most of our observations are made by S-E winds). The suitability to application of some expressions for the calculation of wind effects on latitude is considered.

R. Grujić, R. Krga, Z. Stančić: *"Night error" in the Belgrade latitude observations made in the period 1960–1980*, Publ. Obs. Astron. Belgrade **33** (1985), 62–65.

"Night error" in the Belgrade latitude observations, made in the period 1960 through 1980, has been investigated and found that, being significant prior to the instrumental and methodical improvements implemented in 1969–1971, it has substantially been reduced in the subsequent period. The dependence of this error on the observer has been demonstrated, too.

M. Djokić: *Correction to the angular value of the screw revolution of the Belgrade zenith-telescope micrometer derived from latitude observations*, Publ. Obs. Astron. Belgrade **33** (1985), 70–74.

Correction to the angular value of the screw revolution of the Belgrade zenith-telescope micrometer is being determined and discussed for period 1971.9–1982.5.

G. Teleki, R. Grujić: *Effects of the level bubble length variation on the latitude values*, Publ. Obs. Astron. Belgrade **33** (1985), 66–69.

The level bubblelength variations during observation are found to affect the latitude values derived by Talcott method. The real amount of these effects is hard to bring out. Hence, one has to be careful at deducing the daily variations of latitude as these effects must not be ignored.

R. Grujić, Dj. Teleki: *O katalogu deklinacije Beogradskih zenitskih zvezda*, VIII Kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Priština, (1985), 345.

M. Djokić: *Constant of aberration from the latitude observations with the Belgrade zenith-telescope*, Bull. Obs. Astron. Belgrade **136** (1986), 29–30.

Values of the constant of aberration are determined from the latitude observed under the new Belgrade latitude program and compared with those derived from observations under the old program as well as the results obtained at other observatories.

R. Grujić, G. Teleki: *Investigations of the EW-WE effect in the latitude determinations with the Belgrade zenith-telescope in the period 1969.0–1981.0*, Bull. Obs. Astron. Belgrade **137** (1987), 11–29.

The EW-WE effect in the latitude determinations with the Belgrade zenith-telescope in the period 1969.0–1981.0 have been analysed and it was concluded that they are smaller ones as well as more accurately determined than in the period 1960.0–1969.0 (Teleki, Grujić, 1982). This is due to alterations (thermal insulation of the instrument, rebuilding of the pavilion improvements in the observational procedcure and data processing) executed in the period 1968–1970 (Milovanović et al., 1981). The results obtained by formula (3) point to several sources giving rise to the EW-WE effects, but it can be proved that the influences of these sources are remarkably weaker in the period 1969.0–1981.0 then before that.

R. Grujić, G. Teleki, B. Jovanović: *Declination variations of zenith stars*, IAU Coll. 100, Belgrade, Sept. 8–11, (1987).

G. Teleki, R. Grujić: *Catalogues of declinations and proper motions of 36 Belgrade zenith stars*, Astron. Astrophys. **177** (1987), 313–316.

Using observations made with the Belgrade zenith telescope in the period 1960.0–1981.0, catalogues (in three systems) of the declination and proper motions in declination of 36 zenith stars were calculated for the equinox and epoch of 1970.0. Analyses show that, relatively, the most accurate are the system 1 declinations ($BZS1_{70}$). The declinations systems of our catalogues are in good agreement with the corresponding FK4 system. But the system of proper motions in declination is less comparable with the FK4 system. It follows that the Belgrade zenith telescope is capable of yielding star declinations with relatively high precision (currently about $0''.22$).

G. Teleki, R. Grujić: *Belgrade catalogues of declinations and proper motions of zenith stars*, Bull. Obs. Astron. Belgrade **137** (1987), 5–10.

The analyses are given of three Belgrade catalogues of declinations and proper motions in declination of 36 zenith stars for the equinox and epoch 1970.0. These stars were observed with zenith telescope. The catalogues are based on the observation data collected in the period 1960.0–1981.0. The conclusion is that the results ar highly satisfying.

R. Grujić, G. Teleki: *The widened Belgrade latitude observational programme and its characteristics*, Bull. Obs. Astron. Belgrade **137** (1987), 14–29.

The original Belgrade latitude observational programme (Ševarlić, Teleki, 1960), which was observed from 1960.0, needed some improvement and therefore a widened programme was developed. The paper gives some informations on the characteristics of this new, widened programme. The preliminary value of sistematic differences between the latitudes obtained in the complete and the original programmes is $0''.010$.

R. Grujić, M. Djokić, B. Jovanović: *Analysis of the change in the geographic latitude between 1969.0 and 1975.0*, IX Nac. konf. astronoma Jug., Zbornik rezimea, Sarajevo, (1988), 29.

Period 1969.0–1975.0 is chosen to be analysed because it is the most favourable one taking into account the program of observation, the influence of the error in the micrometer screw revolution and the number of observations.

It is represented the change of mean latitude (0″.1) and annul z-term which is correlated with the change of Talcott levels inclination.

G. Teleki, R. Grujić: *Personal errors of observer in visual determinations of latitude by the Talcott method*, Kinem. i Fiz. Nebesn. Tel, Vol. 4, **1** (1988), 71–74.

Using latitude data obtained with the Belgrade Astronomical Observatory zenith telescope during 1960.0–1986.0, we investigated latitude differences determined by two experienced observers. It was established that these differences (the result of the observers' individual errors) are significant and that they correlate with the inclination of the moving micrometer hair. Certain recommendations pertaining to organization of observations are given.

R. Grujić, M. Djokić, R. Krga, S. Šegan, N. Djokić: *Observations à la lunette zenithale (de 110 mm) du Service de latitude de de l'Observatoire de Belgrade en 1981, 1982, 1983, 1984, 1985*, Bull. Obs. Astron. Belgrade **140** (1989), 69–81.

On présente les valeurs de latitude ansi que quelques données météorologiques prises au cours d'observations.

6. EARTH'S ATMOSPHERE
6. ZEMLJINA ATMOSFERA

6.1. Astronomical Refraction
6.1. Astronomska refrakcija

G. Teleki: *Evolution of the Earth's atmosphere and the astronomical refraction*, Publ. Astron. Obs. Sarajevo 1 (1981), 111–114.

The author reaches the conclusion that the evolution of the Earth's atmosphere over the last millenniums did not practically affect the value of the refractional influences and that the same might be expected in the near future. Thus, the present-day (good) tables of refraction may well continue to be used unchanged during the time of mankind's civilisation.

G. Teleki: *On the modern invetigations of refraction influences*, Zbornik *Zadachi sovremenoj astrometrii v sozdanii inertsial'noj sistemy koordinat*, Izd. Fan, Tashkent, (1981), 423–427.

G. Teleki: *New tendencies of the research into the astronomical refraction*, Bull. Obs. Astron. Belgrade **131** (1981), 3–8.

A review is given of the more recent researches into the refrectional influences, with special emphasis on those new tendencies in studying or eliminating the infuence of the astronomical refraction (prevention, three-dimensional refraction, multi-wave methods, the use of the artifical satellites) of which it is expected to considerably promote our knowledge of this phenomenon.

G. Teleki, J. Saastamoinen: *Problems of three-dimensional refraction in astrometry*, Sun and Planetary System, D. Reidel Publ. Comp., Dordrecht, Holland – Boston, U.S.A. – London, England, (1982), 455.

G. Teleki, O. Atanacković: *The growth of knowledge on astronomical refraction I.* Rep. No. 19, Dep. of Geodesy, Univ. of Uppsala, Sweden, (1983), 255–271.

After the short historical survey on astronomical refraction, the growth of knowledge of this phenomenon is assessed proceeding from the number of the published papers dealing with that matter as well as the accuracy of the refraction tables. The growth of the published papers in the course of time has had a non-uniform pattern, being, however, very fast after the Second World War. The accuracy of the refraction tables has been increasing since Tycho's time up to the present, the time of doubling being about 26 years. It is demonstrated that the accuracy growth of the refraction tables proceeded at a slower rate than that of the observational catalogues of stellar positions. It is therefore understandable that the obstacles in the accounting for the atmospheric — the refractional ones inclusive — effects on the astrometric observations set limits to the development of the ground-based astrometry.

G. Teleki: *Progress report on the astronomical refraction*, Bull. Obs. Astron. Belgrade **134** (1984), 39–47.

A presentation is given of works on astronomical refraction, published in the period 1979 to 1982. Particular emphasis is given to research currently of special interest to astrometry, as for instance that relating to three dimensional refraction, atmospheric turbulence etc.

A. Yu. Yatsenko, G. Teleki: *Harzer's works on astronomical referaction viewed from today's standpoint*, Bull. Obs. Astron. Belgrade **135** (1985), 1–15.

A detailed survey and a critical analysis of P. Harzer's ideas and methods of computation of astronomical refraction in a three-dimensional medium is presented. On stating that Harzer's conceptions were of interest, ways of their possible application in the current astronomical practice are indicated.

G. Teleki: *Sadašnje mogućnosti u određivanju refrakcijskih uticaja*, VIII Kongres matematičara, fizičara i astronoma Jugoslavije, Saopštenja, Priština, (1985), 350.

G. Teleki: *Optical refraction: therminology and standards*, Publ. Astron. Obs. Belgrade **35** (1987), 338–342.

In continuation of the fundamentals and definitions advanced earlier by this author (Teleki, 1974), two more definitions relating to the optical refraction: "real (astronomical) refraction" (astronomical refraction taking place in the naturally distributed air layers of the Earth global atmosphere) and "OL (Oriani-Laplace) refraction" (refractional infuences over zenith distances less than 70° are suggested. Standards associated with the atmospheric models, pure refraction and OL refraction are given.

G. Teleki, C. Sugawa: *On the nature of astronomical refraction*, Publ. Astron. Obs. Belgrade **35** (1987), 1–16.

A survey is presented of factors — astrometric and meteorological — iluminating the nature of astronomical refraction. As a result of the general circulation of the atmosphere, the tilting of equal refractivity in the troposphere is really compensated by the reversed tilt in the lower stratosphere. From all the analysis there follows a general conclusion that, provided the surface airstrata are not excessively perturbed, the actual refraction influences are — for zenith distances under 70° — representable by the pure (normal) refraction with an error less than 0.″1. The Oriani-Laplace's theorem proves to be applicable on the (mean) three-dimensional atmosphere too.

G. Teleki: *Present-day potentialities of refraction influences determination and perspective developments*, Bull. Obs. Astron. Belgrade **136** (1986), 61–72.

A critical survey and analysis is presented of those questions that are of acute interest in the astronomical refraction investigation. Special weight is accorded to the development and the present accuracy in the refraction determination as well as to the prospective ways of its further improvement. Regarding further development put under scruting are: implementation of more accurate formulae in the refraction calculus; introduction of atmospheric models better matching the reality, accounting for the refraction influences within an instantaneous meteorological field; instrumental determination and the supression of refraction influences; prevention and more rigorous turning to advantage of the laws governing the radiation propagating. The effects associated with the radio refraction are discussed separately. The conclusion is derived that a marked accuracy improvement in the determination of the refraction influences might be expected in the years ahead.

6.2. The Quality of the Atmosphere — Site Testing
6.2. Kvalitet atmosfere — site testing

J. Arsenijević: *Selection of potential high altitude sites for an optical astronomical station*, Publ. Obs. Astron. Belgrade **31** (1981), 87.

A set of parameters relevant in selecting an astronomical observing station has been considered and a three-step procedure proposed. The first step is

shown in detail. A review of 7 different parameters in 17 regions qualifying a site for the next selecting steps has been given. Qualification of diferent sites according to four of those parameters has been applied. The mean rank gave the priority sequence of sites (the last column in Table I) from the aspect of their suitability for astronomical observations. The first five sites are in Macedonia, followed by two sites in Serbia.

J. Arsenijević, A. Kubičela, I. Vince, G. Djurašević, Z. Ivanović: *Some results of site-testing photometric measurements*, Publ. Obs. Astron. Belgrade **31** (1981), 89.

Stellar fluxes, extinction coefficients and sky brightness have been measured at Belgrade Astronomical Observagtory and several potential mountain observatory sites in SR Serbia during 1976–1980 period. All measurements, although not frequent, point to the very poor observing conditions at Belgrade and much better ones at the mountain sites. The photometrical differences among the potential observatory sites seem to be unsubstantial. The influence of urban sky glow of Prokuplje and Niš at Vidojevica have been examined more thoroughly and a definite location of the future high altitude station has been proposed at Jovanova Glava, 1020 m above the see level.

I. Vince, A. Kubičela: *Polarimetric measurements of relative air turbidity*, Publ. Obs. Astron. Belgrade **31** (1981), 49.

Based on measurements of sky polarization parameters a method for comparing various observatory sites according to their for daylight and one for night observations have been constructed. The observations during 1978 preliminarily indicate Preslap as the best considired location. The method is suitable for long-term monitoring of large-scale air polution.

G. Teleki: *Astrometric site selection*, Sun and Planetary System, D. Reidel Publ. Comp., Dordrecht, Holland – Boston, U.S.A. – London, England, (1982), 483.

J. Arsenijević: *Seasonal variations of the Hvar extinction coefficients*, Publ. Obs. Astron. Belgrade **33** (1985), 36.

Mean montly values of the extinction coefficients, measured at the Hvar Observatoy in the period 1972–78, and the gas density of some atmospheric layers at +45° latitude are discussed. High anticorrelation of these quantities over the atmospheric layers up to 7.5 km is stated. The amount of the gas component in total extinction is variable during the year, being minimum in the summer period when the extincion coeficient is maximum. The seasonal variations of the extinction are mainly the result of the aerosol component variations. The gas component causes a lessening of the effect of aerosol component variation in the total extinction.

O. Atanacković: *Preliminary investigation of the image motion at the Belgrade Observatory*, Publ. Obs. Astron. Belgrade **33** (1985), 83–87.

Image motion at different zenith distances has been investigated on the basis of star trails recorded photographically. Correlation between the image motion and meteorological parameters has been established. Correlation proved

rather close with the wind velocity and with relative humidity. The image motion amplitude is several tenths of arc second and its average period about 2.5 sec for the zenith distances 0° through 70°.

G. Teleki: *Atmospheric effects and selection of places for astrometric stations*, Kinematika i fizika nebesnyh tel **1**, No. 2 (1985), 85–91.

The paper deals with the Earth's atmosphere effect on astrometric instruments and on the stellar seeing. The problems of the protection against the atmospheric effect as well as the criteria for selection of places for astrometric stations are discussed.

7. PLANETARY SYSTEM
7. PLANETSKI SISTEM

7.1. Origin and Dynamics of the Earth-Moon System
7.1. Poreklo i dinamika sistema Zemlja-Mesec

P. Savić, G. Teleki: *Origin and dynamics of Earth's core*, Acta Geodaet., Geophys. et Montanist. Hung., Budapest, **20**, 1 (1985), 13.

P. Savić, G. Teleki: *Comments on "The origin of the Earth-Moon system"*, Earth, Moon and Planets **36**, 2 (1986), 139.

M. B. Protitch, V. Protitch-Benishek: *Quelques remarques sur l'hypothèse de la nonuniformité de la rotation terrestre*, IAU Colloquium No. 100 "Fundamentals of astrometry", (1987), Belgrade, Yugoslavia.

V. Protitch-Benishek, M. Protitch: *On the lunar secular acceleration: a possible approach*, Proc. of the 141st Symposium of IAU "Inertial Coordinate system on the Sky", Leningrad, (1990), 201–202.

On the basis of an original approach to the problem of secular acceleration of the Moon and fluctuations, lunar observations in the period 1861–1985 are analysed.

V. Protitch-Benishek, M. B. Protitch: *An approach to the problem of secular acceleration of the Moon*, Bull. Obs. Astron. Belgrade **142** (1990), 17–21.

If we adopt the solution of extended method in the Delaunay theory of the Moon as real and entirely logical and substitute the square term in the Moon's mean longitude by the very long period inequality, the remaining residuals — fluctuations — can be treated as the consequence of collected effect of a few other inequalities. The frequencies of these periodical terms correspond to the identical relative positions of the Moon's node, Sun and Earth. On the basis of such an approach to the problem of secular acceleration of the Moon and fluctuations, lunar observations in the period 1681–1985 are analysed. The results are quite consistent with values presented by other authors.

7.2. Astrometric Aspects of Eclipses, Transits and Occultations
7.2. Astrometrijski aspekti pomračenja, prolaza i okultacija

V. Protich-Benishek: *Occultations of stars by the Moon observed at the Belgrade astronomical observatory in the years 1978 and 1979*, Bull. Obs. Astron. Belgrade **131** (1981), 38–39.

During the period 1978–79, 63 occultations of stars by the Moon were observed at the Belgrade Astronomical Observatory with Askania refractor 135/1600 by the author. The UTC timings, corrected for personal equation in amount of $0^s.3$, $O-C$ residual distances of the stars from the computed positions of the Moon's outline for the given times of occultations, and all other relevant data are presented in two tables.

V. Protitch-Benishek: *Occultation de la planète Venus par la Lune du 20 janvier 1980 observée à Belgrade*, Bull. Obs. Astron. Belgrade **131** (1981), 40–42.

This paper gives the results of the observation of occultation of Venus by the Moon on 1980 January 20th, made with Askania astrograph of Belgrade Astronomical Observatory.

V. Protitch-Benishek: *Some results of the Mercury transit observations in 1970 and 1973 at Belgrade observatory*, in: W. Fricke, G. Teleki (eds.), Sun and Planetary System, D. Reidel Publ. Comp. (1982), 447–448.

The transits of Mercury across the solar disk in 1970 and 1973 have been observed at the Belgrade Observatory too. The photographs in 1970 have been taken in the focal plane of the refractor 650/10550 mm, whereas those in 1973 were achieved with the refractor guidescope of the astrograph 11/128 mm to which a special solar camera was attached. 56 in 1970 and 28 photographs in 1973 were obtained. Even though the revision of the observations of Mercury's transits made in Belgrade has been undertaken principally with the aim of deducing solar parallax in spite of the long prevaling view of the unsuitability of these transits for such refined calculation, we determined also other parameters connected with this phenomenon. In this paper the times of the contacts, the time of the least angular distance of centers and the semi-diameters of the Sun and Mercury are given.

V. Protitch-Benishek: *Transits of Mercury: results of Belgrade observations in 1970 and 1973*, Astron. Nachr. **304**, 6 (1983), 313–315.

Photographic observations of the transits of Mercury over the solar disk in 1973 at the Belgrade Observatory were used not only in order to determine the classical parameters, as the times of contacts and least distances to determine the apparent radii of the Sun and Mercury. The mean value of the Sun semi-diameter reduced to the distance unit differes from Auwers' value by about $1''.3$ while radius of the Mercury is in good agreement with Le Verrier's value. On the basis of quite homogenous observational material and precise observing data it was possible to derive the parallax of the Sun by means of the angular distance changes due to the parallactic effect in the course of transit. The

values are determined as: $8''.800 \pm 0''.008$ (1970) and $8''.788 \pm 0''.032$ (1973). The mean value resulting from the two transits is $\pi_s = 8''.794 \pm 0''.013$, an amount in striking agreement with that currently used.

V. Protitch-Benishek: *Merkurovi prolazi i paralaksa Sunca (Transits of Mercury and Solar Parallax*, (M.Sc. Thesis) (monografija sa bibliografijom), Publ. Obs. Astron. Belgrade **32** (1984), 1–159.

V. Protitch-Benishek, H. Božić: *Occultation of Sigma Sagittarii by Venus on 17 november 1981 observed from Hvar observatory*, Bull. Obs. Astron. Belgrade **136** (1986), 82–83.

Essentials are reported of the occultation of Sigma Sagittarii (Nunki) by Venus on November 17, 1981 observed at Hvar Observatory (Yugoslavia). The parameters of such exeptional phenomenon are given and analysed.

V. Protitch-Benishek: *Occultations of stars and planet Venus by the Moon observed at the Belgrade Astronomical Observatory in the years 1980–1984*, Bull. Obs. Astron. Belgrade **139** (1988), 67–69.

The paper contains results of visual observations of hundred stellar occultations and planet Venus by the Moon during the years 1980–1984 with Askania refractor 135/1600 at the Belgrade Observatory. The timings of Sigma Sagittarii occultation by Venus on 17 November 1981, observed from Hvar observatory, are also given.

7.3. Asteroids
7.3. Asteroidi

Z. Knežević: *Positions of minor planets obtained in 1979*, Bull. Obs. Astron. Belgrade **131** (1981), 33–37.

K. Pavlovski, Z. Knežević, M. Muminović: *Photometry of the asteroid (5) Astraea*, Proceedings of the IV Nat. Conf. of Yugoslav Astronomers, Sarajevo 1979, Publ. Astron. Obs. Sarajevo **1** (1981), 225–230.

Z. Knežević: *Observations made at Belgrade*, Minor Planet Circular, No. 5255.

Z. Knežević: *Observations made at Belgrade*, Minor Planet Circular, No. 7067.

Z. Vizi, Z. Knežević: *Observations made at Piskestet*, Minor Planet Circular, No. 7107.

Z. Knežević, V. Zappala: *An improved representation of the average opposition magnitudes of asteroids*, in: W. Fricke, G. Teleki (eds.), Sun and Planetary System, D. Reidel Publ. Comp., (1982), 299–302.

Z. Knežević: *Variation of the mean and median inclinations in the numbered minor planet sample*, Bull. Astron. Inst. Czech. **33** (1982), 267–231.

Z. Knežević, G. Djurašević, K. Pavlovski: *A review of photoelectric photometry of asteroids made at Hvar observatory*, Hvar Obs. Bull. **6** (1982) 1, 141–146.

A brief review is presented of results of the photoelectric observations of asteroids made at Hvar. The lightcurves are shown, and the interpretation of data demonstrated. Special attention is paid to the unusual case of 216 Kleopatra.

D. Olević, D. Djurović: *Contribution to the statistical analysis of Kirkwood's gaps*, Bulletin T. LXXIX de l'Académie Serbe des Sciences et des Arts — 1982, Classe des Sciences mathématiques et naturelles, Sciences mathématiques **12**.

On the sample of 2042 mumerated asteroids the statistical stability of width of Kirkwood's gaps (KG) has been investigated. On the basis of those data the authors show that asteroids the absolute magnitude $B(1,0)$ of which is greater than 13.0 do not affect the KG width. The correlation between the angle of eccentricity and the width of KG has been identified. The population density of the external side of vicinity of KG is greater than the internal one.

V. Zappala, M. di Martino, F. Scaltriti, G. Djurašević and Z. Knežević: *Photoelectric analysis of asteroid 216 Kleopatra: Implications for its shape*, Icarus **53** (1983), 458–464.

In some recent theoretical papers it has heen suggested that gravitationally bound "rubble piles" in hydrostatic equilibrium possibly exist among the asteroids. For a higher-than-critical value of the angular momentum acquired by such a body, the instability phenomena can produce fission into a binary system. S. J. Weidenschilling [*Icarus* **44**, 807-809 (1980)] suggestcd that 216 Kleopatra may represent a binary asteroid, since it has a large light curve amplitude (1.3–1.4 mag). In this paper new observations of Kleopatra are presented suggesting the equal plausibility of the single triaxial ellipsoid model. Namely when phase and aspect effects are taken into account, the actual maxiellipsoid model. Namely when phase and aspect effects are taken into account, the actual maximum amplitude is reduced to about 0.9 mag at 90° of aspect which is close to the value predicted by theory for the instability limit. Moreover, multiple-scattering effects [M. Poutanen, E. Bowell, and K. Lumme, *Bull. Amer. Astron. Soc.* **13**, 725 (1981)] can reduce the axial ratio a/b even more. If the single-body model is adopted, the density of Kleopatra should be on the order of $1.7\,\mathrm{g/cm^3}$. This low value seems reasonable for "rubble pile" models.

V. Zappala, Z. Knežević: *Photoelectric investigations of asteroids: selected observational programs for 1984*, Minor Planet Bull. **4** (1983), 29–31.

Z. Knežević: *The minor planet premature and related discoveries*, Bull. Obs. Astron. Belgrade **133** (1983), 16–26.

V. Zappala, P. Farinella, Z. Knežević, P. Paolicchi: *Collisional origin of the asteroid families: mass and velocity distributions*, Icarus **59** (1984), 261–285.

V. Zappala, Z. Knežević: *Rotation axes of asteroids: results for 14 objects*, Icarus **59** (1984), 436–455.

V. Zappala, M. Di Martino, Z. Knežević, and G. Djurašević: *New evidence for the effect of phase angle on asteroid lightcurve shape: 21 Lutetia* (research note), Astron. Astrophys. **130** (1984), 208–210.

New observations of the asteroid 21 Lutetia, obtained in 1981 and 1983 apparitions, are presented. They allowed a definitive value of the rotation period ($8^h.17$) to be deduced, instead of the previously adopted value of $6^h.133$. A comparison between 1962 and 1981 lightcurves, obtained at nearly the same ecliptic coordinates, revealed new convincing evidence for the phase angle effect on the lightcurve shape. This effect is very important for understanding asteroid morphology, but it sometimes leads to erroneous determinations of rotation periods.

Z. Knežević, P. Farinella: *Recent work on asteroid families*, XIX IAU Gen. Assembly, Commission 15, New Delhi, 1985.

M. Geffert, S. Wagner, S. Ninković: *Photographic observations of Minor Planets*, Acta Astronomica **35** (1985), 181.

40 positions of 11 minor planets are given which were measured on plates of the astrograph at Hoher List Observatory.

H. Debehogne, V. Protitch-Benishek: *135 precise astrometric positions of minor planets obtained at the GPO telescope of ESO — La Silla*, Bull. Obs. Astron. Belgrade **135** (1985), 56–63.

135 precise astrometric positions of minor planets observed at the GPO ($F = 4\,\mathrm{m}$, $D = 40\,\mathrm{cm}$) of the European Southern Observatory (ESO), La Silla, Chile, during February-March 1984 are presented. The observations have been made by H. Debehogne and G. G. Vieira. Two new asteroids were discovered during this mission. The plates were measured on the Ascorecord Zeiss measuring machine of the Observatoire Royal de Belgique. The reductions were performed with the Univac 9200 computer of the Observatoire Royal de Belgique, Institute Royal metéorologique and Institute d'Aeronomie Spatiale, using the dependence method by means of five reference stars. Data on reference stars, including dependences, are also given.

Z. Knežević: *Comparison of the asteriod proper elements obtained from various theories*, in: Asteroids, Comets, Meteors II (C. I. Lagerkvist, B. A. Lindblad, H. Lundstedt, H. Rickman, Eds.), (1986), 129–134.

D. Olević, S. Šegan and R. Pavlović: *Fundamental asteroid positions obtained with the Belgrade Zeiss astrograph*, Bull. Obs. Astron. Belgrade **136** (1986), 104.

Presented are 147 geocentric positions of the "fundamental" asteroids observed in the period 1967 to 1983. The reduction was implemented by the

method of dependences using 4 to 11 reference stars whose positions are taken from AGK3 and SAO catalogues.

H. Debehogne, V. Protitch-Benishek, D. Olević: *275 precise astrometric positions of minor planets obtained at the GPO telescope of ESO — La Silla*, Acta Astronomica **36**, 3–4 (1986), 457–462.

Precise astrometric positions of minor planets: 120 Lachesis, 366 Vincentina, 659 Nestor, 883 Mattarania, 1254 Erfordia, 1273 Helma, 1280 Baillauda, 2759 Idomeneus, 1984 SN 4, 1984 SO 4, 1984 SP 4 and 1984 SQ 4 obtained at the Grand Prism Objectif (GPO, $f = 4\,\mathrm{m}$, $D = 40\,\mathrm{cm}$) of the European Southern Observatory (ESO), La Silla, Chile, during September-October 1984 are presented here. Four new asteroids were discovered during this second mission in 1984 (see Bull. Obs. Astron. Belgrade **135**).

P. Farinella, P. Paolicchi, Ch. Froeschlè, Cl. Froeschlè, R. Gonczi, M. Carpino, V. Zappalá, and Z. Knežević: *Numerical experiments on the orbital evolution of family asteroids*, Bull. Amer. Astron. Soc. **18** (1986), 792.

V. Zappalá, Z. Knežević: *Pole coordinates of the asteroid 511 Davida as determined via the amplitude-magnitude method*, Icarus **65** (1986), 122–128.

Z. Knežević: *Comparison of the asteroid proper elements obtained from various theories*, in: Asteroids, Comets, Meteors (C. I. Lagerkvist, B. A. Lindblad, H. Lundstedt, and H. Rickman, Eds.), (1986), 129–134.

A. Milani, Z. Knežević: *Asteroid proper elements and secular perturbations: a second order theory*, Bull. Amer. Astron. Soc. **20** (1988), 864.

Z. Knežević: *Asteroid mean orbital elements*, Bull. Obs. Astron. Belgrade **139** (1988), 1–6.

Z. Knežević, M. Carpino, P. Farinella, Ch. Froeschlè, Cl. Froeschlè, R. Gonczi, B. Jovanović, P. Paolicchi, and V. Zappalá: *Asteroid short-periodic perturbations and the accuracy of mean orbital elements*, Astron. Astrophys. **192** (1988), 360–369.

Z. Knežević, B. Jovanović: *Asteroid short-periodic perturbations: critical ecentricity and inclination for analytically derived mean semimajor axes*, Proceedings 10th ERAM: Interplanetary matter (Z. Ceplecha and P. Pecina, Eds.), (1988), 107–109.

Cl. Froeschlè, P. Farinella, M. Carpino, Ch. Froeschlè, R. Gonczi, P. Paolicchi, V. Zappalá, and Z. Knežević: *Asteroid families*, in: The Few-Body Problem (M. Valtonen, Ed.), D. Reidel Publ. Co., Dordrecht, (1988), 101–116.

P. Farinella, Cl. Froeschlè, and Z. Knežević: *The puzzle of asteroid families*, in: Long-Term Dynamical Behaviour of Natural and Artifical N-Body Systems (A. E. Roy, Ed.), Kluwer Acad. Publ., (1988), 237–244.

H. Debehogne, V. Protitch-Benishek: *Orbite elliptique de l'asteroide E 3776 decouvert a La Silla*, Acta Astronomica **38** (1988), 153–155.

This paper contains the precise photographic observations of the new discovered minor planet with the Grand Prism Objective (GPO) at the ESO, La Silla in September 1986. On the basis of such minor planet positions the elliptic orbit is derived by Gauss-Encke method.

Z. Knežević: *Sopstveni elementi malih planeta kao parametri klasifikacije u familije*, Ph.D. thesis. Belgrade Univ., (1989).

Z. Knežević: *Report on the workshop "Proper elements and dynamical familes of asteroids"*, in: Asteroids, Comets, Meteors III (C. I. Lagerkvist, H. Rickman, B. A. Lindblad, M. Lindgren, Eds.), Uppsala Univ., (1989), 599–600.

P. Farinella, M. Carpino, Ch. Froeschlè, Cl. Froeschlè, R. Gonczi, Z. Knežević, and V. Zappalá: *The ages of asteroid families*, Astron. Astrophys. **217** (1989), 298–306.

Z. Knežević: *Asteroid long-periodic perturbations: the second order Hamiltonian*, Celestial Mechanics **46** (1989), 147–158.

G. B. Valsechi, A. Carusi, Z. Knežević, L. Kresàk, and J. G. Williams: *Identification of asteroid dynamical families*, in: Asteroids II (R. P. Binzel, T. Gehrels and M. S. Matthews, Eds.), Univ. Arizona Press, Tucson, (1989), 368–385.

Z. Knežević, A. Milani: *Asteroid proper elements from an analytical second order theory*, in: Asteroids II (R. P. Binzel, T. Gehrels and M. S. Matthews, Eds.). Univ. Arizona Press, Tucson, (1989), 1073–1089.

H. Debehogne, V. Protitch-Benishek: *Precise minor planet positions obtained at ESO — La Silla in February 1985*, Bull. Obs. Astron. Belgrade **140** (1989), 53–68.

During the first mission in 1985, 258 accurate positions of minor planets were obtained from observations in February by GPO telescope of ESO, La Silla, Chile. The measurements were carried out on a measuring machine Optronics at ESO, Garching and with Ascorecord Zeiss of the Observatoire Royal de Belgique. Three new minor planets were discovered.

H. Debehogne, D. Olević, V. Protitch-Benishek: *546 precise astrometric positions of minor planets obtained at the GPO telescope of ESO — La Silla*, Bull. Obs. Astron. Belgrade **141** (1989), 15–45.

Precise astrometric positions of minor planets: 383 Janina, 1111 Reinmuthia, 1586 Thiele, 1674 Groeneveld, 2682 Soromundi, 2911 1938 GJ, 3009 Coventry, 3032 Evans and 19 new ones, which provisional designations 1986 QB_1 – 1986 QC_3 have been given by the Minor Planet Center, are presented in this paper. Photographic observations of minor planets were carried out in August

and September 1986 with Grand Prism Objective (GPO) at the European Southern Observatory, La Silla, Chile, by H. Debehogne.

H. Debehogne, V. Protitch-Benishek, D. Olević: *Les orbites elliptiques des petites planètes E 3777 et E 3778 découvertes a La Silla*, Acta Astronomica **40** (1990), 4.

In this paper the precise astrometric positions of two new-discovered minor planets, observed with GPO at the ESO — La Silla in 1986, are presented. On the basis of such positions the elliptic orbits are calculated by Gauss-Encke method.

V. Zappalà, A. Cellino, P. Farinella, Z. Knežević: *Asteroid families. I. Identification by hierarchical clustering and reliability assessment*, Astron. J. **100**, 6 (1990), 2030.

Substantial discrepancies between the existing classifications and inconsistencies with the results of physical studies have motivated a research program aimed at deriving an improved classification of asteroids in dynamical families. We analyzed a set of 4100 numbered asteroids, whose proper elements had been computed by a new second-order, fourth-degree secular perturbation theory [Milani and Knežević 1990, Celestial Mech. (submitted)], and checked with numerical inegrations to assess their long-term stability. A mulitivariate data analysis technique (*hierarchical clustering*) was applied to build for each zone of the belt a *dendrogram* in the space of proper elements, with a distance function related to the incremental velocity needed for orbital change after ejection from a fragmented parent body. Families were then identified by comparing this dendrogram with a similar one, derived for a quasirandom distribution of elements matching the large-scale structure of the real distribution. A significance parameter was associated with each family, measuring its departure from random concentrations, and two robustness parameters were obtained by repeating the classification procedure after varying the elements by small amounts (consistent with the results of numerical tests of their long-term stability) and changing the coefficients of the distance function. The most significant and robust families are those associated with Themis, Eos, and Koronis, that collectively include about 14% of the known main-belt population; but 12 more reliable and robust families were found throughout the belt, most of which partially match those found in previous classifications. In the Flora region of the inner belt, a reliable identification of families is difficult, since the background has a high density and the accuracy of proper eccentricities and incilinations is poor, mainly because of the proximity to the strong ν_6 secular resonance. Other results include: a relatively populous Eunomia family, lacking large C-type members; a small family having Vesta as its largest object; the disappearance of the unlikely association in one family (Nysa-Hertha) of M, F, and E types; the existence of two small, but robust families with sizeable largest members in the Themis region, at moderate inclinations.

A. Milani, Z. Knežević: *Secular perturbation theory and computation of asteroid proper elements*, Celestial Mechanics and Dynamical Astronomy **49** (1990), 347–411.

A new theory for the calculation of proper elements, taking into account

terms of degree four in the eccentricities and inclinations, and also terms of order two in the mass of Jupiter, has been derived and programmed in a self contained code. It has many advantages with respect to the previous ones. Being fully analytical, it defines an explicit algorithm applicable to any chosen set of orbits. Unlike first order theories, it takes into account the effect of shallow resonances upon the secular frequencies; this effect is quite substantial, e.g. for Themis. Short periodic effects are corrected for by a rigorous procedure. Unlike linear theories, it accounts for the effects of higher degree terms and can thus be applied to asteroids with low to moderate eccentricity and inclination; secular resonances resulting from the combination of up to four secular frequencies can be accounted for. The new theory is self checking: the proper elements being computed with an iterative algorithm, the behaviour of the iteration can be used to define a quality code. The amount of computation required for a single set of osculating elements, although not negligible, is such that the method can be systematically applied on long lists of osculating orbital elements, taken either from catalogues of observed objects or from the output of orbit computations. As a result, this theory has been used to derive proper elements for 4100 numbered asteroids, and to test the accuracy by means of numerical integrations. These results are discussed both from a quantitative point of view, to derive an a posteriori accuracy of the proper elements sets, and from a qualitative one, by comparison with the higher degree secular resonance theory.

7.4. Comets
7.4. Komete

V. Protić-Benišek: *Parabolic orbit of the comet 1977m – Kohler*, Proceedings of the National Conference of Yugoslav astronomers, Publ. Obs. Astron. Sarajevo **1** (1981), 287–291.

On the basis of photographic observations of the comet 197m – Kohler, carried out at the Belgrade Observatory from 3 October to 22 November 1977, its parabolic orbit was derived. The Olbers' method, adjusted to the given case, was employed. Three positions, equidistant with respect to the mean time of observations, were selected from the whole series and the first system of elements was derived. The $(O - C)$ values were then smoothed and a final system established. A good accordance of our orbital elements with those of B. Marsden, derived on the basis of a large number of observations of this comet, covering a considerable longer time interval, can be stated.

V. Protitch-Benishek: *Comet astrographic positions obtained at Belgrade astronomical observatory during 1977–1982*, Bull. Obs. Astron. Belgrade **135** (1985), 54.

During the period 1977–1982 the photographic observations of the four bright comets: 1977 m Kohler, 1979 l Bradfield, 1980 u Panther and 1982 f Chyrymov-Gerasimenko were carried out with the Askania astrograph of the Belgrade Astronomical Observatory. 43 astrographic positions for the equinox 1950.0 were obtained.

V. Protitch-Benishek: *Observations of comet Panther from Belgrade astronomical observatory*, Minor Planet Circular, No. 9437, (1985).

V. Protitch-Benishek: *Observations of comet Chyrymov-Gerasimenko from Belgrade astronomical observatory*, Minor Planet Circular, No. 9513, (1985).

V. Protitch-Benishek: *Precise astrographic positions of comet Giacobini-Zinner observed from Belgrade astronomical observatory*, Minor Planet Circular, Nos. 9981, 9988, 9989, (1985).

The comet Giacobini-Zinner was observed over a nearly two months period, from 22 July to 14 September 1985, mostly with the 125/1000 mm Askania photo-visual equatorial. According to the number of its observations this Observatory stands at the 27th place among 61 participants in the Giacobini-Zinner comet imaging. These astrographic positions, together with observations of other observatories, served for establishing accurate comet's orbit (IHW orbit No 31), shortly before its encounter with the ICE spacecraft. A curious event took place on 14 September: the comet Giacobini-Zinner approached apparently Halley as closely as 2°. However, since it was Halley that we tracked, a diffuse Giacobini-Zinner comet's trail appears on our photograph in consequence of its apparent motion having been considerably faster.

V. Protitch-Benishek: *Observations of comet P/Halley from Belgrade astronomical observatory*, Minor Planet Circulars, Nos. 10209–10211, (1985).

This paper contains the results of comet H alley observations from September 11, 1985 until 27 May 1986, when it was observed as many as 75 times. On 9 December 1985 the occultation of BD +6°5207 by Halley was observed.

V. Protitch-Benishek: *Results of comet Halley observations at the Belgrade observatory*, Proc. 20th ESLAB Symposium on the Exploration of Halley's Comet, Heidelberg, 27–31 October 1986, ESA SP-250 (1986), 265–266.

With fifty years experience and tradition in Comet observation and research the Belgrade Observatory joined the International Halley Watch as soon as the Comet got within the reach of its instruments — actually not earlier than September 1985. Comet Halley observations were carried out from September 1985 through June 1986, 75 plates in all having been acquired during this period. The resulting precise astrographic positions were immediately communicated to the IHW Center. The periodic comet Giacobini-Zinner was also systematically observed during the period June-September 1985, the observations having particularly been intensified in the interval just preceding the ICE spacecraft's closest approach to it. On 9 December 1985 the occultation of BD +6°5207 by Halley was observed. The results of observing this event are briefly reviewed in the present paper.

V. Protitch-Benishek: *Precise astrographic positions of Halley comet*, Minor Planet Circular, No. 10331, (1986).

Some of astrographic precise positions of comet Halley after its perihelion passage are presented.

Komete — svedoci prošlosti, editori: J. Arsenijević i Dj. Teleki, Astronomska opservatorija i Astronomsko društvo "Ruđer Bošković", Beograd, (1986), pp. 142.
- V. Kršljanin: *Nastanak i poreklo kometa*, 7.
- Dr. M. Dimitrijević: *Izgled i struktura kometa*, 33.
- Mr. I. Vince: *Stanje materije u kometama*, 45.
- Dr. V. Vujnović: *Otkuda potječe svijetlost kometa*, 55.
- Dr. M. Dimitrijević: *Uticaj kometa na Zemlju*, 63.
- S. Jankov: *Prošlost Halejeve komete*, 69.
- Dr. Dj. Teleki: *Ujedinjenim snagama u istraživanje Halejeve komete*, 79.
- N. Čabrić: *Vidljivost Halejeve komete iz Beograda*, 99.
- Mr. V. Protić-Benišek: *Prvi plodovi istraživanja Halejeve komete u 1985–86. god.*, 105.
- N. Janković: *Kometa u srpskim zapisima i letopisima*, 111.
- M. Protić: *Smrt jedne komete*, 121.
- Mr. J. Arsenijević: *Neki podaci o kometama*, 125.
- Mr. V. Protić-Benišek: *Posmatranja kometa sa Astronomske opservatorije u Beogradu*, 127.
- M. Prosen: *Astronomi-amateri i komete*, 135.
- M. Djokić: *O nastanku termina kometa i neki stari pokušaji objašnjenja kometskih pojava*, 141.

V. Protitch-Benishek: *Comet astrometry in the post-Halley era*, IX Nacionalna konferencija astronoma Jugoslavije, Sarajevo, (1988).

This paper presents a brief review on the major astrometric results collected during the IHW Astrometric Network and attention is drawn to different aspects of such future investigations.

8. SUN
8. SUNCE

A. Kubičela, J. Arsenijević, S. Manola, Z. Stokić, N. Uzelac, I. Vince: *Flash spectrum observations during total solar eclipse, 1980*, Proc. Symp. Phys. Ion. Gases (SPIG), Ed. B. Čobić, **298** (1980).

A. Kubičela: *Ortogonalne komponente prividne godišnje precesije Sunca*, Saopšteno na VII Kongresu MFA Jugoslavije, Bečići, (1980).

A. Kubičela, M. Karabin: *Detailed treatment of syndic solar rotation*, Publ. Dept. Astron. Univ. Beograd **11** (1981), 35.

Begining with a previous vectorial results about the synodic solar rotation dependance on the inclination of solar equator, the classical definition of synodic solar rotation has been reconsidered in some detail. The angular difference between one synodic and sidereal solar rotation turn, $\Delta\lambda$, as a function of the longitude of the Earth and the inclination of the solar equator,

β, indicates a substantially different nature of trigonometric and vectorial definition of synodic solar rotation. Only a long-term mean value of $\Delta\lambda$ does not depend on β. For the extreme case, $\beta = 90°$, $\Delta\lambda$ shows a purely geometrical discontinuity. On the contrary, the sidereal, apparent annual and synodic rotations of the solar globe are smooth and can be described by the corresponding vectorial angular velocities.

A. Kubičela, M. Karabin: *Line-of-sight velocity field of synodic solar rotation*, Saopšteno na VI Evropskom regionalnom astronomskom sastanku, Dubrovnik, (1981).

A. Kubičela, M. Karabin: *An integral supergranular contribution to the global-scale photospheric line-of-sight velocity field*, Publ. Astron. Obs. Sarajevo **1** (1981), 185.

Taking the contribution of an unresolved supergranular line-of-sight velocity of a given sign as proportional to the mean velocity and to the relative area under the same given velocity, and taking into account the curvature of the photosphere within a supergranule, a new integral effect of higher contribution of approaching velocities in supergranules has been found. It is not negligible near the limb and must be of certain importance in photospheric global-scale velocity and limb effect observations.

A. Kubičela: *Observation of total solar eclipse of 16. February 1980*, Observation of the Total Solar Eclipse of February 16th 1980, ed. S. K. Trehan, Indian National Sci. Academy (1981), 16.

The electronic and photographic equipment used by Belgrade solar expedition in India to observe the partial phases of the eeclipse, the flash spectrum, and the polarization of the corona, as well as the obtained results have been described.

A. Kubičela, V. Ruždjak: *Near future research in solar physics in Yugoslavia*, Near Future Plans for Solar Research, ed. C. Jordan, Oxford, (1981), 78.

The research programs in solar physics of Belgrade Astronomical Observatory and Hvar observatory in 1980-ies have been envisaged. The former one is concentrated on very large scale photospheric velocity research observing with the existing equatorial solar spectrograph. In cooperation with Ondřejeov Observatory, the last one focuses its interest on various photespheric and chromospheric physical aspects of active regions. The need for young astrophysicists and international cooperation has been stressed.

A. Kubičela, M. Karabin: *Line-of-sight velocity field of synodic solar rotation*, Proc. VI European Regional Meeting in Astronomy, ed. W. Fricke, G. Teleki, Reidel Publ. Co., (1982), 73.

Angular velocity components of synodic solar rotation have been treated as vectors. A colinear and a perpendicular components with respect to the solar

rotation axis have been found. Factor $\cos 7°.25$ has been introduced into the apparent efect of the Earth's orbital motion.

A. Kubičela: *Orthogonal components of the apparent yearly precession of the Sun*, Hvar Obs. Bull. Suppl., **1** (1982), 39.

Starting from the apparent yearly precession of the Sun described elsewhere, the components of that motion in the plane of the solar disk have been calculated. A westward apparent velocity amounting up to $2.2\,\mathrm{ms}^{-1}$ has been found.

A. Kubičela, I. Vince: *Effects of extrafocal observation wth the solar spectrograph of the Belgrade astronomical observatory, I. Solar Rotation Line-of-sight Velocities*, Bull. Obs. Astron. Belgrade **133** (1983), 1.

The optical averaging of line-of-sight velocities in regions $3'.8 \times 3'.8$ at the solar disk has been numerically imitated. The contributions of local line-of-sight velocities at any point of the disk have been assumed as proportional to the photospheric continuum intensity at the same point. Such a procedure yields systematically smaller line-of-sight velocities of the solar rotation. The necesary corrections depending on heliographic parameters P and B_0 have been fond.

A. Kubičela, M. Karabin: *Another view of synodic solar rotation*, Solar Phys., **84** (1983), 389.

Adding the angular velocity of sidereal solar rotation and the apparent rotational effect of the Earth's revolution vectorially, a new synodic solar rotation vector has been obtained. The sidereal and synodic solar rotation axes (and equators) are separated. Using the known parameters of the Earth's orbital motion, the synodic rotation angular velocity and the inclination of the synodic equator, the corresponding sidereal rotation parameters have been calculated ($\omega = 2.915 \times 10^{-6}\,\mathrm{rad\,s}^{-1}$ and $i_1 = 6°.76$). Various linear rotational velocities at the solar globe are briefly described.

A. Kubičela, I. Vince: *Effects of extrafocal observation with the solar spectrograph of the Belgrade astronomical observatory, II. Cases of Various Wavelengths and Space-resolutions*, Bull. Obs. Astron. Belgrade **134** (1984), 37.

According to an already published procedure, the space-averaging of the solar image within square regions from $3'.8$ to $0'.5$ side and for wavelengths 630 nm, 500 nm and 400 nm have been calculated. For a selected sample of P and B_0 the effect has been found amounting up to $33\,\mathrm{ms}^{-1}$.

A. Kubičela: *Dva prodora u dinamici sunčeve fotosfere*, Pregledno predavanje na VIII Kongresu MFA Jugoslavije, Priština, 1985.

A. Kubičela, M. Karabin, Z. Ivanović: *Merenje radijalnih brzina tačaka na Sunčevom disku*, Saopšteno na VIII Kongresu MFA Jugoslavije, Priština, 1985.

A. Kubičela, I. Vince, Z. Ivanović: *Effects of extrafocal observation with the solar spectrograph of the Belgrade astronomical observatory, III. Integration of the limb effect*, Bull. Obs. Astron. Belgrade **135** (1985), 21.

Besides six already konwn limb effect functions, another one (the Belgrade-Oxford function) has been evaluated. Simulating numerically extrafocal observations of the solar disk, a set of corrections for space-integration of solar radiation within the squares of 3'.8, 2'.0 and 1'.0 sides has been calculated for all the limb effect functions. The corrections amount up to $112\,\mathrm{ms}^{-1}$ (or up to $4\,\mathrm{ms}^{-1}$ in the case of Belgrade observations).

Z. Ivanović, I. Vince: *Correction to the solar line-of-sight velocities for topocentric motion of the observer*, Publ. Obs. Astron. Belgrade **33** (1985), 19–22.

Method for determining the radial velocity of an observer moving around the Sun is described. The Julian day (JD) as a unique independent variable is used. The method is developed for the reduction of data obtained at Belgrade astronomical observatory in the course of the solar spectral line shift observations. The accuracy is about $\pm 0.1\,\mathrm{m/s}$.

A. Kubičela, M. Karabin, I. Vince, Z. Ivanović: *Further Belgrade results of the large-scale photospheric velocity research*, Bull. Obs. Astron. Belgrade **136** (1986), 1.

From a series of FeI 630.25 nm Doppler shift observations solar equatorial rotational velocity of $2.82\,\mu\mathrm{rad\,s}^{-1}$ has been found. There is a difference between the active and quiet photosphere. The central meridian and equatorial limb effect curves as well as the meridian excess have been evaluated and discussed.

A. Kubičela: *Problem sinodičke rotacije Sunca*, Saopšteno na I Seminaru "Astrofizika u Jugoslaviji", Ljubljana, (1986).

A. Kubičela: *Relation between solar sidereal and synodic rotation axes*, Solar Phys. **106** (1986), 403.

Kinematic picture concerning the solar synodic and sidereal rotation axes has been considered in some detail. Large changes in the synodic rotation pole have been found for some hypothetical cases of out-of-ecliptic intra-Mercurian orbits. The influence of solar differential rotation and variable planetary velocity along the orbit have been taken into account and a continuous set of co-existing synodic poles oscillating around a mean position has been found. The relevant numerical values for the Earth are given and the possibility of detecting the existence of the two rotation axes has been pointed out.

M. Vukićević-Karabin, J. Arsenijević: *Solar and stellar activity phenomena*, Bull. Obs. Astron. Belgrade **136** (1986), 53.

A review is presented of highlghts in the solar and stellar activity researches based on latest information, published in the works of other authors, and on the measurements caried out at the Belgrade Observatory. New assumptions

are advanced concerning discret magnetic solar field of 1–2 KG strength in tubes of 200–400 km diameter. Dependence is outlined of the stellar rotation rate and magnetic activity on stellar age. It is demonstrated that stars with covective zone display magnetic activity which in some of the stars is cyclically repetitive.

E. Ribes, J.-C. Ribes, I. Vince, Ph. Merlin: *On the oscillation of the solar diameter*, C. R. Acad. Sci. Paris **307**, Serie II (1988), 1195–1201.

Systematic visual measurements of the solar diameter (both polar and equatorial) made with the meridian circle have been carried out at the Belgrade astronomical observatory from 1975. The measurements indicate an oscillation similar to that obtained by Laclare with the astrolabe measurements, i.e. a similar period, phase and amplitude. This result confirms the solar (or terestrial atmosphere) nature of the observed oscillation, thus eliminating the personal equation and instrumental biases.

E. Ribes, J.-C. Ribes, I. Vince, Ph. Merlin: *A survey of historical and recent solar diameter observations*, Adv. Space Res. Vol. **8**. No. 7 (1988), 129–132.

We report new observational evidence of periodic changes in the solar diameter. Progress has been made at two levels:

— Systematic measurements of the solar diameter (both horizontal and vertical) have been made using a Meridian Circle at the Belgrade Observatory, from 1974 to 1986. An oscillation (amplitude of ± 0.20 arcsec, period of about 900 days) is present in both diameters. Although the data are fewer and noisier than the astrolabe measurements made by Laclare (1987), they provide an independent confirmation of the presence of the damped oscillation reported by Delache et al. (1985), with the same phase, period and amplitude.

— A Fourier analysis of the solar diameters observed by La Hire (6.797 values), from 1683 to 1718, has been made. The analysis exhibits a number of peaks, all of which are present in the power spectrum of modern diameter data. In paraticular, a peak at 9.6 years is clearly visible. This result indicates that the solar cycle occured during the Maunder minimum, although the dearth of sunspots at the solar surface is confirmed. Some possible implications of these findings are suggested with respect to climatic variability on Earth.

A. Kubičela: *Problem of synodic solar rotation*, Bull. Obs. Astron. Belgrade **140** (1989), 105.

The problem of combining solar sidereal rotation and Earth's revolution in order to determine the solar synodic rotation is pointed out. The early attempts to solve the problem — the hypothesis of the apparent yearly precession and the projection of angular velocity vectors onto the solar rotation axis — are reviewed, and the ripening of the Belgrade hypothesis of separate synodic and sidereal solar rotation axes, as well as some of its results, are presented.

E. Ribes, I. Vince, E. Ferreira: *Meridian Circulation and Solar Rotation Over Solar Cycle 21.*, in: The Sun and Cool Stars: Activity, Magnetism, Dynamics, IAU Colloquium 130 (1990), 51.

M. Vuletić, P. Cugnon, J. Arsenijević: *Changes in residual polarization of the corona and the solar activity cycle*, Proc. 6th Europ. Meeting on Solar Phys., The dynamic Sun, Debrecen, ed. L. Dezső, (1990), 106.

9. STARS
9. ZVEZDE

9.1. Double and Multiple Star Systems
9.1. Dvojni i višestruki zvezdani sistemi

S. Kříž, J. Arsenijević, J. Grygar, P. Harmanec, J. Horn, P. Koubský, K. Pavlovski, J. Zverko, F. Ždárský: *Strongly interacting binary RX Cas*, Bull. Astron. Inst. Czech. **31**, 5 (1980), 284.

UBV photoelectric observations of RX Cas made in the years 1975 to 1977 at Hvar and Skalnaté Pleso Observatories are presented. The asymmetry of the light curve and the long-term light variations with the period of 516 days are most conspicuous in the U colour. The high increase of the orbital period ($\Delta P/P = 6.3 \times 10^{-7}$ per cycle) leads to an estimated rate of mass exchange greater than 10^{-6} m/year. The spectroscopic elements by Struve (1944) are re-computed. The case B of mass transfer or the second reverse transfer seems to be appropriate for RX Cas. Possible explanations of light anomalies are discussed.

G. M. Popović: *Orbites nouvelles (ADS 1976)*, Circ. Inf., No. 81, UAI, Comm. des Etoiles Doubles, (Juin 1980).

G. M. Popović: *Étoiles doubles nouvelles (GP 156)*, Circ. Inf., No. 81, UAI, Comm. des Etoiles Doubles, (Juin 1980).

D. J. Zulević: *Orbites nouvelles (ADS 1548, 8145, 10085, 16368)*, Circ. Inf., No 81, UAI, Comm. des Etoiles Doubles, (Juin 1980).

V. Erceg: *Orbites nouvelles de ADS 2301 = A 2414*, Circ. Inf., No. 81, UAI, Comm. des Etoiles Doubles, (Juin 1980).

V. Erceg: *Les orbites de deux etoiles doubles visuelles. (ADS 2301 = A2414 et ADS 2531 = A 829)*, Bull. Obs. Astron. Belgrade **131** (1981), 20–22.

The autor presents: the orbitae elements, the dynamical parallaxes, the Thiele-Innes constants, the masses, the absolute magnitudes and the ephemerides.

V. Erceg: *Orbite nouvelle de ABS 1345 = A 1*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

V. Erceg: *Orbites nouvelles de ADS 674 = A 921AB*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

V. Erceg: *Orbites nouvelles de ADS 1393 = HU 804*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

D. J. Zulević: *Orbits of five visual binaries*, Bull. Obs. Astron. Belgrade **131** (1981), 15.

Orbits and dynamical parallaxes are presented for five visual binary systems: ADS 1548, ADS 8145, ADS 10085, ADS 16131 and ADS 16368. Calculated positiona are compared with observations and ephemerides are given for each system.

D. J. Zulević: *Micrometer measures of double stars (ser. 32)*, Bull. Obs. Astron. Belgrade **131** (1981), 27.

Presented here are 153 measures of 78 Double Stars made with 65/1055 cm refractor of Belgrade Observatory.

D. J. Zulević: *Orbites nouvelles (ADS 1371, 7758, 11989, 16877)*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

G. M. Popović: *Orbites nouvelles (ADS 3174)*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

G. M. Popović: *Étoiles doubles nouvelles (GP 158, 162, 163, 161, 157, 165)*, Circ. Inf., No. 85, UAI, Comm. des Etoiles Doubles, (Oct. 1981).

G. M. Popović: *New double stars discovered in Belgrade with the Zeiss refractor 65/1055 cm, Supplement VI*, Bull. Obs. Astron. Belgrade **131** (1981), 23.

G. M. Popović: *Glavni pravci i dostignuća savremenih ispitivanja višestrukih sistema*, Publ. Astron. Obs. Sarajevo **1**, No 1, (1981), 269.

D. Olević, D. Djurović: *The periodicity of residuals $\Delta\rho$ and $\Delta\theta$ of the double star ADS 11520*, Publ. Department of Astronomy, Univ. Belgrade **11** (1981).

The periodical variations of the residuals of radius $(O - C)_\rho$ and positional angle $(O - C)_\theta$ of double star ADS 11520 was remarked. From the observations made in period 1900–1976 the corrections of Van den Boss's orbital elements are computed and it is shown that the periodical variations of residuals relative to the new orbital elements exist.

V. Erceg: *Les orbites de trois étoiles doubles visuelles: (ADS 674=A921AB, ADS 1445=AL et ADS 1393=HU 804)*, Bull. Obs. Astron. Belgrade **132** (1982), 22.

The autor presents: the orbital elements, The Thiele-Innes constants, the dynamical parallaxes, the masses and ephemerides.

V. Erceg: *Orbites nouvelles de ADS 2609AB=BU 787AB*, Circ. Inf., UAI, Comm. des Etoiles Doubles.

V. Erceg: *Orbites nouvelles de ADS 3058 = HU 302*, Circ. Inf., No. 88, UAI, Comm. des Etoiles Doubles, (Oct. 1982).

D. J. Zulević: *Orbits of four visual binaries*, Bull. Obs. Astron. Belgrade **132** (1982), 17.

Orbits and dynamical parallaxes are presented for four visual binary systems: ADS 1373, ADS 7758, ADS 11989 and ADS 16877. Calculated positions are compared with observations and ephemerides are given for each system.

D. J. Zulević: *Micrometer measures of double stars (ser. 33)*, Bull. Obs. Astron. Belgrade **132** (1982), 25.

Presented here are 289 measures of 134 Double Star made sith 65/1055 cm refractor of Belgrade Observatory.

G. M. Popović: *An unidentified object in the constellation Cetus from 1911*, Bull. Inf. Cent. Données Stellaires, No. 22 (1982), 96.

G. M. Popović: *Orbites nouvelles (ADS 5958)*, Circ. Inf., No. 86,, UAI, Comm. des Etoiles Doubles (Février 1982).

G. M. Popović: *Étoiles doubles nouvelles, (GP 169, 171, 170, 172)*, Circ. Inf., No. 88, UAI, Comm. des Etoiles Doubles, (Octobre 1982).

G. M. Popović: *Orbital elements of visual binary systems Σ 248 = ADS 1786 and Σ 535 = ADS 3174*, Bull. Obs. Astron. Belgrade **132** (1982), 13.

G. M. Popović: *Micrometer measures of double stars (series 34)*, Bull. Obs. Astron. Belgrade **132** (1982), 34.

V. Erceg: *Orbites nouvelles de ADS 2111 = BU 83*, Circ. Inf., UAI, Comm. des Etoiles Doubles, (1983).

V. Erceg: *Orbites nouvelles de GLE 1 = IDS 04148S6072*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (1983).

V. Erceg: *Orbite nouvelle de ADS 8636 = A3009*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (Oct. 1983).

V. Erceg: *Orbite nouvelle de HU 1566 = IDS 05312S5108*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (Oct. 1983).

G. M. Popović: *Orbites nouvelles (ADS 13028AB)*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (Oct. 1983).

G. M. Popović: *Étoiles doubles nouvelles (GP 178 AB, AC, 173)*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (Oct. 1983).

G. M. Popović: *Orbital elements of the binary system ADS 5958 = Σ 170*, Bull. Obs. Astron. Belgrade **133** (1983), 27.

G. M. Popović: *Micrometer measures of double stars (series 35)*, Bull. Obs. Astron. Belgrade **133** (1983), 31.

D. J. Zulević: *Orbites nouvelles (ADS 4)*, Circ. Inf., No. 91, UAI, Comm. des Etoiles Doubles, (1983).

D. J. Zulević: *Micrometer measures of double stars (ser. 36)*, Bull. Obs. Astron. Belgrade **133** (1983), 38.

Presented here are 167 measures of 77 double stars made with 65/1055 cm refractor of Belgrade Observatory.

V. Erceg: *Les orbites de quatre Etoiles doubles visuelles. (ADS 2111 = BU 83, ADS 2609AB = BU 787AB, ADS 3058 = HU 302, GLE 1)*, Bull. Obs. Astron. Belgrade **134** (1984), 54.

The autor presents: the orbital elements, the Thiele-Innes constants, the dynamical paralaxes, the masses and ephemerides.

V. Erceg: *Orbites nouvelles de ADS 5707AB = A 3042*, Circ. Inf., No. 93, UAI, Comm. des Etoiles Doubles, (Juin 1984).

D. Olević, V. Erceg: *Orbites nouvelles de ADS 8718 = HU 641*, Circ. Inf., No. 95, UAI, Comm. des Etoiles Doubles, (Feb. 1984).

D. J. Zulević: *Micrometer measures of double stars (ser. 38)*, Bull. Obs. Astron. Belgrade **134** (1984), 64.

Presented are 262 measures of 107 double stars made with the 65/1055 cm refractor of Belgrade Observatory.

D. J. Zulević: *Orbits of two visual binaries*, Bull. Obs. Astron. Belgrade **134** (1984), 58.

Orbits and dynamical parallaxes are presented for the binaries ADS 4,974. Calculated positions are compared with observations and ephemerides are given for each system.

D. J. Zulević: *Orbites nouvelles (ADS 2446)*, Circ. Inf., No. 93, UAI, Comm. des Etoiles Doubles, (1984).

G. M. Popović: *Micrometer measures of double stars (series 37)*, Bull. Obs. Astron. Belgrade **134** (1984), 60.

D. Olević, V. Erceg: *Orbite nouvelle de 8926 = A 1789*, Circ. Inf., No. 95, UAI, Comm. des Etoiles Doubles, (Feb. 1985).

V. Erceg, D. Olević: *Orbite nouvelle de SLR 19 = IDS 14012S4924*, Circ. Inf., No. 96, UAI, Comm. des Etoiles Doubles, (Juin 1985).

V. Erceg: *Les orbites de trois étoiles doubles visuelles. (ADS 3686, IDS 05312S5108, ADS 5707AB)*, Bull. Obs. Astron. Belgrade **135** (1985), 45–46.

The author presents: the orbital elements, the Thiele-Innes constants, the dynamical parallaxes, the masses and the ephemerides.

D. J. Zulević: *Étoiles doubles nouvelles (Lunette de 65 cm Belgrade)*, Circ. Inf., No. 96. UAI, Comm. des Etoiles Doubles, (1985).

G. M. Popović: *IDS triple systems*, Publ. Obs. Astron. Belgrade **33** (1985), 88.

G. Djurašević: *Critical equipotential surfaces in close binary systems*, Astrophys. Space Sci. **124** (1986), 5–25.

The well-known problem of reckoning the critical surfaces (equipotential zero-velocity surfaces) in the close binary systems is approached by an independent method. The formulation of the problem is based on the assumptions of the binary's matter consisting of ionized hydrogen, the system possessing black-body radiation, a potential magnetic field, being in adiabatic equilibrium. Total pressure and total internal energy are examined. The model, implying synchronous rotation of the components, is described by hydromagnetic equations. For a statical case, however, it is representable by the equation of motion alone. Next, the temperature field is reproduced whereby the ratio $P_r/P_g = \alpha$ is playing part of a free parameter. The resulting potential functions, applied to particular binaries, furnish the Lagrangian collinear points, critical surfaces and potentials over them in terms of α. The families of surfaces thus obtained, compared with those originating from the Roche model, differ qualitatively in their geometry, position of the collinear equilibrium points, number of possible equilibrium states and the values of critical potentials. At identifying the allowed and forbidden regions of the gas motion new areas have been disclosed across which the gas outflow can take place and more possibilities of shell forming both around the individual components and the system as a whole. As the gas enthalpy and radiation are increased, the surface geometry is undergoing changes. The method enables the intensity of gas velocity to be ascertained at any point in the system. The results of the method outlined here complement the picture of possible equilibrium states in the close binary systems in the presence of radiation and magnetic field.

V. Erceg and D. Olević: *Orbits of four visual double stras ADS 8718, ADS 8926, IDS 14012S4924, IDS 14571S4012)*, Bull. Obs. Astron. Belgrade **136** (1986), 78–81.

Presented are preliminary orbital elements, dynamical parallaxes, absolute magnitudes, masses, ephemeris and residuals of four visual double stars.

V. Erceg, D. Olević: *Orbite nouvelle de I 1262 = IDS 14571S4012*, Circ. Inf., No. 98, UAI, Comm. des Etoiles Doubles, (Feb. 1986).

V. Erceg, D. Olević: *Orbites nouvelles de HU 657 = ADS 9711*, Circ. Inf., No. 100, UAI, Comm. des Etoiles Doubles, (Oct. 1986).

D. J. Zulević: *Orbites nouvelles (ADS 8242, 10459)*, Circ. Inf., No. 98, UAI, Comm. des Etoiles Doubles, (1986).

D. J. Zulević: *Orbites nouvelles (ADS 10385)*, Circ. Inf., No. 99, UAI, Comm. des Etoiles Doubles, (1986).

D. J. Zulević: *Micrometer measures of double stars (Ser. 40)*, Bull. Obs. Astron. Belgrade **136** (1986), 91–99.

Presented here are 289 measures of 103 double stras made with 65/1055 cm refractor of Belgrade Observatory.

G. M. Popović: *Orbite nouvelle: ADS 15007*, Circ. Inf., No. 98, UAI, Comm. des Etoiles Doubles, (1986).

G. M. Popović: *Étoiles doubles nouvelles (GP 192, 193, 191, 188, 190)*, Circ. Inf., No. 98, UAI, Comm. des Etoiles Doubles, (1986).

G. M. Popović: *Orbite nouvelle: ADS 9595*, Circ. Inf., No. 100, UAI, Comm. des Etoiles Doubles, (1986).

G. M. Popović: *New double stars discovered at Belgrade observatory with the Zeiss refractor 65/1055 cm. Supp. VII*, Bull. Obs. Astron. Belgrade **136** (1986), 49–52.

G. M. Popović: *Micrometer measures of double stars (Series 39)*, Bull. Obs. Astron. Belgrade **136** (1986), 84–90.

D. Olević, V. Erceg: *Orbits of two visual double stars. (IDS 15428N5059 and IDS 16358S3653)*, Bull. Obs. Astron. de Belgrade **137** (1987), 80–81.

The autors present: the orbital elements, the Thiele-Innes constants, the dynamical parallaxes, the masses and the ephemerides.

V. Erceg, D. Olević: *Orbites nouvelles de SEE 318 = IDS 16594S3829*, Circ. Inf., No. 103, UAI, Comm. des Etoiles Doubles, (Oct. 1987).

V. Erceg, D. Olević: *Orbites nouvelles de I 600 = IDS 17225S6022*, Circ. Inf., No. 103, UAI, Comm. des Etoiles Doubles, (Oct. 1987).

G. Djurašević: *Light curve variabilities of close binaries*, Publ. Astron. Institute of Czechosl. Acad. Sciences **70** (1987).

In the paper is considered a possibility of the determination of the parameters of close binaries of the type RS CVn by means of the comparison of the light

curve derived from photoelectric measurements to a synthetic curve obtained on the basis of a model of a binary system. The inverse problem method based on the nonlinear least square method is used. A few test examples and a shorter analysis of the proposed method are given.

D. J. Zulević: *Orbites nouvelles (IDS 16594S3829)*, Circ. Inf., No. 102, UAI, Comm. des Etoiles Doubles, (1987).

S. Ninković, G. M. Popović: *Unseen Companions to Stars*, Bull. Obs. Astron. Belgrade, **137** (1987), 44.

The existing data concerning 32 unseen companions are compiled and presented in Table I of the paper. The contribution of unseen companions to the local mass density is estimated. A value of 0.0044 $\mathfrak{M}_\odot$ pc^{-3} is found. Only one of the stars listed in Table I (Barnard's star) seems to be a strong candidate to possess a planetary system, according to the accepted criteria.

G. M. Popović: *Étoiles doubles nouvelles (GP 194, 197)*, Circ. Inf., No. 103, UAI, Comm. des Etoiles Doubles, (1987).

G. M. Popović: *The binary star Σ 2799 = ADS 15007*, Bull. Obs. Astron. Belgrade **137** (1987), 82–84.

D. J. Zulević: *Micrometer measurements of double stars (Ser. 42)*, Bull. Obs. Astron. Belgrade **138** (1988), 63–75.

Presented here are 420 measurements of 154 double stars made with 65/1055 cm refractor of Belgrade Observatory.

D. J. Zulević: *Orbites nouvelles (ADS 15988)*, Circ. Inf., No. 106, UAI, Comm. des Etoiles Doubles, (1988).

G. M. Popović, V. Trajkovska: *Relative motion of the components of the system GP 34 AB*, Bull. Obs. Astron. Belgrade **139** (1988), 65.

The rectilinear trajectory and ephemeris of the GP 34 AB to the 2020.0 are given. Relative proper motion of the component B, i.e. BD +34°3568 star, of 0″.116/year in the direction 341°.5 results from the trajectory elements.

G. M. Popović: *Micrometer measurements of double stars (Series 41)*, Bull. Obs. Astron. Belgrade **138** (1988), 55–62.

D. J. Zulević: *Orbites nouvelles (ADS 12631)*, Circ. Inf., No. 107, UAI, Comm. des Etoiles Doubles, (1989).

G. M. Popović, D. J. Zulević: *Micrometer measurements of triple stars (Ser. 43)*, Bull. Obs. Astron. Belgrade **140** (1989), 83.

326 measurements of triple systems from the Belgrade Survey of triple Systems, IDS Catalogne (up to 200 pc) and from the Leningrad Programme of Nearby Triple Stars are communicated.

D. J. Zulević: *Micrometer measurements of double stars (Ser. 44)*, Bull. Obs. Astron. Belgrade **140** (1989), 99.

Presented here are 156 measurements of 74 double stars made with 65/1055 cm refractor of Belgrade observatory.

G. M. Popović, Z. Ćatović: *Orbite nouvelle: ADS 10838*, Circ. Inf., No. 107, UAI, Comm. des Etoiles Doubles, (1989).

G. M. Popović, Z. Ćatović: *Orbite nouvelle: ADS 10429*, Circ. Inf., No. 109, UAI, Comm. des Etoiles Doubles, (1989).

G. M. Popović, D. J. Zulević: *Micrometer measurements of triple star systems — Series No. 43*, Bull. Obs. Astron. Belgrade **140** (1989), 83–97.

G. M. Popović, V. Trajkovska: *Relative proper motions of components of 16 triple star systems*, Bull. Obs. Astron. Belgrade **140** (1989), 43–46.

By comparing the proper motions determined from meridian measurements with the relative proper motions obtained from rectilinear trajectories it is concluded that out of 16 examined triple systems 11 systems have at least one optical component.

D. J. Zulević: *Orbites nouvelles (ADS 6582)*, Circ. Inf., No. 111, UAI, Comm. des Etoiles Doubles, (1990).

D. J. Zulević: *Orbites nouvelles (ADS 9425)*, Circ. Inf., No. 112, UAI, Comm. des Etoiles Doubles, (1990).

G. M. Popović, Z. Ćatović: *Orbite nouvelle: ADS 16242*, Circ. Inf., No. 112, UAI, Comm. des Etoiles Doubles, (1990).

Ž. P. Anosova, G. M. Popović: *Programma izucheniya trojnykh zvezd. Vydelenie sistem s fizicheski svyazanimi komponentami*, Kinematika i fizika nebesnykh tel, VINITI, No. 5694-B89, (1990).

Ž. P. Anosova, G. M. Popović: *Discovery of triple stars with physically connected components*, Kinematika i fizika nebesnykh tel, 1990/1.

9.2. Variable Stars
9.2. Promenljive zvezde

J. Arsenijević, A. Kubičela, I. Vince: *Surprisingly high optical polarization of μ Cephei*, Inf. Bull. Var. Stars, 1859, (1980).

J. Arsenijević: *Optical polarization of some cool supergiants*, Publ. Obs. Astron. Belgrade **28** (1980), 1.

Mathematical description of linearly polarized light is briefly presented in this paper. Also, some mechanisms of the origin of polarized radiation in stars

are described. In the case of six late spectral type supergiants the optical polarization has been measured. The analysis of the measured polarization of all observed stars has led to the positive conculsion about the existence of the intrinsic polarization changes originating in the circumstellar envelopes.

J. Arsenijević: *Polarimetry in astronomy*, Proc. IV National Conf. Yugoslav Astronomers, Sarajevo, (1981), 181.

Polarization as one of the fundamental properties of radiation and polarimetry as a method capable of giving important informations in astronomy has been presented. The complementary character of polarimetric and photometric methods is stressed. Some results of variable stars polarimetry are shown.

J. Arsenijević: *Synchronous changes of polarization, brightness and radial velocities of o Andromedae*, Bull. Obs. Astron. Belgrade **131** (1981), 13.

The complex event on the star o And in the interval of time JD 2442700-800 is analysed. It seems likely that synchronous changes of linear optical polarization, brightness and radial velocities were observed.

J. Horn, P. Koubský, J. Arsenijević, J. Grygar, P. Harmanec, J. Krpata, S. Kříž, and K. Pavlovski: *Radial-velocity and photometric variations of o And: Critical evaluation of possible periods*, Be stars, Proc. IAU Simp. 98, eds. M. Jacshek, H. G. Groth, (1982), 315.

All available data on radial velocities and, photometric measurements in the visible region are collected and evaluated periodicities are reported.

J. Arsenijević: *A possible eruptive event on M-supergiant μ Cephei*, Astron. Astrophys. **145** (1985), 430.

A sudden fast brightening of μ Cep amounting to 0.034 magnitude in V spectral region has been observed on August 3, 1981 at $0^h31^m.9$ UT. The observation was done with the Belgrade polarimeter using 4^s integration intervals. Standard deviation of the measurements was ± 0.011 mag. The shape and duration of the disturbed portion of the light curve of the observed event evokes those of an ordinary M-dwarf flare. New complex observations of μ Cep are necessary.

J. Arsenijević, S. Jankov, G. Djurašević, I. Vince: *Promene optičke polarizacije nekih Be zvezda*, Saopštenja, VIII Kongres fiz. mat. astronoma Jugoslavije, (1985), 341.

M. Vukićević-Karabin, J. Arsenijević: *Aktivni fenomeni na Suncu i zvezdama*, Saopštenja, VIII Kongres fiz. mat. i astron. Jugoslavije, (1985), 342.

G. Djurašević, J. Arsenijević, Z. Knežević: *Short-term variations of o And?*, Bull. Obs. Astron. Belgrade **135** (1985), 32-39.

Photoelectrical observations of o And revealed this object probably having short-term variations (on a time scale of 0.1 days) of low amplitude (about

0.01 magnitude), superimposed on the variations of longer (on the time scale of 1 day) priods. These short-term variations, if assumed to be a consequence of a pulsating mechanism in the star and treated as such, furnish a period consistent with the obeserved one.

J. Arsenijević, S. Jankov, G. Djurašević, I. Vince: *Variations of the liner optical polarization of κ Draconis*, Bull. Obs. Astron. Belgrade **136** (1986), 6–11.

It is demonstrated that the slow going variations in the linear intrinsic polarization of the star κ Dra in the spectral band V were present in the period 1979 to 1984.

The variations were within approximately 0.13 and 0.61 polarization percent, the minimum having taken place during 1980. The position angle varied between 5° and 22°. As of 1981 the polarization percent is continuously increasing while the position polarization percent has been occasioned by the emission from the shell which is largely unpolarized.

J. Arsenijević, S. Jankov, I. Vince and G. Djurašević: *Optical polarization changes of 88 Her in the period 1974–1985*, Bull. Obs. Astron. Belgrade **137** (1987), 49.

Linear optical intrinsic polarization of 88 He (HD 16273) measured with the Belgrade polarimeter in the period 1974–1985 has been presented. The polarization percentage changed from 0.15% (1976) to 0.56% (1979). Small values of polarization percentage corresponded to the period with negligible envelope effects. The maximum polarization has been found during the early period of a strong shell phase, about one year after brightness minimum. The polarization positon angle varies between 58 and 83 degres. An indication of the correlation between polarization percentage and H-alfa emission line intensities is demonstrated.

J. Arsenijević, A. Kubičela, I. Vince: *Be stars-challenge to the observers and theoreticians*, II Workshop Astrophysics in Yugoslavia, Abstracts, Beograd, Ed. M. Dimitrijević, (1987), 1.

J. Arsenijević, S. Jankov, G. Djurašević: *Long-term polarization changes of 88 Her*, Proc. IAU Coll. 92, Physics of Be Stars, (Eds. A. Slettebak, T. P. Snow), (1987), 200.

Linear optical polarization of 88 Her has been measured in V spectral region during the period 1974–1985. The mean annual values of the intrinsic polarization parameters are presented. The polarization percentage changes from 0.15% (1976) to 0.56% (1979). Small values of the polarization percentage correspond to the period when the envelope effect is negligible. The maximum of polarization percentage has been found during the early period of strong shell phase. The polarization position angle varies between 53 and 83 degress.

S. Jankov, B. Foing: *Indirect imaging of active RS CVn stars*, Proc Cambridge Workshop: Cool Stars, Stellar Systems and the Sun, (eds. J. L. Linsky and R. E.

Stencel), Springer-Verlag, Berlin-Heidelberg (1987), 528.

The RS CVn system HR 1099 has heen monitored over the orbital period to study spectroscopic variabilhty in photospheric lines and in Hα. The information provided by the variability of profiles, together with the limits of the Doppler imaging method are also presented. Different inversion algorithms were applied to test the image reconstruction of HR 1099, showing the role of such constraints as chi-square adjustment of the spectra and maximum entropy of the input image.

B. Foing, S. Jankov: *Doppler imaging, MUSICOS (Multi Site Continous Spectroscopy)*, Proc. Meudon Workshop, eds. C. Catala and B. Foing, (1987).

R. Duemmler, A. Kubičela, V. Doazan, B. Bourdonnau and J. Arsenijević: *The development and weakening of the shell spectrum of 88 Herculis (1977–1987). I. A radial velocity study*, Astron. Astrophys. Suppl. Ser. **75** (1988), 311.

We present new radial velocity measurements of 88 Her during 1977–1987, when the shell spectrum first developed and subsequently weakened. The data show that: (i) the radial velocity variations of the blue Balmer shell lines continued without any detectable change of the 86.72 day period; (ii) the radial velocity of the Hα shell line of the new set of data seems to follow the same behaviour as the blue Balmer shell lines; (iii) the V/R at Hα shows a clear trend toward values < 1 when the blue Balmer lines are more negative than the gamma velocity, and conversely; (iv) the FeII shell lines follow the same periodic behaviour as the Balmer shell lines, with a suggestion of slightly more negative values; (v) the radial velocities of the CaII (K) and NaI (D1 and D2) lines are variable, but they do not follow the periodic radial velocity curve of the blue Balmer shell lines. Their mean values are significantly more negative than that of all the other shell lines studied in this paper.

J. Arsenijević, A. Kubičela and I. Vince: *Be stars — a challenge to the observers and theoreticians*, Bull. Obs. Astron. Belgrade **138** (1988), 31.

The main historical steps in the investigation of the B stars with emission lines, starting with the year 1922 when IAU Commission 29 introduced the name "Be stars" at the first General Assembly of the Union in Rome and closing with the IAU Colloquium No. 92 "Physics of Be Stars" organized in Augst 1986 in Boulder, are briefly reviewed. The enormous quantity of the existing observational data and their significant characteristics over broad spectral region from X-ray to radio wavelengths are discussed. One of the main characteristics — photometric and spectral time variablity — is analysed with a special attention to long-term changes. The correlation of long-term photometric and spectral changes with the polarimetric ones for some stars has been mentioned. Obeservational results in confrontation with the theoretical interpretations from Struve's hypothesis to the contemporary empirical Be stars models are presented.

J. Arsenijević, S. Jankov, G. Djurašević, I. Vince: *Long-term changes of linear optical polarization of Be stars*, Bull. Obs. Astron. Belgrade **140** (1989), 1.

As a part of a more extensive research program at Belgrade Astronomical

Observatory, the first results of ten-year optical polarization measurements of o And, 88 Her, κ Dra and γ Cas have been shown. The existence of slow changes of polarization parameters has been established in all four stars. For two of them, 88 Her and κ Dra, the intrinsic polarization has been determined. A further analysis of these results is in preparation.

J. Arsenijević, A. M. Hubert, S. Jankov, I. Vince: *Common properties of some Be stars observational parameters*, Abstracts, Treći seminar Astrofizika u Jugoslaviji, Zagreb, ed. V. Vujnović, (1989).

J. E. Neff, F. M. Walter, S. L. Skinner, A. Brown, K. G. Strassmeier, M. Rodono, G. Cutispoto, S. Jankov, S. Char: *Ultraviolet, visible and radio observaton EI Eri*, Proc. IAU Coll. 106, Evolution of Peculiar Red Giant Stars, eds. H. R. Johnson and Zuckerman, (1989).

B. Foing, S. Jankov: *Imagerie Doppler d'étoilles active de types RS CVn*, Proc. MUSICOS Workshop, Meudon, (1989), 6.

J. Arsenijević, S. Jankov, G. Djurašević: *Changes of some envelope characteristics of Be star gamma Cas*, Contributed papers, XV SPIG, Dubrovnik, ed. D. Veža, (1990), 374.

J. Arsenijević, S. Jankov: *Long-term polarimetric activity of cold supergiant μ Cep*, Abstracts, IAU Coll. 130, The Sun and cool Stars, (1990), 104.

S. Jankov, B. Foing: *ESO remote control observations from Garching for MUSICOS'89 campaign*, Proc. II MUSICOS Workshop, eds. C. Catala and B. Foing, Meudon, (1990), 65.

B. Foing, S. Char, S. Jankov, C. Catala, D. S. Zhai: *First results from MUSICOS'89 campaign: Active surface structure and flares on HR1099*, Proc. II MUSICOS workshop, eds. C. Catala, and B. Foing, Meudon, (1990), 117.

10. STAR CLUSTERS AND GALAXIES
10. ZVEZDANA JATA I GALAKSIJE

S. Ninković: *Disc-to-Halo Nonthermal Emissivity Ratio according to a Study of the Radio Background at 10 MHz*, Publ. Astron. Obs. Sarajevo **1** (1981), 219.

An analysis of the data of Caswell's (1976) map aimed at determining the disc-to-halo nonthermal emissivity ratio is undertaken. A comparison with Fenkart's (1977) results gives indications in favour of the existence of a correlation between disc-to-halo mass ratio and disc-to-halo nonthermal emissivity ratio.

S. Ninković: *On the Study of the Clobular Cluster ω Cen*, Bull. Appl. Math. **193** (1983), 53.

A short report on a study of the globular cluster ω Cen is given. Examinations on the basis of the virial theorem and a tidal radius determination show that

a large mass, like that obtained in a paper by Ogorodnikov et al. in 1976, is possible for this cluster. An empirical model of the cluster, indicating that the largest fraction of the total mass is present near the centre, is constructed, as well.

S. Ninković: *On Eccentricities of Globular Cluster Galactocentric orbits*, Astron. Nachr. **304** (1983), 305.

The House-Wiegandt method is modified and applied to a large sample of globular clusters belonging to our Galaxy. The results obtained indicate high orbital eccentricities for them, but clearly demonstarting the diffeerences among globular clusters of different chemical composition.

P. Brosche, M. Geffert, S. Ninković: *Lessons from the Globular Cluster NGC 5466*, Publ. of the Astron. Inst. of the Czechosl. Acad. Sciences **56** (1983), 145.

NGC 5466 is a "loose" globular cluster (large core radius) with low metallicity. Its absolute velocity has been measured and leads to perigalactic distances around 6 kpc. The value of the observed "tidal radius" is clearly too large in comparison with the theoretical value.

S. Ninković: *Opredelenie mass sharovykh skoplenij po sobstvennym dvizheniyam*, Astrofizika **20** (1984), 283.

A determination for globular cluster masses for M 15, M 92 and M 13 by use of the methods proposed by Naumova and Ogorodnikov and by applying the virial theorem is made. A discussion of obtained results is presented as well.

S. Ninković: *Results of the Galactocentric Orbit Calculation for a Globular Cluster NGC 5466*, Pub. Obs. Astron. Belgrade **33** (1985), 32.

In the calculation in addition to the other data, the proper motion of NGC 5466, recently determined at Bonn observatory, is also used. In spite of a large proper motion error the obtained results clearly indicate an orbit, highly inclined to the galactic plane ($80° \pm 10°$) and highly elongated (eccentricity 0.7).

S. Ninković: *On the Structure and Mass of the Galactic Halo*, Astrophys. Space Sci. **110** (1985), 379.

On the basis of a globular cluster study a crude estimate of the total mass of the galactic halo within 20 kpc from the centre is done. It gives a minimal halo mass of the order of $10^{10}\,\mathfrak{M}_\odot$, yielding possibilities for a mass as large as $10^{11}\,\mathfrak{M}_\odot$. The content of the interstellar matter in the halo is estimated too. It is found that the gas content is a few percents the minimal mass, the gas temperature is very high-about 1×10^6 K, the magnetic field weak-about 0.25 nT. A weak nonthermal radio emission might be expected from such a halo.

S. Ninković: *On Tidal Radius Determination for a Globular Cluster*, Astron. Nachr. **306** (1985), 237.

A tidal radius determination for a globular cluster based on its density minimum, which is caused by the galactic tidal forces and derivable from a model of the Galaxy, is proposed. Results obtained on the basis of the Schmidt model for two clusters are in a satisfactory agreement with those obtained earlier by means of other methods. A mass determination for the clusters through the tidal radius, when the latter one is identified with the cluster perigalactic distance, yields unusually large mass values. Probably, the tidal radius should be identified with the instantaneous galactocentric distance. Use of models more recent than the Schmidt one indicates that a globular cluster may contain a significant portion of an invisible interstellar matter.

P. Brosche, M. Geffert, A. R. Klemola, R. S. Ninković: *One more Space Motion of a Globular Cluster: NGC 147*, Astron. J. **90**, 2033 (1985), 126.

From measurements of 39 stars with respect to the extargalactic Lick reference system, we derived the absolute proper motion of NGC 4147 and-using in addition the radial velocity — the space velocity with respect to various standards. The membership of individual stars of special astrophysical interest is discussed. Parameters of the cluster's galactic orbit are presented together with those of the previously treated cluster NGC 5466. Among these, the relatively low angular momenta seem to be especially remarkable.

S. Ninković: *K otsenke orbital'nogo ékstsentrisiteta*, Astrofizika **24** (1986), 411.

A Criterion for orbital eccentricity evaluating for objects moving in a spherically symmetric force field with mass distribution $\mathfrak{M}\alpha r^{\beta}$, based on the radial component rate in total kinetic energy is proposed. The latter quantity preserves a nearly constant value over a sufficiently large fraction of the orbit, admitting thus its instantaneous value to be a measure of the eccentricity.

S. Ninković: *A Further Study of the Globular Cluster M 71*, Bull. of Astron. Inst. of Czech. **38** (1987), 147.

For the purpose of determining the galactocentric orbit and tidal radius of the globular cluster M 71 (NGC 6838) is used, inter alia, the most recent observational material: the proper motion and heliocentric distance, determined by Cudworth. An attempt aimed at mass determination is done, too, whereby, inter alia, the method proposed by Naumova and Ogorodnikov is used.

Main results:

i) The cluster moves almost in the galactic plane, along a low-eccentricity orbit. The orbital eccentricity is most likely equal to 0.2, with a possible uncertainty limit of 0.1; apo- and perigalactic distances are most likely equal to 7.7 kpc and 5.1 kpc, respectively.

ii) The tidal radius appears to be within the limits 19–46 pc depending on the assumed concept.

iii) The mass value of $3 \times 10^4 \mathfrak{M}_\odot$ expected on the basis of the luminosity, seems justified, though the possibility of a higher mass cannot be excluded.

S. Ninković: *Orbital Eccentricity Study for the Spherical Component of our Galaxy*, Astrophys. Space Sci. **136** (1987), 299.

An analysis of the data concerning high-velocity stars from Eggen's catalogue aimed at a determination of the approximate slope of the mass function for the spherical component of our Galaxy, and at estimating the local circular velocity, as well as the local rotation velocity, as by-products, has been performed. Our conculsions are that:

(i) a linear dependence of the mass on the radius is very likely;

(ii) the value of the limiting radius is most likely equal to $(40 \pm 10)\,\mathrm{kpc}$

(iii) the two local velocities are approximately equal to each other, being both equal to $(230 \pm 30)\,\mathrm{km\,s^{-1}}$.

(iv) the local escape velocity appears to be most likely equal to $(520 \pm 30)\,\mathrm{km\,s^{-1}}$;

(v) the total mass of a corona, obtained in this way, is $(5 \pm 1) \times 10^{11} \mathfrak{M}_\odot$.

S. Ninković: *Dynamical Constants for our Galaxy*, Publ. of the Astron. Inst. Czechosl. Acad. Sciences **69** (1987), 317.

According to the present author's results a following system of the galactic dynamical constants is proposed: local escape velocity $u_e = (520 \pm 30)\,\mathrm{km\,s^{-1}}$, local circular velocity, $u = (230 \pm 30)\,\mathrm{km\,s^{-1}}$, local angular velocity of rotation, $\omega = (25 \pm 5)\,\mathrm{km\,s^{-1}\,kpc^{-1}}$, local circular frequency of planar oscillations, $\kappa_p = (40 \pm 10)\,\mathrm{km\,s^{-1}\,kpc^{-1}}$, local circular frequency of vertical oscillations, $\kappa_z = (70 \pm 20)\,\mathrm{km\,s^{-1}\,kpc^{-1}}$. The value of $(9 \pm 1)\,\mathrm{kpc}$ is assumed for the galactocentric distance of the Sun. The latter three values yield $(0.09 \pm 0.03)\mathfrak{M}_\odot\,\mathrm{pc^{-3}}$ for the local matter density, a value very close to the density obtained by use of statistical methods. On the basis of the proposed value it is concluded that the dark matter should be present in the form of a large, rarefied, massive, spherical corona.

S. Ninković: *Galactocentric Orbit and Tidal Radius of M 22*, Bull. Obs. Astron. Belgrade **139** (1988), 21.

The globular cluster M 22 (6656) appears to be in a not very eccentric orbit — $e = 0.5 \pm 0.2$ — especially not highly inclined to the galactic plane — $i = 150° \pm 20°$, as predicted by the present author (Ninković, 1983) on the basis of a statistical study. The tidal radius is found to be within the limits 28–86 pc depending on the cluster's mass and tidal radius concept assumed.

S. Ninković, A. D. Chernin, M. B. Shakenov: *O raspredelenii skrytykh mass v Mestnoj gruppe galaktik*, Astron. Tsirk. **1541** (1989), 1.

Dynamical models of the Local Group of galaxies involving various types of distribution of dark matter have been studied with numerical simulation. The

results have proved to be in favour of models with individual massive coronae around the two major galaxies of the Group.

S. Ninković: *On the Flattening of the Galactic Corona*, Bull. Astron. Inst. Czech. **41** (1990), 236.

A possibile flattening of the galactic (dark) corona is examined. It was found that, if the corona makes an essential contribution to the local density of the galactic matter, it should be at least as flattened as 0.1.

11. THEORETICAL ASTROPHYSICS AND PLASMA PHYSICS
11. TEORIJSKA ASTROFIZIKA I FIZIKA PLAZME

11.1. Radiative Transfer
11.1. Prenos zračenja

O. Atanacković, E. Simonneau: *Effects of elastic collisions on the local frequency redistribution in the transfer of resonant line photons*, Annales de Physique, Colloque No. 3, Vol. **11** (1986), 137–138.

The effects of elastic collisions on the local frequency redistribution of resonant line photons are shown through the behaviour of the velocity distribution function of the excited atoms, emission profile coefficient and radiation intensity.

O. Atanacković: *Analiza nelokalnih efekata u ne-LTR prenosu zračenja u rezonantnim linijama zvezdanih atmosfera*, Magistarski rad, Beograd, Decembar 1986.

O. Atanacković-Vukmanović, E. Simonneau: *Kinetic effects in non-LTE line transfer in stellar atmospheric conditions*, Bull. Obs. Astron. Belgrade **137** (1987), 66–79.

A survey of the main stages in the development of radiative transfer theory is given. Special attention is dedicated to an analysis of kinetic (local and non-local) effects of the transport of the excited atoms in two approximations of the general, selfconsistent solution. In both cases, emission profile coefficient is coherently derived proceeding from the velocity distribution function of the excited atoms.

O.Atanacković-Vukmanović, E. Simonneau: *Parameters characterizing non-LTE line radiative transfer in some astrophysical conditions*, Bull. Obs. Astron. Belgrade **137** (1987), 58–65.

In this paper, the values of three dimensionless parameters: ε, ζ and η, characterizing non-LTE line formation, and measuring, respectively, the importance of inelastic collisions, elastic collisions and streaming of excited atoms, are estimated for different astrophysical conditions. The estimation is performed for the atmospheres of main sequence stars, those of white dwarfs and gaseous

nebulae and for the resonance lines formed therein. It is shown that in all cases except for the Lyman α line, for which kinetic non-local effects can be significant, local "classical" partial redistribution theory should be used.

O. Atanacković-Vukmanović, M. S. Dimitrijević, E. Simonneau: *Karakteristike prenosa zračenja u pražnjenjima visokog pritiska koja se koriste u svetlosnim izvorima*, Zbornik radova sa 29. Simpozijuma "Etan u pomorstvu", Zadar, (1987), 282–284.

O. Atanacković-Vukmanović, E. Simonneau: *An approximative solution in the frame of kinetic non-LTE approach of Lyman alpha line transfer in chromospheric conditions*, II Workshop "Astrophysics in Yugoslavia", Beograd, (1987), 21–22.

O. Atanacković, J. Borsenberger, J. Oxenius, E. Simonneau: *Resonance line transfer and transport of excited atoms — III. Self-consistent solutions (2)*, J. Quant. Spectrosc. Radiat. Transfer **38** (1987), 427–446.

In this last part of our study on non-LTE line transfer with convective transport of excited atoms, we present self-consistent solutions of the radiative transfer equation and the kinetic equation of the excited two-level atoms when the excited atoms undergo elastic velocity-changing collisions. We assume pure Doppler broadening of the spectral line and investigate reflecting and destroying boundaries for the excited atoms. Concerning elastic collisions of the excited atoms, our study covers all cases, from a collisionless gas (free particle streaming) discussed in Part II of this series of papers, to a collision — dominated gas with the limiting case of complete redistribution. We present arguments that the streaming pattern of the gas of excited atoms does not depend critically on the shape of the line profile. Therefore, our results for a pure Doppler profile may also be used for other line profiles (Voigt, Lorentz) in a first approximation, at least when the streaming parameter η is not too large.

O. Atanacković: *Non-LTE radiative transfer*, Bull. Obs. Astron. Belgrade **140** (1989), 127–130.

A brief review is given of some basic points in the development of non-LTE radiative transfer theory along with some remarks concerning the activity in this field at Belgrade Observatory.

E. Simonneau, O. Atanacković-Vukmanović: *Iteration factors in the solution of the NLTE line transfer problem*, in: Stellar atmospheres: Beyond classical models, NATO Advanced Research Workshop, Trieste, (1990); Pré-publication No. 333 (1990), Institut d'Astrophysique de Paris.

11.2. Spectral Line Shapes in Astrophysics and Plasma Physics
11.2. Profili spektralnih linija u astrofizici i fizici plazme

M. Dimitrijević: *Stark broadening and its astrophysical applications*, XI Int. School for Young Astronomers, Hvar, (1980), 22.

M. Dimitrijević, N. Konjević: *Modified semiempirical formula for the electron-impact width of ionized atom lines*, V. Int. Conf. on Spectral Line Shapes, Berlin, (1980), Program and Abstracts 53.

N. Konjević, M. S. Dimitrijević: *On the systematic trends of Stark broadening parameters of isolated ion lines*, V Int. Conf. on Spectral Line Shapes, Berlin, (1980), Program and Abstracts 55.

M. S. Dimitrijević, N. Konjević: *Uticaj oblika spektralne linije na interakciju zračenja sa plazmom*, 22 ETAN u pomorstvu, Zadar, (1980), Vol. 2, 365.

M. Dimitrijević, N. Konjević: *Semiempirical Stark line widths of alkali like ions*, X SPIG, Dubrovnik, (1980), 204.

M. S. Dimitrijević, N. Konjević: *Stark broadening of NII, NIII and NIV lines*, V ESCAMPIG, Dubrovnik, (1980), 88.

M. S. Dimitrijević, D. P. Grubor: *Stark line widths of some lithium isoelectronic sequence ions*, V ESCAMPIG, Dubrovnik, (1980), 89.

M. S. Dimitrijević: *Semiclassical calculations of the Stark widths of CIII and CIV*, V ESCAMPIG, Dubrovnik, (1980), 90.

M. S. Dimitrijević, N. Konjević: *Stark widths of doubly-and triply-ionized atom lines*, J. Quant. Spectrosc. Radiat. Transfer **24** (1980), 451–459.

In this paper, we report modifications of well known semiempirical and semiclassical approximation formulas for Stark line-width calculations. Comparisons with experiments for doubly ionized atoms yield, as an average ratio of measured to calculated widths 1.06 ± 0.31 for a modified semiempirical formula and 0.96 ± 0.24 for a modified semiclassical formula. For triply ionized atoms these ratios are 0.91 ± 0.42 and 1.08 ± 0.41, respectively. Comparison with other theoretical calculations have also been made.

M. S. Dimitrijević and N. Konjević: *Semiempirical Stark linewidths of alkali like ions*, Astron. Astrophys. **102** (1981), 93.

In this paper we have tested the applicability of modified semi-empirical formula with newly proposed Gaunt factors for evaluation of Stark linewidths of alkali like ions. The comparison with experiments and other, already tested theoretical approaches indicates that these new Gaunt factors can be used successfully for Stark linewidth calculations.

M. S. Dimitrijević and N. Konjević: *On the Stark broadening of ionized nitrogen lines*, J. Quant. Spectrosc. Radiat. Transfer **25** (1981), 387.

In this paper, we report an analysis of the experimental procedure and results obtained in a recently published paper on the Stark broadening of singly, doubly-, and triply-ionized nitrogen lines. The results of this analysis indicate that the influence of self-absorption on the line profiles is not taken into account properly and that therefore the results of Ref. 6 cannot be applied with confidence. Comparison of experimental results with numerous theoretical calculations have also been performed.

M. S. Dimitrijević, N. Feautrier and S. Sahal-Bréchot: *Comparison between quantum and semiclassical calculations of the electron impact broadening of the Li I resonance line*, J. Phys. B: At. Mol. Phys. **14** (1981), 2559.

We present quantum mechanical calculations of Stark broadening parameters for the Li I $2s^2S$-$2p^2P$ line. Semiclassical calculations have also been performed and both have been compared with other available results. A detailed analysis of Stark broadening parameters as functions of the impact electron angular momentum quantum number and of the temperature is carried out. The influence of the polarisation potential and of the completeness of the set of energy levels on the Stark broadening parameters is investigated. The low temperature behaviour of the half width is discussed too.

N. Konjević, M. S. Dimitrijević: *Širenje spektralnih linija u plazmi*, Savremena istraživanja u fizici, redaktor V. Urošević, Institut za fiziku i Naučna knjiga, Beograd, (1981), 191.

M. S. Dimitrijević, N. Konjević: *Modified semiempirical formula for the electron-impact width of ionized atom lines*, in: Spectral line shapes, ed. B. Wende, Walter de Gruyter, Berlin, (1981), 211.

N. Konjević, M. S. Dimitrijević: *On the systematic trends of Stark broadening parameters of isolated lines in plasmas*, in: Spectral line shapes, ed. B. Wende, Walter de Gruyter, Berlin, (1981), 241.

M. S. Dimitrijević, D. P. Grubor, N. Konjević: *Electron impact broadening of multiply charged ion lines*, 2 Colloque sur l'influence des processus collisionnels sur le profil des raies spectrales, Orleans, (1981), 9.

M. S. Dimitrijević, N. Feautrier, S. Sahal-Bréchot: *Quantum and semiclassical Stark width calculation for the Li I resonance line*, 2 Colloque sur l'influence des processus collisionnels sur le profil des raies spectrales, Orleans, (1981), 8.

M. S. Dimitrijević: *Electron impact broadened line widths in a supermultiplet*, IECAP, Heidelberg, (1981), 529.

M. S. Dimitrijević: *Štarkovo širenje jonskih linija u sudarnoj aproksimaciji*, II Jugoslovenski seminar o fizici atomskih sudara, Stubičke Toplice, (1981).

M. S. Dimitrijević: *Stark broadening of some OIII lines*, Proc. IV Nat. Conf. Yug. Astronomers, Sarajevo, Publ. of the Astronomical Observatory of Sarajevo **1**, Sarajevo, (1981), 215.

M. S. Dimitrijević: *Similarities of Stark line widths within a given spectrum and irregular energy level structure*, Hvar. Obs. Bull. **6** (1982), 185.

M. S. Dimitrijević: *Stark broadening of non hydrogenic ion lines within the impact approximation*, in: The Physics of Ionized Gases, Ed. G. Pichler, Institute of Physics of the University, Zagreb, (1982), 397.

In this talk various methods for Stark broadening parameter estimation will be examined and their limitations will be discussed. This will be done on the basis of comparison with experimental data for singly, doubly and triply ionized atoms.

M. S. Dimitrijević, N. Feautrier, S. Sahal-Bréchot: *Influence of different kinds of collisions on the Stark broadening of the Li I resonance line*, XI SPIG, Dubrovnik, (1982), 277.

M. Dimitrijević, M. Cornille, N. Feautrier, S. Sahal-Bréchot: *Resonant scattering (autoionization) contributions to Stark broadening of ion lines*, XI SPIG, Dubrovnik, (1982), 281.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening parametres for infrared lines of He I*, 6th Conf. on Spectral Line Shapes, Boulder, (1982), 281.

N. Konjević, M. S. Dimitrijević: *On the Stark broadening of non-hydrogenic spectral lines of heavy elements in plasmas*, 6th Conf. on Spectral Line Shapes, Boulder, (1982), 23.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of the He I resonance lines*, XI SPIG, Dubrovnik, (1982), 273.

M. S. Dimitrijević: *On the variation of Stark line widths within a supermultiplet*, Astron. Astrophys. **112** (1982), 231.

In order to find out if similarities among Stark broadening parameters within a supermultiplet are apparent to such a degree that accurate interpolation of new data and critical evaluation of experimental results are possible, the exceptions to this rule in the available theoretical data have been analysed and reasons for such situations have been discussed. The reasons may be divided into two categories: (i) irregular atomic energy level structure and (ii) inadequacy of the used model of the emitter structure. For the O II 3s-3p quartets, semi-classical calculations for Stark broadening parameters have been performed taking into account the emitter structure properly.

M. S. Dimitrijević: *Stark broadening of heavy ion solar lines*, in: Sun and Planetary System, eds. W. Fricke and G. Teleki, Astrophysics and Space Science Library **96**, D. Reidel PC, Dordrecht, (1982), 101.

M. S. Dimitrijević and N. Konjević: *Semiclassical calculations of electron impact Stark widths of S(III), Cl(III) and S(IV) isolated lines*, J. Quant. Spectrosc. Radiat. Transfer **27** (1982), 65.

In this paper we report results of semiclassical calculations of electron impact Stark widths of doubly-ionized sulfur and chlorine and of triply-ionized sulfur. Comparison with available experimental data yields an average ratio of measured to calculated line widths of 0.73 and 0.74 for S(III) and Cl(III), respectively, and of 0.50 for a single S(IV) line.

M. Dimitrijević: *Stark broadening of heavy solar lines*, VI ERMA, Dubrovnik, (1982), 32.

M. S. Dimitrijević, N. Konjević: *On the Stark broadening of heavy non-hydrogenic neutral atom lines in plasmas*, Int. Conf. on Plasma Physics, Göteborg, (1982), 343.

M. Dimitrijević, A. Mihajlov: *Istraživanje oblika kalijumovih linija u pražnjenjima srednjeg i visokog pritiska*, 25. ETAN u pomorstvu (1983), 530.

M. Dimitrijević, M. Cornille, J. Dubau, N. Feautrier, S. Sahal: *Diagnostic spectroscopique des plasmas denses: contribution des resonances d'autoionisation a l'élargissement Stark des raies emises par des ions*, Collisions et Rayonnement, Orleans, (1983), P27.

M. S. Dimitrijević, S. Sahal-Bréchot: *L'élargissement Stark des raies de l'helium neutre*, Collisions et Rayonnement, Orleans, (1983), P26.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening parameters for He II infrared lines*, in: Spectral Line Shapes, Vol. 2, ed. K. Burnett, Walter de Gruyter Co., Berlin-New York, (1983), 103.

N. Konjević, M. S. Dimitrijević: *On the Stark broadening of non-hydrogenic lines of heavy elements in plasmas*, Vol. 2, ed. in: Spectral line shapes, K. Burnet, Walter de Gruyter Co., Berlin – New York, (1983).

I. Vince, M. S. Dimitrijević: *Doprinos limb-efektu raznih mehanizama širenja spektralnih linija u seriji Na I* ($4s^2S - np^2P$), VI Nac. Konf. Astr. Jugoslavije, Hvar, (1983), 123.

M. S. Dimitrijević: *Astrofizičke primene izučavanja profila spektralnih linija*, VI Nac. Konf. Astr. Jugoslavije, Hvar, (1983), 13.

I. Vince: *On the telluric lines position instability*, Bull. Obs. Astron. Belgrade **133** (1983), 5–15.

On the ground of the observational data as well as the measurements of the relative positions of the telluric lines in the solar spectrum it has been established that these lines have an unstable position. To a position change during

a day corresponds a Doppler velocity of $100\,\mathrm{m\,s^{-1}}$. The existence is pointed out of the diurnal position variations of the telluric lines and there is some indication of the diurnal variation being superimposed by some long-periodical or irregular changes. The aerological factors are found to contribute to the position instability of the telluric lines, while the instabilities of the position differences of the investigated spectral lines of water vapor and molecular oxygen can practically completely be accounted for by the convective motion of air masses. The possibility of the position instability of telluric lines being only a consequence of the instrumental errors has also been examined.

M. S. Dimitrijević, N. Konjević: *Stark broadening of isolated spectral lines of heavy elements in plasmas*, J. Quant. Spectrosc. Radiat. Transfer **30** (1983), 45.

In this paper we present results of semiclassical calculations of Stark broadening parameters for some lines of heavy neutral atoms. Comparisons with experiment show large discrepancies previously undetected for lighter elements. Critical evaluation of experimental data indicate that in most cases the experiment must be blamed for these discrepancies.

M. S. Dimitrijević, N. Feautrier and S. Sahal-Bréchot: *Influence of different collisional processes on the Stark broadening*, Fizika **15** (1983), 205.

Using a semiclassical formalism, elastic, inelastic and strong collision's contributions to the electron impact width of the Li I ($2s^2S-2p^2P^0$; $\lambda = 670.78\,\mathrm{nm}$) resonance line have been computed for different angular momenta of the incoming perturbing electron and for $T = 2500$, 10000 and 20000 K. On the basis of the obtained results, the relative importance of elastic, inelastic and strong collision's contributions to the line width are discussed.

M. S. Dimitrijević: *Stark broadening of Si II and Si III spectral lines*, Astron. Astrophys. **127** (1983), 68.

Modified semiempirical and approximative semiclssical methods have been used for the calculation of recently measured Si II and Si III Strk line widths in order to test both methods, as well as the new experimental data (Kusch and Schröder, 1982).

V. Vujnović, Č. Vadla, V. Lokner and M. S. Dimitrijević: *Half-widths of neutral fluorine spectral lines*, Astron. Astrophys. **123** (1983), 249.

The profiles of 29 fluorine spectral lines from seven transitions, emitted by a wall-stabilized arc, were measured and the electron impact broadening half-widths of the transitions were calculated using the semiclassical perturbation appoach. The plasma conditions were given by $T = 14.000\,\mathrm{K}$ and $N_e = 10^{23}\,\mathrm{m^{-3}}$. A close agreement between the experimental results and the calculations was found, depending on the calibration of the electron concentration and on the evaluation approach.

M. S. Dimitrijević, N. Konjević: *On the dependence of Stark width and shift on the ionization potential*, Z. Naturforsch **39a** (1984), 553.

The simple relations between the Stark broadening parameters and the ionization potential derived by Purić et al. are discussed, and attention is drawn to the serious limitations for their application. The periodic dependence of the Stark width and shift on nuclear charge number obtained by the same authors is also explained.

N. Konjević, M. S. Dimitrijević and W. L. Wiese: *Experimental Stark widths and shifts for spectral lines of neutral atoms (a Critical Review of selected Data for the Period 1976 to 1982)*, J. Phys. Chem. Ref. Data **13** (1984), 619.

A critical review of all experimental data on Stark widths and shifts of spectral lines of neutral elements published during the period 1976–1982 has been carried out. This work represents an extension and update of an earlier review which covered the period before 1976. Data tables containing the selected experimental Stark broadening parameters are presented together with estimated accuracies. Comparisons with comprehensive calculations based on the semiclassical theory are made whenever possible.

N. Konjević, M. S. Dimitrijević and W. L. Wiese: *Experimental Stark widths and shifts for spectral lines of positive ions (a Critical Review and Tabulation of Selected Data for the Period 1976 to 1982)*, J. Phys. Chem. Ref. Data **13** (1984), 649.

A new critical review of the available experimental data on the Stark widths and shifts for lines of non-hydrogenic ionized spectra has been carried out which covers the period from 1976 to the present and represents a continuation of an earlier critical review. The relevant literature, compiled by the NBS Data Center on Atomic Lines Shapes and Shifts as well as by the present authors, was critically evaluated, and data tables containing the selected experimental Stark broadening parameters have been assembled. The data are arranged according to spectra and elements and these are presented in alphabetical order. The accuracy of the experimental data is estimated on the basis of guidelines developed during the previous review. Comparisons with theoretical results are made whenever possible since the comparison with theory has often been a principal motivation for the experiments.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of neutral helium lines*, J. Quant, Spectrosc. Radiat. Transfer **31** (1984), 301.

Using a semiclassical approach for the Stark broadening of atomic linea, we have calculated electron and proton impact line widths and shifts of 56 neutral He lines in the ultraviolet, visible and i.r. region of the spectrum. The comprehensive set of results obtained is used for investigation of Stark-broadening parameter regularities within the spectral series.

M. S. Dimitrijević: *Electron impact line widths of the resonance lines of Be-like ions*, Astron. Astrophys. **131** (1984), 327.

Analytical expressions recently obtained for the collisions strengths of reso-

nant transitions of Be-like ions are used for the calculation of Stark broadening parameters.

M. S. Dimitrijević: *The trajectory effect in calculations of the phaseshift for binary collisions and broadening of neutral atom lines*, J. Phys. B: At. Mol. Phys. **17** (1984), L283.

The trajectory effect for $C_n r^{-n}$ ($n = 2, 3$ and 4) potential is estimated and compared with the results obtained according to the approximate method of Valee et al. based on the use of effective rectilinear trajectories.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of neutral helium lines of astrophysical interest. Regularities within spectral series*, Astron. Astrophys. **136** (1984), 289.

Following our earlier work, and using a semiclassical perturbation formalism for the Stark broadening of atomic lines, we have calculated electron and proton impact line widths and shifts of 36 neutral He lines. Stark broadening parameters were calcualted for lines originating from upper energy levels with 4 to 10, and for an electron density of $10^{13}\,\mathrm{cm}^{-3}$. The comprehensive set of results obtained is used for the investigation of line-broadening parameter regularities within the spectral series.

M. S. Dimitrijević, S. Sahal-Bréchot: *Semiclassical calculation of the He I Stark broadening parameters*, XVI ICPIG, Düsseldorf (1983), 630.

M. S. Dimitrijević, S. Sahal-Bréchot: *Approximative electron and proton-impact line widths within a spectral series*, XVI ICPIG, Düsseldorf, (1983), 628.

M. S. Dimitrijević, S. Sahal-Bréchot: *Élargissement des raies spectrales par collisions avec les électrons et les protons: Formule asymptotique de la largeur lorsque le nombre quantique principal augmente*, Collisions et Rayonnement, Orleans (1983) p. 25.

M. S. Dimitrijević: *The trajectory effect and broadening of neutral atom lines*, XIIth SPIG, Šibenik (1984), 465.

I. Vince, M. S. Dimitrijević, V. Kršljanin: *Collisional broadening and solar limb effect: Na I $3p^2P^0 - ns^2S$ lines*, 7th Conf. on Spectral Line Shapes, Aussois (1984), F4.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of He I lines of astrophysical interest: Regularities within spectral series and influence of Debye shielding*, 7th Conf. on Spectral Line Shapes, Aussois (1984), A10.

M. Dimitrijević, N. Konjević: *Elektronnoe ushirenije spektral'nykh linij ionizirovannykh atomov*, Fotoprocessy, vozbuzhdeniya i jonizacii, Leningrad, (1984), 41.

M. Dimitrijević, N. Konjević: *O Shtarkovskom ushirenii linij nejtral'nykh atomov rubidiya, kadmiya i cinka*, Fotoprocessy, vozbuzhdeniya i jonizacii, Leningrad, (1984), 47.

M. S. Dimitrijević: *Dependence of Stark widths and shifts on the ionization potential: $np^{k-1}(n+1)s - np^4$ resonance transitions*, Astron. Astrophys. **145** (1985), 439–442.

Simple relations between the Stark broadening parameters and the ionization potential are derived for $np^{k-1}(n+1)s - np^4$ resonance transitions of singly ionized emitters, using the semiclassical approach. The relations obtained are compared with those derived by Purić et al. (1980).

M. S. Dimitrijević, N. Konjević: *A simple formula for estimating Stark broadening parameters of neutral atom lines*, Collisions et Rayonnement, Orleans, (1985), 21.

S. Jankov: *Instrumental profile of the Belgrade solar spectrograph*, Bull. Obs. Astron. Belgrade **135** (1985), 25.

The instrumental profile of the Belgrade solar spectrograph is determined using the O_2 telluric lines. The Fourier transform method is applied. A procedure of simultaneous use of several calibration curves has been developed for minimizing the errors, occasioned by the photographic calibration. The telluric line absorption coefficient is approximated by Voigt function. A procedure of normalisation of the natural profile, suitable for computer processing, has been developed. The actual resolving power of the spectrograph is 106 780 and 134 040 in the 4th and 5th order spectrum, which makes about 37% of its theoretical value.

M. S. Dimitrijević, S. Sahal-Bréchot: *Comparison of measured and calculated Stark broadening parameters for neutral-helium lines*, Physical Review A, **31** (1985), 316.

Stark broadening parameters for neutral helium lines obtained using a semiclassical pertubation formalism are compared with critically selected experimental data. Our data are also compared with the results of Benett and Griem as well as with the semiclassical convergent calculations of Bassalo, Cattani, and Walder.

I. Vince, M. S. Dimitrijević: *Influence of different line broadening mechanisms on the limb-effect within Na I ($4s^2S - np^2P^0$) series*, Publ. Obs. Astron. Belgrade **33** (1985), 15.

M. S. Dimitrijević: *Astrophysical significance of spectral line shapes investigation*, Publ. Obs. Astron. Belgrade **33** (1985), 11.

M. S. Dimitrijević, V. Kršljanin: *Semiempirical Stark shifts of ion lines*, XVII ICPIG, Budapest, (1985), 975.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of Na I lines: Regularities within a spectral series*, XVII ICPIG, Budapest, (1985), 978.

M. S. Dimitrijević, Truong-Bach: *Sur l'inégalite des largeurs Stark a l'interieur d'un multiplet ou supermultiplet de l'argon*, Collisions et Rayonnement, Orleans 1985, P 23.

V. Kršljanin, I. Vince: *Zastupljenost natrijuma u sunčevoj atmosferi*, VIII Congress of the Mathematicians, Physicists and Astronomers of Yugoslavia, ed. Dj. Teleki, SDMFAJ, Priština, (1985), 340.

I. Vince, V. Kršljanin: *Uticaj sudarnih procesa na limb efekt u pegama: linija Na I* $3p^2P^0 - 6s^2S$, VIII Congress of the Mathematicians, Physicists and Astronomers of Yugoslavia, ed. Dj. Teleki, SDMFAJ, Priština, (1985), 341.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of neutral sodium lines*, J. Quant. Spectrosc. Radial. Transfer **34** (1985), 149–161.

A semiclassical apporach has been used to evaluate. Stark broadening of atomic lines and also electron-and proton-impact line widths and shifs of 30 neutral sodium lines. The results are used to investigate Stark broadening-parameter regularities within the spectral series.

I. Vince, M. S. Dimitrijević, V. Kršljanin: *Pressure broadening and solar limb effect*, J. E. Beckman and L. Crivellari (eds.), Progres in Stellar Spectral Line Formation Theory (1985), 373–380.

The pressure broadening contribution to the solar limb effect has been discussed for the case of a spectral series using Na I 3p-ns and 4p-ns series as an exemple. We have found that the influence of the pressure broadening on the solar limb effect is reduced due to different signs of hydrogen and electron impact shifts in the case considered. We have discussed also the behaviour of pressure broadening contribution to the solar limb effect within a spectral series and we have compared our results with simple radial-current theory predictions.

M. S. Dimitrijević: *Electron impact broadening dependence on the ionization potential:* $np^{k-1}(n+1)s - np^k$ *resonance transitions*, II ECAMP, Amsterdam, (1985), 206.

M. S. Dimitrijević, S. Sahal-Bréchot: *L'élargissement Stark des raies du potassium neutre*, Collisions et Rayonnement, Orleans, (1985), P 22.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of He I lines of astrophysical interest: Regularities within spectral series and influence of Debye shielding*, Spectral Line Shapes III, W. de Gruyter, Berlin – New York, (1985), 53.

I. Vince, M. S. Dimitrijević, V. Kršljanin: *Collision broadening and solar limb effect: Na I* $3p^2P^0 - ns^2S$ *lines*, Spectral Line Shapes III, W. de Gruyter, Berlin – New York, (1985), 649.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical approach as a source for Stark broadening data in astrophysics: Li-like lines in stellar atmospheres*, Coll.

on Atomic Spectra and Oscillator Strengths for Astrophysics and Fusion Research, Toledo, (1986), 84.

M. S. Dimitrijević: *On the Stark broadening within a F I transition array*, Astron. Astrophys. Suppl. Ser. **64** (1986), 591–594.

Using a semiclassical formalism, electron impact widths and shifts within 3s-3p transition array of F I have been computed. A detailed analysis of Stark broadening parameters as functions of the impact electron angular momentum quantum number and the temperature is carried out. On the basis of the results obtained, the differences between the contribution of elastic, inelastic and strong collisions to the line widths within a transition array are discussed, as well as the Stark shift and width behaviour of the various components.

I. Vince, M. S. Dimitrijević: *Influence of spectral lines pressure shift on the convective layer diagnostic*, XIII SPIG, Šibenik, (1986), 325.

M. S. Dimitrijević, S. Sahal-Bréchot: *L'élargissement Stark des raies du potassium neutre*, Annales de Physique, Coll. No. 3, Suppl. au No. 3, Vol. 11 (1986), 181.

Nous avons calculé les largeurs et les déplacements de 50 raies spectrales de K I, dus aux collisions avec les électrons, les protons et Ar II, dans l'approximations des impacts. Les resultats obtenus sont utilisé pour étudier les comportements des parametres d'élargissement dans une série spectrale.

M. S. Dimitrijević, N. Konjević: *Simple formulae for estimating Stark broadening parameters of neutral atom lines*, Annales de Physique, Coll. No. 3, Suppl. au No. 3, Vol. 11 (1986), 197.

Simples formulae for estimating Stark width and shift of neutral atom lines are presented.

M. S. Dimitrijević, Truong-Bach: *Sur l'inégalité des largeurs Stark a l'intérieur d'un multiplet ou supermultiplet de l'argon II*, Annales de Physique, Coll. No. 3, Suppl. au No. 3, Vol. 11 (1986), 183.

Les paramètres Stark de divers composants à l'intérieur du multiplet $4s^2P - 4p'^2P$ et du supermultiplet $4p-4d$ ($^2P-^2P$, $^2P-^2D$, $^2D-^2D$) de l'Argon II sont calculés suivant un formalisme semi-classique. La possibilité de difference entre ces largeurs ou déplacements est discutée en fonction de l'effet d'écran Debye et des irrégularités dans le diagramme des nivaux d'énergie.

M. S. Dimitrijević, Truong-Bach: *On the Stark broadening of singly ionized argon lines*, Z. Naturforsch. **41a** (1986), 772–776.

Using a semi-classical formalism which includes Debye shielding, Stark broadening parameters of various components within the $4s^2P - 4p'^2P^0$ multiplet and the $4p - 4d$ ($^2P^0 - ^2P$, $^2D^0 - ^2P$, $^2D^0 - ^2D$) supermutiplet of Ar II are computed. We show that when various components of a multiplet (supermultiplet or transition array) are broadened inequally by an embedded close-lying

perturbing level, use of a perturber parameter cut-off at the Debye length can restrain the calculated differences between Stark widths within the multiplet.

M. S. Dimitrijević, V. Kršljanin: *Electron-impact shifts of ion lines: modified semiempirical approach*, Astron. Astrophys. **165** (1986), 269–274.

A simple method for calculation of ion line shifts produced by electron impacts, based on the modified (Dimitrijević and Konjević, 1980) semiempirical (Griem, 1968) approach is presented. Obtained relations have been applied to a number of Be II, Mg II, Al II, Ar II and Ca II lines and the results are compared with semiclassical and semiempirical values as well as with critically selected experiments.

M. S. Dimitrijević, N. Konjević: *Simple formulae for estimating Stark widths and shifts of neutral atom lines*, Astron. Astrophys. **163** (1986), 297–300.

Formulae for estimating Stark widths and shifts of neutral atom lines, based on the simple method of Freudenstein and Cooper and the GBKO semiclassical theory, are presented. For the calculations, most of the available personal computers are sufficient. Obtained formulae have been applied to He I and Mg I lines and results are compared with calculations of Benett and Griem and values obtained according to the method of Freudenstein and Cooper.

M. S. Dimitrijević, V. Kršljanin: *Modified semiempirical estimates of ion lines Stark shifts: spectra of hot DA white dwarfs*, XIII SPIG, Šibenik, (1986), 321.

M. S. Dimitrijević, M. C. Artru: *Stark broadening of Ga II and Ga III spectral lines*, XIII SPIG, Šibenik, (1986), 317.

M. S. Dimitrijević, N. Konjević: *Ion line Stark broadening in stellar plasmas*, XIII SPIG, Šibenik, (1986), 313.

M. S. Dimitrijević, N. Feautrier, S. Sahal-Bréchot: *Resonance structures in electron scattering cross sections and Stark broadening*, XIII SPIG, Šibenik, (1986), 303.

B. Grabowski, M. S. Dimitrijević: *Trajectory effects on the phase shift in the impact approximation*, XIII SPIG, Šibenik, (1986), 299.

M. S. Dimitrijević, A. A. Mihajlov, M. Popović: *On the electron-impact broadening for the resonance lines of the alkalis*, VIII ESCAMPIG, Greifswald, (1986), 89.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of KI: Regularities within spectral series*, VIII ICSLS, Williamsburg, (1986), A10.

M. S. Dimitrijević, N. Konjević, V. Kršljanin: *Modified semiempirical estimates of ion lines Stark broadening: I Theory*, VIII ICSLS, Williamsburg, (1986), A11.

M. S. Dimitrijević, N. Konjević, V. Kršljanin: *Modified semiempirical estimates of ion line Stark broadening: II Application*, VIII ICSLS, Williamsburg, (1986), A12.

A. Kubičela, I. Vince, M. S. Dimitrijević, R. Dümmler: *Differential Fe I limb effect around $\lambda = 630.2\,nm$*, VIII ICSLS, Williamsburg, (1986), DA1.

I. Vince, M. S. Dimitrijević: *Solar spectral line asymmetries and pressure broadening*, VIII ICSLS, Williamsburg, (1986), DA2.

M. S. Dimitrijević: *Stark broadening of spectral lines in the spectrum of Am 15 Vulpeculae*, IAU Colloq. No. **94**, Physics of Formation of Fe II Lines Outside LTE, ed. R. Viotti, Capri, (1986), 47.

S. Jankov: *Restauration des spectrogrammes astronomiques en application de la fonction de filtration selon Wiener dans les conditions du manque d'information a priori sur l'objet de recherche*, Master Science Thesis, Univ. Beograd, (1986) (in serbocr.).

I. Vince: *Uticaj sudarnih procesa na limb-efekt (Influence of Collisional Proceses on the Limb-effect)*, doktorska disertacija, (Ph. D. Thesis), Univ. Beograd, (1986).

I. Vince: *A részecskeütközések hatása a nap- és a csillagkonvekció diagnosztikájára*, Magyarok szerepe a világ természettudományos és müszaki haladásában (eds. Fodor O., Nagy F., Stefkoné Vermes J.), Budapest, (1986), 897.

V. Kršljanin, I. Vince: *Collision broadening and microturbulence sensitivity of some Na I non-resonant lines*, Bull. Obs. Astron. Belgrade **136** (1986), 12–19.

Profiles of six weak and moderate weak Na I lines in the centre and on the limb of the solar disk have been synthetized using the Smirnov-Roueff potential. The sensitivity has quantitatively been examined of a variety of parameters of the spectal line profiles (equivalent width, central intensity, half-width and line shape parameter) to microturbulent velocity variations. The results are displayed both numerically and graphically. Inadequate knowledge of the collision broadening can lead to the value of the microturbulence velocity, obtained from these spectral lines being significantly distorted.

V. Kršljanin: *Štarkov pomak jonskih linija kod toplih zvezda*, M. Sc. Thesis, Faculty of Sciences, Belgrade University, (1986), 1–151.

J. Arsenijević, M. Karabin, A. Kubičela, I. Vince: *Beginning of a study of long-term changes of selected Fraunhofer spectral lines*, Abstracts, II Workshop, Astrophysics in Yugoslavia, Beograd, Ed. M. Dimitrijević, 31, (1987).

J. Arsenijević, M. Karabin, A. Kubičela, I. Vince: *A Belgrade program for monitoring of activity-sensitive spectral lines of the Sun as a star*, Abstracts, Fifth Europ. Meeting on Solar Phys., Solar and Stellar Physics, Titisee, FRG, (1987), P5.

M. S. Dimitrijević, G. Peach: *Regularities in line widths due to neutral nonresonant collisions*, in: Radiative Excitation and Ionization Processes, ed. V. Vujnović, Institute of Physics, Zagreb, (1987), 19.

M. S. Dimitrijević, V. Kršljanin: *An aproximate method for electron impact shift calculation*, in: Radiative Excitation and Ionization Processes, ed. V. Vujnović, Institute of physics, Zagreb, (1988), 22–25.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of highly excited C IV lines*, in: Radiative Excitation and Ionization Processes, ed. V. Vujnović (Proc. of lectures given at a seminar held in Zagreb), Institute of Physics, Zagreb, (1987), 76.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of K I: Regularities within spectral series*, in: Spectral Line Shapes, Vol. 4, ed. R. J. Exton, A. Deepak Publ., Hampton, Virginia, (1987), 61.

S. Jankov: *Imagerie indirecte des étoiles à partir des obsérvations spéctroscopiques et photométriques*, DEA Astrophysique et Tehniques Spatiales, Université Paris VII (1987).

I. Vince, M. S. Dimitrijević: *Solar spectral line asymmetries and pressure broadening*, in: Spectral Line Shapes, Vol. 4, ed. R. J. Exton, Deepak Publ., Hampton, Virginia, USA, (1987), 621.

It is confirmed that the convection is the major cause of solar line asymmetries and wavelength shifts. However, the influence of pressure broadening on solar line shapes must be taken into account in some cases. E.g. convective motions of solar granulation are manifested in the spatially unresolved spectrum as slight asymmetries and wavelength shifts of photospheric spectral lines. For the investigation of this effect the line bisectors (medians), i.e. the loci of points midway between equal-intensity points on either side of the line are commonly usedi. Consequently, it is important to know the influence of pressure broadening on the bisector shape formation. Here, we investigate the influence of collisional processes on solar Na I 616.1 nm line bisector. Our results are compared also with observational data. We calculated line bisectors for different positions on the solar disk by solving the radiative transfer equation using HSRA solar atmosohera model. Shift produced by absorber-neutral atom collisions is calculated using Smirnof-Roueff exchange potential. For Stark broadening contribution semiclassical data are used.

M. S. Dimitrijević, A. A. Mihajlov, and M. M. Popović: *Stark broadening trends along homologous sequences*, Astron. Astrophys. Suppl. Ser. **70** (1987), 57–61.

Using a semiclassical formalism, a detailed analysis of Stark broadening parameters as a function of the impact electron angular momentum quantum number and the temperature is caried out for resonance lines of the alkalis. On the basis of the results obtained, the differences between the contribution of elastic, inelasstic and strong collisions to the line widths for analogous transitions in homologous atoms are discussed.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of neutral potassium lines*, J. Quant. Spectrosc. Radiat. Transfer **38** (1987), 37–45.

Using a semiclassical approach, we have calculated electron-proton and Ar II impact line widths and shifts of 50 neutral potassium lines. The compre-

hensive set of results obtained is used for investigation of Strak-broadening-parameter regularities within the spectral series.

M. S. Dimitrijević, N. Konjević: *Simple estimates for Stark broadening of ion lines in stellar plasmas*, Astron. Astrophys. **172** (1987), 345–349.

Simple analytical expressions for estimation of Stark widths and shifts of ionized atom lines have been derived from the low temperature limit of a modified semiempirical formula.

A. Kubičela, I. Vince, M. S. Dimitrijević, R. Dümmler: *Differential Fe I limb effect around* $\lambda = 630.2\,nm$, in: Spectral Line Shapes, Vol. 4, ed. R. J. Exton, Deepak Publ., Hampton, Virginia, USA, (1987), 619.

For heliocentric angles up to 52° a relative limb effect of Fe I 630.15 nm and 630.25 nm, amounting to $50\,m\,s^{-1}$ has been found. The differential pressure broadening shifts have been estimated as negligible. The observed differential limb effect is probably caused by some unresolved photospheric velocities.

M. S. Dimitrijević, N. Feautrier, S. Sahal-Bréchot: *On neutral oxygen lines formation in* γ *Cas*, II Workshop: Astrophysics in Yugoslavia, Beograd, (1987), 39.

Y. Vitel, M. Skowronek, M. S. Dimitrijević, M. M. Popović: *Electron-impact broadening along homologous sequences of noble gases*, II Workshop: Astrophysics in Yugoslavia, Beograd, (1987), 15.

I. Vince, M. S. Dimitrijević: *On the C IV line profiles in the white dwarfs*, II Workshop: Astrophysics in Yugoslavia, Beograd, (1987), 5.

T. Lanz, M. S. Dimitrijević, M.-C. Artru: *Influence of Stark broadening on equivalent widths of Si II visible lines in stellar atmospheres*, II Workshop: Astrophysics in Yugoslavia, Beograd, (1987), 33.

I. Vince, M. S. Dimitrijević: *Uticaj sudarnih procesa na profile linija natrijuma u sunčevim i zvezdanim spektrima*, V Jug. skup iz fizike atomskih sudara, Kopaonik, (1987), G1.

M. S. Dimitrijević: *Mehanizam formiranja linija neutralnog kiseonika u zvezdanim omotačima*, V Jug. skup iz fizike atomskih sudara, Kopaonik, (1987), G2.

M. S. Dimitrijević, N. Feautrier, S. Sahal-Bréchot: *On lines formation in stellar envelopes*, VII Gen. Conf. European Phys. Soc. "Trends in Physics", Helsinki, (1987), 165.

M. S. Dimitrijević, S. Sahal-Bréchot: *On the Stark broadening of C IV lines*, VII Gen. Conf. European Phys. Soc. "Trends in Physics", Helsinki 1987, 171.

M. S. Dimitrijević, N. Konjević, V. Kršljanin: *Modified semiempirical estimates of ion lines Stark broadening, I. Theory*, in: Spectral Line Shapes, Vol. 4, ed. R. J. Exton, A. Deepak Publ., Hampton, Virginia, (1987), 63.

M. S. Dimitrijević, N. Konjević, V. Kršljanin: *Modified semiemprical estimates of ion lines Stark broadening II. Application*, in: Spectral Line Shapes, Vol. 4, ed. R. J. Exton, A. Deepak Publ., Hampton, Virginia, (1987), 65.

I. Vince, M. S. Dimitrijević: *Influence of non-resonant collisions with neutral atom on the Na I lines in the solar spectrum*, in: Radiative Excitation and Ionization Processes, Inst. Phys. Univ., Zagreb, (1987), 84.

M. S. Dimitrijević, S. Sahal-Bréchot: *On the Stark broadening of Si IV lines: Regularities within spectral series*, IX Int. Conf. Spectr. Line Shapes, Toruń, (1988), A12.

M. S. Dimitrijević, G. Peach: *Line width regularities and systematic trends due to collisions with neutral perturbers*, IX Int. Conf. Spectr. Line Shapes, Toruń, (1988), D9.

M. S. Dimitrijević, M. M. Popović: *Stark broadening of noble gas ions as a function of the ionization potential*, XIV SPIG, Sarajevo, (1988), 289.

M. S. Dimitrijević, G. Peach: *Line widths due to neutral non-resonant collisions witin a homologue sequence: An investigation of the Van der Waals formula*, XIV SPIG, Sarajevo, (1988), 321.

M. S. Dimitrijević, A. A. Mihajlov, B. Grabowski: *The influence of Debye shielding on the Stark widths and shifts of ion lines in the adiabatic limit*, XIV SPIG, Sarajevo, (1988), 329.

M. S. Dimitrijević, S. Sahal-Bréchot: *Comparison between calculated, and measured Stark widths of C IV lines*, XIV SPIG, Sarajevo, (1988), 333.

M. S. Dimitrijević: *Classical trajectory method in line shapes investigations*, Int. Conf. on Classical Dynamics in Atomic and Molecular Physics (CDAMP), Brioni, (1988), 21.

M. S. Dimitrijević: *Stark broadening of the Fe II lines in the solar and stellar spectra*, R. Viotti et al. (eds.), Physics of Formation of Fe II Lines Outside LTE (1988), 211–216.

Recently developped modified semiempirical approach (Dimitrijević and Konjević, 1980, 1986; Dimitrijević and Kršljanin 1986) is applied to the Stark broadening calculation of Fe II lines in the Solar spectrum and the spectrum of Am 15 Vulpeculae.

M. S. Dimitrijević, Z. Djurić, A. A. Mihajlov: *Electron-impact broadening of Cu IV lines from an electrodynamic macroparticles accelerator arc plasma*, Int. Conf. on Phys. of Multiply Charged Ions, Grenoble, (1988), 2.16.

Y. Vitel, M. Skowronek, M. S. Dimitrijević, and M. M. Popović: *Stark broadening along a homologous sequence of noble gas atomic lines in dense plasmas*, Astron. Astrophys. **200** (1988), 285–290.

We present experimental results on the broadening and shift of some rare gas atomic lines emitted by high electron density plasmas created in linear flash-tubes. From a semiempirical formula, we find a theoretical dependence of the Stark broadening parameters on the ionisation potential for lines broadened by electron impacts. Experimentally, a non-linear dependence is found between the Stark width w and shift d, and the electron density. At the lowest electron density, our values of w and d agree with other experimental determinations. We have observed a regularity of w and d for analogous lines of homologous atoms.

M. S. Dimitrijević: *Comparison between different approximate approaches for the calculation of Stark widths of doubly- and triply-charged ion lines of astrophysical importance*, Bull. Obs. Astron. Belgrade **139** (1988), 31–58.

Stark widths of spectral lines from 127 astrophysically important multiplets of doubly- an triply-charged ions were calculated by means of the Griem's (1968) semiempirical method, Griem's simplified semiclassical method (1974), and a modified version of this latter method (Dimitrijević and Konjević, 1980). Obtained results were compared with those (Dimitrijević, 1988) derived by using the modified semiempirical method (Dimitrijević and Konjević, 1980).

M. S. Dimitrijević: *Electron-impact widths of doubly and triply charged ion lines of astrophysical impotance*, Astron. Astrophys. Suppl. Ser. **76** (1988), 53–59.

A recently developed modified semiempirical approach (Dimitrijević and Konjević, 1980, 1987: Dimitrijević and Kršljanin, 1986) is applied to the Stark boradening of spectral lines from 127 astrophysically important multiplets of doubly and triply charged ions.

T. Lanz, M. S. Dimitrijević, and M. C. Artru: *Stark broadening of visible Si II lines in stellar atmospheres*, Astron. Astrophys. **192** (1988), 249–254.

The Stark broadening of visble Si II lines is studied and its consequence on the intensity of the stellar absorption is analyzed. A complete set of atomic data concerning the Stark widths, is elaborated for 19 multiplets of Si II of astrophysical importance. Previous available determinations are reviewed and new Stark widths are calculated by means of the semi-classical impact theory. The accuracy of different theoretical and empirical methods are discussed. The new adopted Stark widths are applied, in several examples, to the analysis of stellar absorption lines. These widths are generally smaller than the previous theoretical estmates for the low-excitation transitions of Si II. But it leads to reduce only slightly (less than 10%) the equivalent widths, even with enhanced silicon. The only exception is the multiplet 1, whose equivalent width could be reduced from 10% to 35%. On the other hand, the influence of the large Stark widths obtaind for the high-excitation multiplets, is shown

to be critical for the abundance analysis. The example of the 4d-8f transition, at 4201 Å, is detailed.

Radiative widths are also given for these 19 multiplets and could be as large as 40 times the classical damping. Such widths affect particularly the low-excitation transitions and increase the equivalent widths up to 30% with respect to those calculated with the classical value.

M. S. Dimitrijević: *Classical trajectory method in line shapes investigations*, Proc. of the International Conference on Classical Dynamics in Atomic and Molucular Physics CDAMP'88, Eds. T. Grozdanov, P. Grujić, P. Krstić, (1988), 403.

The use of classical perturber trajectories within semiclassical and classical approaches to the line shapes and frequency shift calculations is briefly reviewed and discussed with special emphasis on the deviation of the perturber motion from the uniform one.

V. Kršljanin: *Ion lines Stark shifts in spectra of hot stars*, (M. Sc. Thesis Paper), IX National Conference of Yugoslav Astronomers Abstract Book, Sarajevo (1988), 3.

V. Kršljanin: *Stark broadening of resonance lines for the lithium isoelectronic sequence and some astrophysical applications*, in: Radiative Excitation and Ionization Processes, ed. V. Vujnović, Inst. Phys. Univ. Zagreb, (1988), 80–83.

M. S. Dimitrijević: *On the Stark broadening of C IV lines*, Bull. Obs. Astron. Belgrade **139** (1988), 70–71.

In this paper, results of semiclassical calculations of electron impact Stark widths within C IV multiplets are reported. A comparison with available experimental and theoretical data is performed too.

M. S. Dimitrijević, G. Peach: *An investigation of Van der Waals formula within a homologous sequence*, IX Nat. Conf. Yug. Astr., Sarajevo, (1988), 7.

M. S. Dimitrijević: *Critical selection of line broadening data for astrophysicists*, IX Nat. Conf. Astr. Yug., Sarajevo, (1988), 8.

J. Arsenijević, A. Kubičela, I. Vince and S. Jankov: *Belgrade program for monitoring of activity-sensitive spectral lines of the Sun as a star I. An analog solar scanning monochromator*, Bull. Obs. Astron. Belgrade **138** (1988), 1.

A scanning attachment for the Belgrade equatorial solar spectrograph based on a tipping glass rotation in front of the focal plane is described. An analog position encoder and an X-Y recorder complete the system of a solar scanning monochromator. The reduction procedure is reviewed and some instrumental parameters estimated, e.g. the flexure, the expected temperature influence, the range of flat field factors, the distortion of the wavelength scale, and certain components of the instrumental scattered light.

J. Skuljan, S. Erkapić, I. Vince, A. Kubičela: *Beogradski program za praćenje spektralnih linija osetljivih na aktivnost kod Sunca kao zvezde, III. Prvi spektrofotometrijski rezultati*, Saopšteno na IX Nacionalnoj konferenciji jugoslovenskih astronoma, Sarajevo, oktobar, 1988.

I. Vince, A. Kubičela, J. Arsenijević: *Belgrade program for monitoring of activity-sensitive spectral lines of the Sun as a star, II. Selection of Fraunhofer lines and beginning of a study of their long-term changes*, Bull. Obs. Astron. Belgrade **139** (1988), 25.

The selection of program spectral lines, preceeded by a short review of some earlier results, and progress report on their Belgrade observations are given. The lines are selected according to their various responses to the physical conditions in the photosphere and listed in Table I. Eight series of observations were done during 1987 covering the period of minimal solar activity. The first spectrophotometric errors have been estimated and research aims for the near future have been pointed out.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical Stark shifs of arII lines*, Z. Phys. D – Atoms, Molecules and Clusters **14** (1989), 273–280.

Stark shifts for 47 multiplets of ArII are calculated according to modified semiempirical approach, and compared with critically selected experimental data, as well as with semiclassical values of Jones et al. (1971) when available. Mean experimental to theoretical (modified semiempirical) shift ratio 1.38 ± 0.60 is obtained.

M. S. Dimitrijević, A. A. Mihajlov, Z. Djurić, B. Grabowski: *On the influence of Debye shielding on the Stark broadening of ion lines within the classical model*, J. Phys. B: At. Mol. Opt. Phys. **22** (1989), 3845–3850.

The influence of Debye shielding on the Stark line shift to width ratio is demonstrated in the case of ion lines. The Coulomb cut-off potential, especially suitable for a non-ideal plasma and for highest densites, has been used.

I. Vince: *Investigation of the collisional limb effect and shape of solar spectral lines at the Astronomical observatory in Belgrade*, Bull. Obs. Astron. Belgrade **140** (1989), 117–121.

Besides other research programs, at the Belgrade Astronomical Observatory we investigate the absorber-perturber collision effects on solar limb effect and on spectral line profile. A short review of our method of calculation and some examples of our results of the work on effect of atomic collision processes on the solar limb effect and solar spectral line bisectors are given here.

M. S. Dimitrijević, S. Sahal-Bréchot: *On the Stark broadening parameters for Li-like ions*, Collisions et Rayonnement, Orleans, (1989).

M. S. Dimitrijević, O. Atanacković-Vukmanović: *Plasma screening effects on Stark broadening of ion lines at the adiabatic limit*, Collisions et Rayonnement, Orleans, (1989).

I. Vince: *A Nap sugarának változásai*, A Magyarok szerepe a világ természettudományos és müszaki haladásában (eds. Fodor O., Füzeseri A., Stefokné Vermes J.), II. Tudományos talalkozó, Országos müszaki információs központ és könyvtár, (1989), 753–756.

M. S. Dimitrijević: *Stark broadening in astrophysics*, Bull. Obs. Astron. Belgrade **140** (1989), 111–116.

The importance of Stark broadening in astrophysics is briefly reviewed. A short review of results of Yugoslav research workers on this field is also presented.

M. S. Dimitrijević, M. M. Popović: *Estimates of Stark width along a homologous sequence*, Astron. Astrophys. **217** (1989), 201–203.

A simple analytical expression for Stark widths as a function of the ionization potential suitable for critical evaluation of existing experiments and interpolation of new data along homologous ion sequences at low temperature limit, has been derived.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical Stark widths and shifts of Ar II lines*, Bull. Obs. Astron. Belgrade **140** (1989), 7–14.

The modified semiempirical aproach (Dimitrijević and Konjević, 1980; Dimitrijević and Kršljanin, 1986) was used for calculation of Stark widths and shifts for Ar II lines. Comparison has been made with semiclassical results of Jones et al., (1971) as well as with critically selected experimental data. Since the good average accuracy of the present results has been achieved, tabulation of modified semiempirical Stark broadening parameters for 50 Ar II multiplets is also given.

I. Vince, M. S. Dimitrijević: *Pressure broadening and solar spectral line bisectors*, R. J. Rutten and G. Severino (eds.), in: Solar and Stellar Granulation (1989), 93–97.

In order to show that pressure broadening (atomic collisional processes) may have an important contribution to the spectral line asymmetries in some cases, what is of interest especially for the solar granulation studies, bisectors for Na I $3s^2S - np^2P^0$ solar lines have been calculated for different positions on the solar disk. Our numerical results clearly demonstrate that in the case of the examined spectral series the influence of pressure broadening has not a negligible role for the convective layer diagnostic.

M. S. Dimitrijević, Z. Djurić, A. A. Mihajlov: *Electron-impact broadening of Cu IV lines for the diagnostic of the arc plasma of electrodynamic macro-particle ac-*

celerator, Journal de Physique, Coll. C1, Suppl. au No. 1, Tome **50** (1989), C1-623.

Using a model method of loss energy simulation on the boundary surfaces, temperature and composition of an electrodynamic macroparticle accelerator arc plasma created by the evaporation of a Cu foil, have been calculated. Stark widths for Cu IV lines of interest for the arc plasma diagnostic have been calculated also, by using the modified semiempirical method.

V. Kršljanin: *On pressure shifts of Fe I lines in stellar atmospheres*, in: Solar and Stellar Granulation, eds. R. J. Rutten and G. Severino, Kluwer, Dordrecht, (1989), 91.

Calculated pressure shifts (with hydrogen- and electron-impact contributions taken into account) of two Fe I lines in spectra of A-G main sequence stars are presented and their importance in diagnostics of dynamical processes, particularly in hot stellar atmospheres is emphasized.

V. Kršljanin: *The spectral line synthesis study in Belgrade*, Bull. Obs. Astron. Belgrade **140** (1989), 123–125.

Investigation of both solar and stellar atmospheres using the spectral line synthesis method in the Astrophysical group of the Belgrade Astronomical Observatory started in 1983. The study of the pressure broadening in the astrophysical plasma and related topics are the main research orientation. Corresponding computer programs are developed. A review of the first results and the current investigations concerning line asymmetries and shifts caused by pressure, abundance determinations and microturbulence is given here.

V. Kršljanin: *Inversion of solar absorption lines*, 3rd Workshop: Astrophysics in Yugoslavia, ed. V. Vujnović, Inst. Phys. Univ. Zagreb, (1989), 9.

V. Kršljanin: *Ion lines Stark shifts in spectra of hot stars*, Publ. Obs. Astron. Belgrade **37** (1989), 1–114.

High-resolution UV spectroscopy from spacecrafts reveals different stellar spectral line features connected with line shifts and asymmetries. These features are mainly caused by dynamics of stellar envelopes, mass loss, convective motions and gravitation. Purpose of this work is to determine the contribution of pressure (i.e. Stark) broadening to such effects in spectra of hot ($T_{\rm eff} \geq 20000\,{\rm K}$) main sequence and high gravity stars ($4.5 \leq \log g \leq 9.0$). In that order, modified semiempirical theory for calculation of ion lines electron-impact shifts is developed. The method is tested via comparison with results of the semiclassical and semiempirical theories as well as with critically selected experiments. Stark shifts of astrophysically important Si, C, N, O, ion lines in spectra of hot stars are calculated. Simple analytical expressions for resonance lines Stark shifts in lithium isoelectronic sequence are obtained. Contribution of the Stark shifts to the stellar spectral line shifts mainly by mass loss, gravitation and stellar atmospheric motions is estimated and importance of this contribution is discussed.

M. S. Dimitrijević, M. M. Popović: *Štarkovo širenje duž homolognog niza alkalnih metala*, VI Jug. Skup. iz Fizike Atomskih Sudara, Brioni, (1989), 36.

M. S. Dimitrijević: *Približni metodi za dobijanje parametara Štarkovog širenja*, (Uvodno predavanje), VI Jug. Skup iz Fizike Atomskih Sudara, Brioni, (1989), 35.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical Stark shift examination: Ar II Stark line shifts*, XIX IGPIG, Beograd, (1989), 330.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical Stark shift examination: II. Alkali-like singly charged ion lines Stark shifts*, XIX ICPIG, Beograd, (1989), 332.

M. S. Dimitrijević, S. Sahal-Bréchot: *On the semiclassical Stark widths of C IV lines*, XIX IGPIG, Beograd, (1989), 334.

M. S. Dimitrijević, S. Sahal-Bréchot: *On the Stark broadening of Si IV lines: influence of different collisional processes*, XIX ICPIG, Beograd, (1989), 336.

M. S. Dimitrijević, M. M. Popović: *Stark broadening data along a homologous sequence of earth alkali metal ion lines*, XIX ICPIG Beograd, (1989), 338.

M. S. Dimitrijević, V. Vujnović: *Stark broadening of Cu I lines — New calculation and a review of old results*, XIX ICPIG, Beograd, (1989), 340.

V. Kršljanin, M. S. Dimitrijević: *Modified semiempirical theory of Stark broadening in astrophysics: Ar II line shifts in spectra of B stars*, III Seminar Astrofizika u Jugoslaviji, Zagreb, (1989), 11.

M. S. Dimitrijević, S. Sahal-Bréchot: *Semiclassical calculations of astrophysically important Stark broadening parameters*, III Seminar Astrofizika u Jugoslaviji, Zagreb, (1989), 10.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of He I lines*, Astron. Astrophys. Suppl. Ser. **82** (1990), 519–529.

Using a semiclassical approach for the Stark broadening of atomic lines, we calculated electron-, proton and ionized helium-impact line widths and shifts for 77 neutral helium multiplets in the ultraviolet, visible and infrared regions of the spectrum.

S. Djurović, N. Konjević, and M. S. Dimitrijević: *Stark broadening of halogen atom lines from* $(^1D)np$ *levels*, Z. Phys. D — Atoms, Molecules and Clusters **16** (1990), 255–260.

We report results of a study of the Stark broadening of halogen atom lines from $(^1D)np$ levels. Wall stabilized arc is used as a plasma source. Electron densities $2.2\text{–}3.2 \times 10^{22}\,\mathrm{m}^{-3}$ are determined from the width of H_β line and electron temperature 9300–10000 K from plasma composition data. The agreement with the results of simple semclassical calculations is within the

limits of the estimated errors of both experiment and theory. And explanation for the large discrepancy between theory and experiment detected for three Br I lines is offered.

M. S. Dimitrijević: *Line shapes investigations in Yugoslavia 1962–1985 (Bibliography and citation index)*, Publ. Obs. Astron. Belgrade **39** (1990), 1–214.

First part of the publication contains review and analysis of the results of spectral line shapes investigations in Yugoslavia in the period 1962–1985, with special emphasis on the importance of such investigations. In the second part, the bibliography of the contributions of Yugoslav scientists is given, together with the citation index.

M. S. Dimitrijević, S. Sahal-Bréchot: *Stark broadening of Li(I) lines: Regularities within a spectral series*, 22 EGAS, Uppsala, (1990), 478.

M. S. Dimitrijević: *Approximate methods for line broadening calculations*, IAU Symposium 145, "Evolution of stars: the photospheric abundance connection", Zlatni Pjasci (Družba), (1990), 16.

V. Kršljanin, M. S. Dimitrijević: *Stark broadening of C IV λ 1549 lines and carbon abundance in hot DA white dwarfs*, IAU Symposium 145, "Evolution of stars: the photospheric abundance connection", Zlatni Pjasci (Družba), (1990), 82.

M. S. Dimitrijević, G. Peach: *An examination of regularities in neutral atom broadening*, 10th ICSLS, Austin, (1990), 57.

M. S. Dimitrijević, N. Ben-Nessib: *Simple convergent formulae for estimating Stark widths of neutral atom lines*, 10th ICSLS, Austin, (1990), 161.

S. Djurović, N. Konjević, M. S. Dimitrijević: *Plasma broadening of Br I and II lines from* $(^1D_2)np$ *levels*, 10th ICSLS, Austin, (1990), 26.

M. S. Dimitrijević, S. Sahal-Bréchot: *Profiles of neutral lithium lines: broadening by charged particles*, 12th European Regional Astronomy Meeting of IAU, Davos, (1990), III 6.

M. S. Dimitrijević, Vladimir Kršljanin: *On the use of the modified semiempirical approach: the case of close perturbing levels*, XV SPIG, Dubrovnik, (1990), 201.

M. S. Dimitrijević, V. Vujnović: *On the Stark broadening of Cu I lines — the influence of the oscillator strength values*, XV SPIG, Dubrovnik, (1990), 241.

M. Karabin, A. Kubičela, J. Skuljan, I. Vince: *Activity cycle variation of some photospheric lines*, Proc. of the E.P.S. 6th European Solar Meeting *The Dynamic Sun*, Publ. of Debrecen Heliophysical Obs. **7** (1990), 104.

The equivalent widths, W, of 10 Fraunhofer lines, observed at Belgrade Astronomical Observatory, have been studied from 1987 till 1990. Four lines

show no change. The lines MnI 539.47 nm, ScII 552.68 nm and FeI 557.61 nm steadily decrease in W from 2.4% to 4.4% per year. The other three, TiII 533.68 nm, CaI 560.13 nm and NaI 568.82 nm slowly increase in W from 2.2% to 6.2.% per year. It is assumed that these changes are correlated to the solar activity.

I. Vince: *Contribution of atomic collisions to the solar limb effect*, XV Summer School and International Symposium on the Physics of Ionized Gases (ed. Veža D.), (1990), 128.

M. S. Dimitrijević: *Semiclassical and approximate methods for Stark broadening investigations of astrophysical and laboratory spectra*, XV SPIG, Dubrovnik, (1990), 322.

V. Kršljanin: *Broadening of NaI lines due to collisions with atomic hydrogen*, in: 22nd EGAS, ed. A. Wannstrom, Univ. Uppsala, (1990), 760–762.

V. Kršljanin: *Simple estimates for Stark widths and shifts of neutral atom lines*, in: 22nd EGAS, ed. A. Wannstrom, Univ. Uppsala, (1990), 757–759.

V. Kršljanin, I. Vince and S. Erkapić: *FeI line asymmetries and shifts caused by pressure broadening and diagnostics of solar convective motions*, in IAU Colloquium 130, The Sun and Cool Stars: Activity, Magnetism, Dynamos; Programme and Abstracts, Helsinki, (1990), 68.

V. Kršljanin, S. Marković-Kršljanin: *On Stark line shifts in spectra of hot main sequence stars*, in: XV SPIG Contributed Papers, ed. D. Veža, Inst. Phys. Univ. Zagreb, (1990), 370–371.

V. Kršljanin: *Hydrogen-impact broadening and solar abundance of sodium*, in: IAU Symposium 145, Evolution of Stars: The Photospheric Abundance Connection, Abstracts of Presented Papers, Golden Sands, Bulgaria, (1990), 26.

V. Kršljanin: *Hydrogen-impact broadening of NaI Fraunhofer lines and solar photospheric abundance of sodium*, Ph. D. Thesis Paper, in: 12th ERAM of the IAU Abstract Book, Davos, Switzerland, (1990), p. PD-2.

M. S. Dimitrijević: *Accuracy of line broadening data*, in: Accuracy of Element Abundances from Stellar Atmospheres, (ed. R. Wehrse), Lecture Notes in Physics **356** (1990), 31–44.

The line broadening calculations for spectral lines broadened by collisions with charged and neutral particles has been reviewed. The accuracy of existing calculations and the possibilities of theoretical approaches suitables for acquisition of new data useful in astrophysics has been discussed.

11.3. Atoms and Atomic Collisional Processes
11.3. Atomi i atomski sudarni procesi

M. S. Dimitrijević, P. Grujić: *An investigation of e-He double ionization near the threshold. The classical trajectories method*, X SPIG, Dubrovnik, (1980), 22.

M. S. Dimitrijević, P. Grujić: *Electron-hydrogen collisions in a homogeneous magnetic field: classical calculations*, ECAP Heidelberg, (1981), 735.

M. S. Dimitrijević, P. Grujić, S. Vučić: *Elastic e-He* $(2S^2)$ *scattering: classical treatment*, ECAP Heidelberg, (1981), 764.

M. S. Dimitrijević, P. Grujić: *Classical investigations of* $e^+ + H \rightarrow H^+ + e^- + e^+$ *reaction near the threshold*, 5th Gen. Conf. EPS, Istanbul, (1981), 84.

M. S. Dimitrijević, P. Grujić: *Electron-helium double ionisation near the threshold: numerical investigations*, J. Phys. B: At. Mol. Phys. **14**, (1981), 1663.

The classical trajectory method is applied to the investigation of low-energy e+He $\rightarrow$ He^{2+}+3e collisions. In contrast to the hydrogenic case numerical calculations appear unable to derive the ionisation threshold law by varying one or two initial parameters. Final electron energies appear as linear functions, of the initial time parameter and it is conjectured that the energy distribution should be uniform within the total energy interval: $0.544 \leq E \leq 6.75\,\mathrm{eV}$. Calculated angular correlations between the three escaping electrons conform to the full central symmetry at very small energies, but go over to axially symmetric configurations as the energy rises. The final angular momenta acquire large values, with dramatic enhancement at the edges of an ionisation interval, where momentum exchange becomes particularly strong. Finally, the applicability of the classical model to non-hydrogenics is discussed, as well as some stochastic effects encountered.

M. S. Dimitrijević, P. Grujić and S. Vučić: *A classical model for e-He* $(2s^2)$ *elastic scattering*, Fizika **13** (1981), 321.

Two variants of the free fall model for helium in the first autoionizational site have been proposed for calculating differential cross section for e-He $(2s^2)$ elastic scattering. At $E = 7\,\mathrm{eV}$ impact energy the cross sections are evaluated numerically, making use of the classical trajectory method and are found sistematically higher for the case of the asynchronous atomic electrons motion than for the synchronous one.

M. S. Dimitrijević, P. Grujić: *The classical trajectory study of* $e^+ + A \rightarrow A^+ + e^- + e^+$ *reaction near the threshold*, J. Phys. B: At. Mol. Phys. **16** (1983), 297.

Numerical investigations of the positron-atom ionisational collisions near the threshold have been carried out within the classical trajectory method. It is found that for an infinitely heavy target the threshold law reads: $I \sim E^{2.49}$, whereas recent analytical calculations predict a value of 2.65 for the exponent. However, in the case of a hydrogen-atom target, the value 1.64 has been

obtained, indicating that the resting target mass assumption, as employed in all previous analytical investigations of $e^{\pm} - A$ processes near the ionisation threshold, breaks down in the case of the positron-light-atom collisions. The energy distribution of the outgoing particles appears non-zero and uniform in larger parts of available energy regions: $e^{+}[E/2, E]$, $e^{-}[0, E/2]$, but turns out, surprisingly, to be zero around $E/2$. The calculated energy dependence of the mutual angle is consistent with the analytically predicted $\theta_{+-} \sim E^{1/4}$ behaviour.

M. S. Dimitrijević: *Energy distribution in the near-treshold positron impact ionization of atoms*, XII SPIG, Šibenik, (1984), 109.

M. S. Dimitrijević, P. Grujić: *Langmuir's helium-like models revisited*, Z. Naturforsch **39A** (1984), 930.

Classical two-electron configurations, proposed by Langmuir in the days of Old Quantum Theory as models for heliumlike atoms, have been examined making use of modern semiclasical theory for the periodic orbits quantization. Combining both analytical and numerical investigations, energy spectra for the rotor-like and oscillator-like models have been evaluated for the nuclear charges $Z = 1, 2, 3, 6$. No essential improvement of the original result (for $Z = 2$) is obtained, signifying that either configuration turns out to be inferior to the simple Bohr's planetary model. Stability of these systems with respect to small perturbations has been examined and a general criterion for selection classical models as candidates for atomic orbitals within the semiclassical theory is discussed.

M. S. Dimitrijević, P. Grujić: *An old two-electron-system model revisited*, SPIG, Šibenik (1984), 112.

A. Mihajlov, M. Dimitrijević: *Determination of the cross section for elastic scattering of the electrons on cut off Coulomb potential in quasi classical method*, XII SPIG, Šibenik (1984), 416.

M. S. Dimitrijević, P. Grujić: *Classical spectrum of an oscillatory helium model*, Fizika **17** (1985), 1.

A generalization of an oscillatory two-electron atomic system, first proposed by Langmuir, has been studied numerically, by calculating electron classical orbits. By applying semiclassical quantization procedure, energy spectrum of the system is evaluated.

A. A. Mihajlov, M. S. Dimitrijević: *Uticaj jon-atomskih sudara na apsorpciju zračenja u atmosferama zvezda A tipa*, VIII Kongres MFAJ, Priština, (1985), 344.

A. Mihajlov, M. Dimitrijević, D. Djordjević: *Kvaziklasično i klasično određivanje preseka za rasejanje čestica na odsečenom Kulonovom potencijalu*, IV, JS FASP, Plitvice, (1985).

A. A. Mihajlov, M. S. Dimitrijević: *Influence of ion-atom collisions on the absorption of radiation*, Astron. Astrophys. **155** (1986), 319–322.

It is shown that for the interpretation of the continuum absorption spectra, of A type stars, the processes $H_2^+ + \hbar\omega \rightarrow H + H^+$ and $H + H^+ + \hbar\omega \rightarrow H + H^+$ must be considered together since their contribution is comparable. The corresponding absorption coefficients are also determined.

N. Simonović, P. Grujić, M. Dimitrijević: *Triatom fragmentation near the break up threshold*, Collision dynamics of clusters and long-lived states, Brioni, (1986).

A. A. Mihajlov, M. S. Dimitrijević, D. Djordjević, M. Luft, W. D. Kraeft; *Quasi-classical and classical cross sections for the scattering of electrons on the Coulomb cut-off potential*, Contrib. Plasma Phys. **27**, 1 (1987), 1–13.

The elastic scattering of electrons on the cut-off Coulomb potential $U_c(r) = -1/r + 1/r_c$, for $r \geq r_c$ and $U_c(r) = 0$, for $r < r_c$. has been considered. It has been shown that for $\varepsilon > 0.5/r_c$ (ε is the energy of free electrons in atomic units) the analytical quasi-elassical expressions describe quite well the behaviour of transport, differential and total cross sections for elastic scattering. It has been shown moreover, that in the energy range considered, transport cross sections could be determined with practically the same accuracy already by means of classical, analytical expressions. Born approximations show larger deviations form exact quantum calculations.

M. S. Dimitrijević, P. Grujić, G. Peach, N. Simonović: *Near-threshold CID processes: numerical studies*, I CDAMP, Brioni, (1988), 48.

A. A. Mihajlov, M. S. Dimitrijević: *Coulomb cut-off potential and modeling of radiation and collision processes in dense plasmas*, I CDAMP, Brioni, (1988), 25.

M. S. Dimitrijević, P. Grujić: *Threshold laws for the fourfold ionization by electrons*, I CDAMP, Brioni, (1988), 47.

Lj. M. Ignjatović, A. A. Mihajlov, M. S. Dimitrijević: *Electron elastic scattering on the cut-off Coulomb and Debye potential*, XV SPIG, Dubrovnik, (1990), 37.

A. A. Mihajlov, M. S. Dimitrijević: *Influence of $H - H^-$ collisions on the continuum absorption spectra of cool stars*, 12th European Regional Astronomy Meeting of IAU, Davos, (1990), III 17.

M. S. Dimitrijević, A. A. Mihajlov: *Influence of ion-atom collisions on the stellar continum absorption spectra*, XV SPIG, Dubrovnik, (1990), 368.

M. S. Dimitrijević, P. Grujić, G. Peach and N Simonović: *Small-energy three-body systems: IV. Classical trajectory calculations for the near-threshold behaviour of collision-induced dissociation*, J. Phys. B: At. Mol. Opt. Phys. **23** (1990), 1641–1653.

Near-threshold collision induced dissociation is simulated numerically for the process $Xe + Xe_2 \rightarrow 3Xe$ by carrying out detailed classical trajectory calculations. A static model of the target is chosen and the system is assumed to

have zero total angular momentum. Then by varying a single parameter, the threshold law $\sigma \sim E^{1.6}$ for the cross section is derived, and this is consistent with analytical results obtained previously. We also consider the distributions of energy, mutual angles and individual angular momenta in the final channel.

M. S. Dimitrijević, P. Grujić, and N. Simonović: *Fourfold ionization by electrons near the threshold*, Z. Phys. D — Atoms, Molecules and Clusters **15** (1990), 203–209.

Threshold law for the process $e + A^{q+} \rightarrow A^{(q+4)+} + 5e$ has been derived within the classical theory. For neutral targets ($q = 0$) the threshold exponent asumes value 5.08 consistent with previous calculations for ionizations of lower orders. The method fails for $q < -4$. The results are compared with recent experimental measurements, which considerably underestimate theoretical findings. An empirical formula for n-fold ionization is provided, which predicts values for the threshold exponent $k = 7.8$ and 12.5 for $n = 5, 6$ respectively.

11.4. Laser Produced and Laboratory Plasmas
11.4. Laserski proizvedene i laboratorijske plazme

M. S. Dimitrijević, N. Konjević: *Uticaj predimpulsa na oštećenje prozračne mete laserskim zračenjem*, 22 ETAN u pomorstvu, Zadar, (1980), Vol. 2, 371.

M. S. Dimitrijević, N. Konjević: *The importance of the pulse shape for the laser-beam target interaction*, Optics and Laser Technology **12** (1980), 145.

Theoretical analysis of a pulsed CO_2 laser beam aluminium target interaction demonstrates increased efficiency if the main laser pulse is preceded by a pulse of enough power to induce breakdown in air and create plasma in front of the metal target surface.

M. S. Dimitrijević, N. Konjević: *O proceni optičke prozračnosti plazme koja nastaje prilikom obrade metala snažnim laserskim zračenjem*, 23 ETAN u pomorstvu, Zadar, (1981), 323.

M. S. Dimitrijević, N. Konjević: *Uticaj oblika laserskog impulsa na profil plazme ispred metalnih meta*, 23 ETAN u pomorstvu, Zadar, (1981), 330.

B. Lončarević, S. Jovićević, M. S. Dimitrijević, N. Konjević: *Apsorpcija laserskog zračenja na metalnoj meti u prisustvu proboja ispred mete*, 23 ETAN u pomorstvu, Zadar, (1981), 335.

S. Jovićević, B. Lončarević, V. Knežević, S. Manola, M. S. Dimitrijević, N. Konjević: *Spektroskopsko proučavanje laserski proizvedene plazme*, 23 ETAN u pomorstvu, Zadar, (1981), 348.

S. Jovićević, M. S. Dimitrijević, N. Konjević: *Uticaj talasne dužine lasera na apsorpciju zračenja na metalu u prisustvu plazme*, 24 ETAN u pomorstvu, Zadar, (1982), 374.

M. S. Dimitrijević, N. Konjević: *Uloga predimpulsa kod praga za oštećenje metalne mete laserskim zračenjem*, 24 ETAN u pomorstvu, Zadar, (1982), 367.

P. K. Cibin, M. S. Dimitrijević: *Influence of electron colisions on the propagation of guided electron plasma waves along the cylindrical interface between two plasmas*, Int. Conf. Plasma Physics, Göteborg, (1982), 319.

N. Konjević, M. S. Dimitrijević: *On the Stark broadening of non-hydrogenic lines of heavy elements in plasmas*, in: Spectral Line Shapes Vol. II, ed. K. Burnett, Walter de Gruyter, Berlin – New York, (1983), 137.

M. S. Dimitrijević: *Apsorpcija laserskog zračenja na metalima u prisustvu plazme ispred mete*, 25 ETAN u pomorstvu, Zadar 1983, 522.

A. Mihajlov, M. Dimitrijević, M. M. Popović: *Determination of electrical conductivity of plasma by the use of classical transport cross-sections calculated on the basis of the cut-off Coulomb potential model*, XII SPIG, Šibenik, (1984), 420.

A. Mihajlov, M. Dimitrijević, M. M. Popović: *Determination of electrical conductivity of plasma on the basis of the cut-off Coulomb potential model*, XVII ICPIG, Budapest, (1985), 357.

A. A. Mihajlov, M. S. Dimitrijević, D. Djordjević, M. M. Popović: *Absorption of electro-magnetic radiation during collisions between lithium atoms and ions in low temperature plasma*, IX Int. Conf. on Gas Discharges, Venezia, (1988), 587.

A. A. Mihajlov and M. S. Dimitrijević: *Cut-off Coulomb potential in atomic and plasma physics*, Proceedings of the International Conference on Classical Dynamics in Atomic and Molecular Physics, Brioni, Yugoslavia, eds. T. Grozdanov, P. Grujić, P. Krstić, (1988).

APPENDIX
DODATAK

LECTURES HELD AT THE ASTRONOMICAL OBSERVATORY IN THE PERIOD 1980–1990

PREDAVANJA I SEMINARI ODRŽANI NA ASTRONOMSKOJ OPSERVATORIJI U BEOGRADU U PERIODU 1980–1990

3.03.1980.
V. A. Fomin (GAO AN SSSR, Pulkovo, Lenjingrad)
RADIOTELESKOP RATAN – 600 I NJEGOVO KORIŠĆENJE ZA ODREĐIVANJE TAČNIH KOORDINATA UNUTRAŠNJIH PLANETA

19.03.1980.
D. Olević
a) RASPODELA MASA U ASTEROIDNOM PRSTENU
b) ANALIZA KIRKWOODOVIH PRAZNINA

4.06.1980.
Dj. Teleki
AKUMULACIJA ZNANJA O POLOŽAJIMA ZVEZDA

22.12.1980.
B. Kovačević (Elektrotehnički fakultet, Niš)
INTERNI VREMENSKI SISTEMI

26.02.1981.
S. Sadžakov, M. Dačić, D. Šaletić
REZULTATI ISPITIVANJA SISTEMATSKIH GREŠAKA ZVEZDA NPZT PROGRAMA BEOGRADA I BORDOA

30.03.1981.
L. Vušković (Institut za fiziku, Beograd)
PRIKAZ ISTRAŽIVAČKOG RADA U OKVIRU VASIONSKOG PROGRAMA U JPL (Pasadena)

9.11.1981.
J. Moczko (Direktor širinske astronomske opservatorije, Borowiec, Poljska)
O RADOVIMA OPSERVATORIJE U BOROWIEC-U

31.03.1982.
A. Kubičela, M. Vukičević-Karabin (Institut za astronomiju PMF-a, Beograd)
NOVI POGLED NA SINODIČKU ROTACIJU SUNCA

7.04.1982.
A. Kubičela, I. Vince
EFEKAT VANFOKUSNOG POSMATRANJA NA SUNČEVOM SPEKTROGRAFU ASTRONOMSKE OPSERVATORIJE U BEOGRADU

29.04.1982.
Z. Knežević
RANA I KASNA OTKRIĆA MALIH PLANETA

11.08.1982.
S. Sadžakov, V. Fomin (GAO AN SSSR, Pulkovo, Lenjingrad), M. Dačić
a) AN INVESTIGATION OF THE SYSTEMATIC ERRORS OF THE BELGRADE NPZT AND AGK3 CATALOGUES ON THE BASIS OF MODERN PZT OBSERVATIONS
b) SYSTEMATIC ERRORS IN LATITUDE OBSERVATIONS OF VARIOUS OBSERVATORIES

28.10.1982.
V. Zappala, M. DiMartino, F. Scaltriti (Astronomska opservatorija, Torino), Z. Knežević, G. Djurašević
PRIRODA ASTEROIDA 216 KLEOPATRA NA OSNOVU NOVIH FOTOMETRIJSKIH POSMATRANJA

17.11.1982.
V. Škodrov (Astronomski odsek Akademije nauka Bugarske)
ASTRONOMSKA ISTRAŽIVANJA U BUGARSKOJ

11.01.1983.
R. Grujić, Dj. Teleki
ISPITIVANJA UTICAJA VETRA NA MERENJA KOD BEOGRADSKIH ŠIRINSKIH POSMATRANJA

18.01.1983.
B. Kovačević, Lj. Golubović (Elektrotehnički fakultet, Niš)
a) PRENOS VREMENSKIH SIGNALA PREKO SATELITA I PRECIZNO ODREĐIVANJE NJIHOVOG MESTA
b) TEHNIČKA OPREMLJENOST ČASOVNE SLUŽBE ASTRONOMSKE OPSERVATORIJE I MOGUĆNOSTI NJENOG OSAVREMENJAVANJA

3.03.1983.
Dj. Božičković
KATALOG APSOLUTNIH DEKLINACIJA 213 FK4 ZVEZDA U ZONI OD −30° DO +90°

4.05.1983.
a) V. Kršljanin
SAVREMENA KOSMOLOGIJA I FILOZOFIJA
b) N. Čabrić, A. Tomić (Narodna opservatorija, Beograd)
OKULTACIJA JUPITERA 6. MARTA 1983.
c) A. Tomić, N. Čabrić (Narodna opservatorija, Beograd)
FIKTIVNI DNEVNI METEORSKI RADIJANTI
d) A. Tomić, N. Čabrić (Narodna opservatorija, Beograd)
DENSITOMETAR SA He Ne LASEROM I LDR
e) S. Ninković
REZULTATI IZRAČUNAVANJA GALAKTOCENTRIČNE ORBITE GLOBULARNOG JATA NGC 5466

7.09.1983.
a) I. Pakvor
IZVEŠTAJ O STANJU RADOVA NA VAKUUMSKIM MERIDIJANSKIM MIRAMA
b) S. Sadžakov, V. A. Fomin (GAO AN SSSR, Pulkovo, Lenjingrad), M. Dačić
SISTEMATSKE GREŠKE TIPA $\Delta\alpha_\alpha$ I $\Delta\delta_\alpha$ POTSDAMSKOG PZT KATALOGA ZVEZDA

17.11.1983.
I. Almár (Konkoly Opservatorija, Budimpešta)
INFORMACIJE O SATELITSKO-GEODETSKIM MERENJIMA I O NJIHOVOJ GEODINAMIČKOJ PRIMENI U MAĐARSKOJ

23.11.1983.
V. A. Fomin (GAO AN SSSR, Pulkovo, Lenjingrad)
ISPITIVANJE SISTEMATSKIH GREŠAKA $\Delta\alpha_\alpha$, $\Delta\delta_\alpha$ TOKIJSKIH KATALOGA FZT

9.12.1983.
L. Sehnal (Opservatorija Ondřejov, Čehoslovačka)
OTPOR ATMOSFERE KRETANJU VEŠTAČKIH SATELITA I NOVI MODELI ATMOSFERE

29.12.1983.
R. Grujić, R. Krga
ISPITIVANJE „GREŠKE NOĆI" KOD BEOGRADSKIH ŠIRINSKIH PODATAKA U PERIODU 1949—1960

10.02.1984.
A. Yu. Yatsenko (Opservatorija Engelhardt, Kazan, SSSR)
a) O TATARSKOJ SSR
b) O KAZANSKOJ OPSERVATORIJI

11.04.1984.
B. Kovačević (Elektrotehnički fakultet, Niš)
UNAPREĐENJE ČASOVNE SLUŽBE NA ASTRONOMSKOJ OPSERVATORIJI

17.05.1984.
J. Vondrak (Opservatorija Ondřejov, Čehoslovačka)
a) OPSERVATORIJA ONDŘEJOV
b) UTICAJ PLANETA NA PRECESIJU I NUTACIJU

22.05.1984.
a) I. Vince, M. Dimitrijević, V. Kršljanin
SUDARNO ŠIRENJE I LIMB EFEKAT NA SUNCU: LINIJE NaI $3p^2P^0 - ns^2S$
b) Dj. Božičković
ODREĐIVANJE NAGIBA MIKROSKOPA

14.06.1984.
A. Yu. Yatsenko (Opservatorija Engelhardt, Kazan, SSSR)
ISTRAŽIVANJA PAVILJONSKE REFRAKCIJE NA ASTRONOMSKOJ OPSERVATORIJI ENGELHARDT

21.06.1984.
V. Zappala (Astronomska opservatorija, Torino), P. Farinella (Univerzitet, Pisa)
ROTATIONAL PROPERTIES AND COLLISIONAL EVOLUTION OF ASTEROIDS

31.08.1984.
I. Vince, M. Dimitrijević, V. Kršljanin
ŠIRENJE PRITISKOM I LIMB EFEKAT NA SUNCU

12.10.1984.
A. Yu. Yatsenko (Opservatorija Engelhardt, Kazan, SSSR), Dj. Teleki
SAVREMENI POGLED NA HARZEROVE RADOVE O ASTRONOMSKOJ REFRAKCIJI

22.10.1984.
Y. Andrillat (Direktor Observatoire Haute-Provence, Francuska)
THE OBSERVATORY HAUTE-PROVENCE

24.10.1984.
H. Debehogne (Observatoire Royal de Belgique)
PLATE REDUCTIONS AND MODERN ALGEBRA. ACCURACY ON LA SILLA-ESO PLATES BY THE TEST-STARS METHOD

25.10.1984.
Y. Andrillat (Direktor Observatoire Haute-Provence, Francuska)
Be ZVEZDE

7.12.1984.
M. Dimitrijević
PARISKA OPSERVATORIJA

11.12.1984.
P. Paquet (Observatoire Royal de Belgique)
PROGRAM „MERIT": DOBIJENI REZULTATI I OČEKIVANJA

19.12.1984.
A. Lesage (Opservatorija Paris-Meudon, Francuska)
VEROVATNOĆE PRELAZA I NJIHOV ZNAČAJ U ASTROFIZICI

31.01.1985.
a) A. Kubičela, I. Vince, Z. Ivanović (IX gimnazija, Beograd)
EFFECTS OF EXTRAFOCAL OBSERVATION WITH THE SOLAR SPECTROGRAPH OF THE BELGRADE ASTRONOMICAL OBSERVATORY. III: INTEGRATION OF THE LIMB EFFECT
b) G. Djurašević, J. Arsenijević, Z. Knežević
OMIKRON ANDROMEDAE — BRZE PROMENE

28.02.1985.
D. Olević, S. Šegan (Institut za astronomiju PMF-a, Beograd)
PROCENA TAČNOSTI ASTROGRAFSKIH POLOŽAJA DOBIJENIH KRATKOFOKUSNIM ASTROGRAFOM BEOGRADSKE OPSERVATORIJE

7.03.1985.
S. Sadžakov, M. Dačić
a) REZULTATI POSMATRANJA ZVEZDA ZA KATALOG DS PROGRAMA I U OKOLINI RADIO-IZVORA
b) POSMATRANJA SUNCA I PLANETA NA MERIDIJANSKOM KRUGU U BEOGRADU

2.04.1985.
M. S. Dimitrijević
ZAVISNOST ŠTARKOVIH ŠIRINA I POMAKA OD JONIZACIONOG POTENCIJALA: $np^{k-1}(n+1)s - np^k$ REZONANTNI PRELAZ

15.04.1985.
J. Vondrak (Opservatorija Ondřejov, Čehoslovačka)
IMPROVEMENT OF POSITIONS AND PROPER MOTIONS OF THE STARS FROM THE PZT OBSERVATIONS AT ONDŘEJOV OBSERVATORY

18.04.1985.
V. Kršljanin, I. Vince
SUDARNO ŠIRENJE I OSETLJIVOST SINTETIZOVANIH PROFILA NEKIH NEREZONANTNIH LINIJA NEUTRALNOG NATRIJUMA NA PROMENE MIKROTURBULENTNE BRZINE

30.05.1985.
A. Čadež (Institut za fiziku, Ljubljana)
GRAVITACIONI TALASI OD PULSARA

3.07.1985.
M. S. Dimitrijević, V. Kršljanin
SEMIEMPIRIJSKA FORMULA ZA ŠTARKOV POMAK SPEKTRALNIH LINIJA JONA

28.08.1985.
M. S. Dimitrijević
a) JEDNOSTAVNA FORMULA ZA PRORAČUN PARAMETARA ŠTARKOVOG ŠIRENJA LINIJA NEUTRALNIH ATOMA
b) O NEJEDNAKOSTI ŠTARKOVIH PARAMETARA UNUTAR JEDNOG MULTIPLETA I SUPERMULTIPLETA ArII
c) ŠTARKOVO ŠIRENJE SPEKTRALNIH LINIJA NEUTRALNOG KALIJUMA

4.09.1985.
O. Atanacković
EFEKTI ELASTIČNIH SUDARA NA LOKALNU FREKVENTNU PRERASPODELU FOTONA U REZONANTNIM LINIJAMA

12.09.1985.
a) G. Roberti (Astronomska opservatorija, Napulj)
THE FORMATION OF THE KI 7699 RESONANCE LINE IN NON-LTE CONDITIONS
b) G. Severino (Astronomska opservatorija, Napulj)
THE EFFECTS OF WAVES ON THE KI 7699 RESONANCE LINE

17.09.1985.
Dj. Alpar (Direktor Kosmičke geodezijske opservatorije u Pencu, Mađarska)
O DOPLER TEHNICI

18.09.1985.
Dj. Alpar (Direktor Kosmičke geodezijske opservatorije u Pencu, Mađarska)
O ANALIZI VREMENSKIH SERIJA

20.09.1985.
T. Kiseleva (GAO AN SSSR, Pulkovo, Lenjingrad)
PRIMENA DUGOFOKUSNIH TELESKOPA ZA ODREĐIVANJE TAČNIH KOORDINATA SATELITA VELIKIH PLANETA, DVOJNIH ZVEZDA I PARALAKSI

24.10.1985.
F. K. Brunner (Wild Heerbrugg, Švajcarska)
EFFECTS OF THE IONOSPHERE AND THE TROPOSPHERE ON GHZ SIGNAL

28.10.1985.
B. Grabovski (Institut Fizyki WSP Opole, Poljska)
„ASTROFIZIČKE" I „RELATIVISTIČKE" MASE BELIH PATULJAKA

29.10.1985.
M. Il (Direktor Astronomske opservatorije u Baji, Mađarska)
AKTIVNOST ASTRONOMSKE OPSERVATORIJE U BAJI

1.11.1985.
a) Z. Knežević
NOVI REZULTATI ISTRAŽIVANJA FAMILIJA MALIH PLANETA
b) I. Pakvor
PROGRESS REPORT ON THE BELGRADE CATALOG OF ABSOLUTE RA'S OF BRIGHT POLAR STARS

6.11.1985.
S. Sadžakov
PRELIMINARNI REZULTATI POSMATRANJA DVOJNIH ZVEZDA I ZVEZDA U OKOLINI RADIO-IZVORA

16.12.1985.
A. Kubičela
VEZA IZMEĐU SUNČEVE SIDERIČKE I SINODIČKE OSE ROTACIJE

26.12.1985.
G. I. Pinigin (GAO AN SSSR, Pulkovo, Lenjingrad)
HORIZONTALNI MERIDIJANSKI KRUG

27.03.1986.
P. Sotirovski (Opservatorija Paris-Meudon, Francuska)
HALEJEVA KOMETA

1.04.1986.
S. Murri-Tolcheljnikova (GAO AN SSSR, Pulkovo, Lenjingrad)
O PROBLEMU KLASIFIKACIJE SAVREMENIH METODA ODREĐIVANJA REKTASCENZIJA ZVEZDA

3.04.1986.
S. Murri-Tolcheljnikova (GAO AN SSSR, Pulkovo, Lenjingrad)
OSNOVNI PRINCIPI POSTAVKE SFERNIH SISTEMA KOORDINATA U ASTROMETRIJI

21.05.1986.
Lj. Dačić (Université de Paris XI, Francuska)
INFORMACIJA O RAČUNSKOM CENTRU PARISKOG UNIVERZITETA 11 — ORSAY

9.07.1986.
a) I. Pakvor
ANALIZA STABILNOSTI VAKUUMSKIH MIRA VELIKOG PASAŽNOG INSTRUMENTA U BEOGRADU
b) V. Trajkovska
REZULTATI ISPITIVANJA PODELE LIMBA VELIKOG MERIDIJANSKOG KRUGA U BEOGRADU NA 0°.5.

27.08.1986.
P. Brault (Opservatorija Paris-Meudon, Francuska)
ASTROPHYSICAL INTEREST OF MOLECULAR AND ATOMIC PHYSICS

7.10.1986.
a) Cl. Froeschle (Astronomska opservatorija, Nice, Francuska)
GRAVITACIONA EVOLUCIJA ASTEROIDNOG PRSTENA
b) P. Farinella (Astronomska opservatorija, Pisa, Italija)
OTVORENA PITANJA ASTEROIDNIH FAMILIJA

8.10.1986.
D. Egret (Centar za zvezdane podatke (CDS), Strasbourg, Francuska)
O AKTIVNOSTI CENTRA ZA ZVEZDANE PODATKE U STRASBOURGU

16.10.1986.
P. Sotirovski (Opservatorija Paris-Meudon, Francuska)
DANAŠNJI MODELI SUNCA I PROBLEMI NEUTRINA

17.10.1986.
Y. Requième (Observatoire de l'Université de Bordeaux) PROGRAM HIPARHA BUDUĆA BAZA ZA ASTROMETRIJU

29.10.1986.
Dj. Sadecki Kardos (Institut za geodeziju u Sopronu Mađarske akademije nauka)
ASTROGEODETSKI RADOVI U MAĐARSKOJ I OKOLNIM ZEMLJAMA

12.11.1986.
B. Grabovski (Institut Fizyki WSP Opole, Poljska)
JONIZACIONI BALANS U ZVEZDANIM ATMOSFERAMA

19.12.1986.
a) E. Simonneau (Institut za astrofiziku, Paris, Francuska)
UOPŠTENA EDDINGTONOVA APROKSIMACIJA ZA REŠAVANJE JEDNAČINE PRENOSA ZRAČENJA PRI SFERNOJ GEOMETRIJI
b) B. Kovačev (predsednik Nacionalnog komiteta za astronomiju Bugarske)
ASTRONOMIJA U BUGARSKOJ

11.03.1987.
V. Doazan (Opservatorija Paris-Meudon, Francuska)
THE LOCAL STELLAR ENVIRONMENT

31.03.1987.
A. Jovanovic (Prirodno-matematicki fakultet, Kragujevac)
ASTRONOMSKI PROGRAM „NAUTILUS"

3.04.1987.
H. K. Eichhorn (Department of Astronomy, Gainesville, Florida, USA)
ESTABLISHMENT OF COMPREHENSIVE STAR CATALOGUES

13.05.1987.
D. Djurović (Institut za astronomiju PMF-a, Beograd)
Serija predavanja: SAVREMENE METODE U OBRADI PODATAKA

20.05.1987.
D. Djurović (Institut za astronomiju PMF-a, Beograd)
Serija predavanja: SAVREMENE METODE U OBRADI PODATAKA
II deo: IZRAVNANJE POSMATRAČKIH PODATAKA METODOM VITEKERA-ROBINSONA-VONDRAKA

27.05.1987.
a) D. Djurovič (Institut za astronomiju PMF-a, Beograd)
Serija predavanja: SAVREMENE METODE U OBRADI PODATAKA
III deo: FURIJEOVE TRANSFORMACIJE U PRAKTIČNOJ PRIMENI
b) D. Petruševski (TV Beograd)
ELEKTRONSKI HRONOGRAF

18.11.1987.
S. Ninković
NEKA PITANJA MODELOVANJA GALAKSIJE

23.03.1988.
S. Ninković
SPLJOŠTENOST GALAKTIČKE KORONE

24.03.1988.
D. Slavić (Elektrotehnički fakultet, Beograd), N. Čabrić (Zavod za udžbenike i nastavna sredstva, Beograd)
PREZENTACIJA PC SKY ATLASA

7.06.1988.
a) I. Vince
ŠIRENJE USLED PRITISKA I BISEKTORI SUNČEVIH SPEKTRALNIH LINIJA
b) I. Pakvor
KATALOG APSOLUTNIH REKTASCENZIJA

30.06.1988.
G. Popović
ANALIZA RELATIVNOG KRETANJA PARA GP 34

21.03.1989.
J. Henrard (Université de Namur, Belgija)
DYNAMICS IN THE 2 : 1 RESONANCE

22.03.1989.
A. Kiseljev, A. Šaht (GAO AN SSSR, Pulkovo, Lenjingrad)
a) PROGRAM ZAJEDNIČKIH ISPITIVANJA VIZUALNO-DVOJNIH ZVEZDA I SATELITA VELIKIH PLANETA PULKOVSKE I BEOGRADSKE OPSERVATORIJE
b) AUTOMATSKA KASETA ZA FOTOGRAFSKA POSMATRANJA DVOJNIH ZVEZDA POMOĆU VELIKOG REFRAKTORA

S. Sadžakov: FUNDAMENTALNA ASTROMETRIJA
D. Djurović (Institut za astronomiju PMF-a, Beograd)
SAVREMENI PROBLEMI ZEMLJINE ROTACIJE I GEODINAMIKE
G. Popović: OBLAST VIŠESTRUKIH SISTEMA
Z. Knežević: MALE PLANETE, ELEMENTI, NEBESKA MEHANIKA
D. Olević: ASTROFOTOGRAFIJA

19.04.1989.
M. Dimitrijević
ISTRAŽIVANJA OBLIKA LINIJA U ASTROFIZIČKIM SPEKTRIMA

10.05.1989.
S. Ninković
ZVEZDANI SISTEMI

31.05.1989.
I. Vince
SUNCE KAO ZVEZDA — BEOGRADSKA ISTRAŽIVANJA

14.06.1989.
a) S. Ninković
GALAKTOCENTRIČNE PUTANJE GLOBULARNIH JATA
b) Juan Zorec (Institut za astrofiziku, Paris, Francuska)
DIFERENCIJALNA ROTACIJA B I Be ZVEZDA

S. Ninković
JEDNA PRIMENA TEOREME VIRIJALA NA NAŠU GALAKSIJU

4.10.1989.
a) A. Kubičela
FOTOSFERSKA KRETANJA VELIKIH RAZMERA
b) M. Dačić
RAD NA BEOGRADSKOM VELIKOM MERIDIJANSKOM KRUGU U TOKU 1968–1988
c) Z. Cvetković
KARAKTERISTIKE BEOGRADSKOG KATALOGA DVOJNIH ZVEZDA

1.11.1989.
S. Jankov
DOPPLER IMAGING SA TEORIJSKOG I POSMATRAČKOG ASPEKTA

15.11.1989.
M. Djokić
PREGLED RAZVOJA ISTRAZIVAČKIH AKTIVNOSTI NA ASTRONOMSKOJ OPSERVATORIJI U BEOGRADU

12.12.1989.
M. Marković (Rudarsko-geološki fakultet Univerziteta u Beogradu) O RADU EVROPSKE FONDACIJE ZA NAUKU (ECF)

27.12.1989.
Z. Knežević
ANALITIČKE TEORIJE SEKULARNIH POREMEĆAJA KRETANJA MALIH PLANETA

21.02.1990.
G. Djurašević
IZUČAVANJE AKTIVNIH TESNIH DVOJNIH SISTEMA

7.03.1990.
I. Vince
BELI FLEROVI

21.03.1990.
J. Milogradov-Turin (Institut za astronomiju, Matematički fakultet, Beograd)
GALAKTIČKI RADIO-HALO

25.04.1990.
J. Arsenijević
TOPLE ZVEZDE SA EMISIONIM LINIJAMA

9.05.1990.
O. Atanacković-Vukmanović
PRENOS ZRAČENJA U ZVEZDANIM ATMOSFERAMA

16.05.1990.
V. Kršljanin
INVERZIJA PROFILA ZVEZDANIH SPEKTRALNIH LINIJA

2.07.1990.
V. Ivanova (Sekcija za astronomiju Bugarske akademije nauka)
POSMATRAČKE MOGUĆNOSTI NACIONALNE OPSERVATORIJE ROZHEN (BUGARSKA)

19.09.1990.
J. Sanz Subirana, R. Cubarsí Morena (Katalonski politehnički univerzitet, Barcelona)
REŠAVANJE BOLTZMANNOVE JEDNAČINE ZA NAŠU GALAKSIJU

25.10.1990.
S. Sadžakov
ULOGA FUNDAMENTALNE ASTROMETRIJE U ASTRONOMSKIM ISTRAŽIVANJIMA

7.11.1990.
M. Dačić
ODREĐIVANJE POLOŽAJA ZVEZDA U OKOLINI RADIO IZVORA

21.11.1990.
V. Čadež (Institut za fiziku, Beograd)
O PRIMENLJIVOSTI DŽINSOVOG KRITERIJUMA

5.12.1990.
M. Dimitrijević
RAZVOJ ISTRAŽIVANJA PROFILA SPEKTRALNIH LINIJA U JUGOSLAVIJI

26.12.1990.
S. Šegan (Institut za astronomiju, Matematički fakultet, Beograd)
SATELITSKA ASTRONOMIJA

27.12.1990.
V. V. Orlov (Lenjingradski državni univerzitet)
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STARK WIDTHS OF FOUR- AND FIVE-TIMES CHARGED ION LINES FOR ASTROPHYSICISTS

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Important astrophysical applications of Stark broadening of multiply charged ion spectral lines are in the physics of stellar interiors (Seaton 1987). In subphotospheric layers, the modelling of energy transport requires radiative opacities and thus, certain atomic processes must be known with accuracy. At these high temperatures (10^5 K or more) and densities (10^{17} -10^{22}cm^{-3}) Stark broadening of strong multicharged ionic lines plays a non-negligible role in the calculation of the opacities, especially in the UV. Moreover, with the development of spectroscopy investigations from space, UV and extreme UV spectral line research has been further stimulated. The aim of this paper is to provide Stark broadening data of astrophysical interest for four- and five-times charged ion lines. In such a way, our intention is to complete such data, together with the published studies for N V and O VI lines (Dimitrijević and Sahal-Bréchot 1992ab) and with studies of C V, O V, P V and S VI lines, which are in preparation. Consequently, in the case of C V and O V, data calulations have been performed only for such cases for which atomic data set is not sufficient for semiclassical perturbation calculations. Since theoretical errors for shifts are considerably larger than for line widths, and since the astrophysical importance of multiply charged ion Stark widths is greater, only width calculations have been performed.

Stark line widths(FWHM) for 3 C V, 50 O V, 12 F V, 9 Ne V, 3 Al V, 6 Si V, 11 N VI, 28 F VI, 8 Ne VI, 7 Na VI, 15 Si VI, 6 P VI, and 1 Cl VI multiplet calculated using the modified semi-empirical approach (Dimitrijević and Konjević 1980) - (WMSE) will be published in Dimitrijević 1993a. A sample of results is presented in Table 1. Data are presented for an electron density of 10^{17}cm^{-3} and temperatures from 50,000 to 800,000 K. Data are linear with electron density, but at very high densities Debye screening should be considered (see e.g. Griem 1974). Moreover, for lines with very near perturbing levels broadening by inelastic proton collisions may be also important. Comparison of the present values with values calculated by using Eq. (526) in Griem (1974) have been performed, and the obtained agreement is satisfactory. As an example, the comparison for C V $3s^1S$ - $3p^1P^0$, N VI $2s^1S$ - $2p^1P^0$ and O V $4p^1P^0$ - $4d^1D$ cases is presented in Table 2. In comparison with the experiment of Purić et al (1988) for two O V lines, both approaches give about two times smaller values.

REFERENCES

Dimitrijević,M.S., 1993a, *A&AS* in press.
Dimitrijević,M.S., 1993b, *Astrophys. Lett. Communications* in press.
Dimitrijević,M.S. and Konjević,N., 1980, *JQSRT* **24**, 451.
Dimitrijević,M.S. and Sahal-Bréchot,S., 1992a, *A&AS* **95**, 109.
Dimitrijević,M.S. and Sahal-Bréchot,S., 1992b, *A&AS* **93**, 359.

Table 1. Stark width (FWHM) in Åunits calculated by using the modified semiempirical approach (Dimitrijević and Konjević 1980), at an electron density of 10^{17} cm^{-3}.

Transition	Lambda(A)	T(K)=50000	100000	200000	400000	800000
C V 1s21S - 3p1P	35.0	0.100E-04	0.881E-05	0.846E-05	0.700E-05	0.660E-05
C V 2s1S - 3p1P	247.3	0.431E-03	0.372E-03	0.362E-03	0.298E-03	0.266E-03
N VI 1s21S - 2p1P	28.8	0.418E-06	0.307E-06	0.248E-06	0.208E-06	0.176E-06
N VI 2s3S - 3p3P	161.2	0.951E-04	0.792E-04	0.676E-04	0.588E-04	0.575E-04
N VI 2p3P - 3d3D	173.9	0.553E-04	0.447E-04	0.367E-04	0.311E-04	0.312E-04
N VI 2p3P - 4d3D	130.3	0.368E-03	0.295E-03	0.239E-03	0.199E-03	0.159E-03
N VI 2p3P - 5d3D	116.8	0.846E-03	0.697E-03	0.577E-03	0.467E-03	0.374E-03
N VI 3p3P - 4d3D	500.9	0.616E-02	0.499E-02	0.408E-02	0.342E-02	0.283E-02
N VI 3p3P - 5d3D	346.7	0.780E-02	0.644E-02	0.534E-02	0.434E-02	0.352E-02
O V 2s21S - 3p1P	172.2	0.148E-03	0.115E-03	0.978E-04	0.838E-04	0.723E-04
O V 2s21S - 4p1P	135.5	0.424E-03	0.370E-03	0.320E-03	0.284E-03	0.271E-03
O V 2p1P -5d1D	154.0	0.153E-02	0.131E-02	0.110E-02	0.921E-03	0.766E-03
O V 3s1S - 4p1P	566.2	0.627E-02	0.543E-02	0.475E-02	0.419E-02	0.398E-02
O V 3p1P -4s1S	662.9	0.606E-02	0.510E-02	0.437E-02	0.394E-02	0.370E-02
O V 3p1P -4d1D	604.4	0.641E-02	0.546E-02	0.474E-02	0.433E-02	0.395E-02
O V 3p1P -5d1D	439.5	0.130E-01	0.111E-01	0.931E-02	0.782E-02	0.652E-02
O V 3d1D - 4p1P	798.3	0.887E-02	0.756E-02	0.649E-02	0.579E-02	0.559E-02
O V 2p21S -3s'1P	265.6	0.324E-03	0.282E-03	0.246E-03	0.210E-03	0.237E-03
O V 2p21S -3d'1P	231.8	0.940E-04	0.757E-04	0.617E-04	0.502E-04	0.495E-04
O V 2p21D -3s'1P	231.1	0.246E-03	0.214E-03	0.187E-03	0.159E-03	0.179E-03
O V 2p21D -3d'1P	205.1	0.841E-04	0.685E-04	0.564E-04	0.463E-04	0.455E-04
O V 2p21D -3d'1D	216.0	0.107E-03	0.861E-04	0.808E-04	0.691E-04	0.574E-04
O V 2p21D -3d'1F	207.8	0.796E-04	0.633E-04	0.516E-04	0.427E-04	0.390E-04
O V 3s3S -4p3P	529.2	0.508E-02	0.432E-02	0.373E-02	0.333E-02	0.310E-02
O V 3s3S -5p3P	390.8	0.790E-02	0.686E-02	0.594E-02	0.529E-02	0.454E-02
O V 3p3P -5s3S	469.1	0.940E-02	0.820E-02	0.722E-02	0.626E-02	0.566E-02
O V 3p3P -5d3D	447.3	0.110E-01	0.944E-02	0.826E-02	0.724E-02	0.609E-02
O V 2p23P -3d'3D	203.9	0.110E-03	0.894E-04	0.744E-04	0.624E-04	0.569E-04
O V 2p23P -3d'3P	202.3	0.107E-03	0.853E-04	0.716E-04	0.603E-04	0.532E-04
O V 2p23P -3s'3P	227.5	0.177E-03	0.141E-03	0.122E-03	0.106E-03	0.910E-04
F V 2p3s2P-2p3p2S	154.2	0.734E-04	0.543E-04	0.447E-04	0.384E-04	0.342E-04
F V 2p3s2P-2p3p2P	162.0	0.710E-04	0.590E-04	0.509E-04	0.439E-04	0.376E-04
F VI 2s21S -2p1P	535.2	0.295E-03	0.209E-03	0.148E-03	0.105E-03	0.830E-04
F VI 2s21S -3p1P	126.9	0.606E-04	0.462E-04	0.381E-04	0.324E-04	0.276E-04
F VI 2s21S -4p1P	99.2	0.173E-03	0.150E-03	0.132E-03	0.119E-03	0.104E-03
F VI 2p1P -3s1S	173.1	0.841E-04	0.667E-04	0.570E-04	0.491E-04	0.417E-04
F VI 2p1P -4s1S	123.3	0.169E-03	0.149E-03	0.130E-03	0.111E-03	0.106E-03
F VI 2p1P -3d1D	121.2	0.232E-04	0.173E-04	0.148E-04	0.121E-04	0.102E-04
F VI 2p1P -4d1D	121.1	0.140E-03	0.121E-03	0.102E-03	0.931E-04	0.857E-04
F VI 3s1S -4p1P	410.7	0.266E-02	0.228E-02	0.201E-02	0.184E-02	0.158E-02
F VI 3p1P -4s1S	476.5	0.297E-02	0.257E-02	0.224E-02	0.191E-02	0.180E-02
F VI 2p21S -3s'1P	183.9	0.111E-03	0.961E-04	0.831E-04	0.699E-04	0.694E-04
F VI 2p21S -4s'1P	129.5	0.263E-03	0.228E-03	0.198E-03	0.195E-03	0.159E-03
F VI 3s'1P -3p'1S	117.6	0.374E-04	0.288E-04	0.242E-04	0.208E-04	0.178E-04
F VI 3s'1P -3p'1P	123.3	0.364E-04	0.300E-04	0.256E-04	0.217E-04	0.202E-04
F VI 3s'1P -3p'1D	118.9	0.471E-04	0.384E-04	0.330E-04	0.330E-04	0.270E-04
F VI 3s'1P -4p'1D	413.5	0.627E-02	0.496E-02	0.392E-02	0.309E-02	0.250E-02
F VI 3s'1P -4p'1P	431.6	0.275E-02	0.241E-02	0.210E-02	0.188E-02	0.172E-02
F VI 2p3P -3s3S	153.8	0.566E-04	0.408E-04	0.326E-04	0.285E-04	0.248E-04
F VI 2p2'3P-3s'3P	161.3	0.685E-04	0.502E-04	0.409E-04	0.354E-04	0.307E-04
Ne V 2p21S -3s1P	184.7	0.895E-04	0.684E-04	0.575E-04	0.494E-04	0.428E-04
Ne V 2p21D -3s1P	173.9	0.790E-04	0.605E-04	0.509E-04	0.437E-04	0.379E-04
Ne V 2p23P -3s3P	167.7	0.686E-04	0.494E-04	0.393E-04	0.342E-04	0.298E-04
Ne VI 2p34S-2p23s4P	142.5	0.471E-04	0.344E-04	0.278E-04	0.241E-04	0.209E-04
Ne VI 2p2P -3s2S	138.6	0.404E-04	0.288E-04	0.229E-04	0.196E-04	0.169E-04
Na VI 2p21S -3s1P	134.5	0.356E-04	0.252E-04	0.186E-04	0.153E-04	0.131E-04
Na VI 2p21D -3s1P	127.8	0.321E-04	0.227E-04	0.168E-04	0.138E-04	0.118E-04
Na VI 2p23P -3s3P	123.9	0.301E-04	0.213E-04	0.168E-04	0.141E-04	0.121E-04
Al V 2p52P -3s2P	130.9	0.325E-04	0.229E-04	0.170E-04	0.139E-04	0.119E-04

Table 2. Comparison of Stark widths calculated here by using the modified semiempirical approach (Dimitrijević and Konjević 1980) (WMSE), with values obtained by using the Eq. (526) in Griem (1974) (WG). The electron density is 10^{17} cm^{-3}.

ELEMENT/TRANSITION LAMBDA(A)		T(K)	WMSE(A)	WG(A)
C V	3s1S - 3p1P	50000.	1.79	1.63
		100000.	1.57	1.36
	12202.6	200000.	1.46	1.18
	X=56.5	400000.	1.22	1.05
		800000.	1.21	0.949
N VI	2s1S - 2p1P	50000.	0.700E-02	0.812E-02
		100000.	0.516E-02	0.607E-02
	2833.7	200000.	0.420E-02	0.475E-02
	X=2.95	400000.	0.357E-02	0.395E-02
		800000.	0.305E-02	0.349E-02
O V	4p1P -4d1D	50000.	4.35	4.16
		100000.	3.79	3.43
	11913.1	200000.	3.30	2.96
	X=29.2	400000.	2.98	2.64
		800000.	2.81	2.41

Griem,H.R., 1974, *Spectral Line Broadening by Plasmas* , Aca- demic Press, New York.
Purić,J., Djeniže,S., Srećković,A., Platiša,M., Labat,J., 1988, *Phys.Rev.A* **37**, 498.
Seaton,M.J., 1987, *J.Phys.B* **20**,6363.

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О ПАРАМЕТРИМА ШТАРКОВОГ ШИРЕЊА СПЕКТРАЛНИХ ЛИНИЈА, ПОТРЕБНИМ ЗА ИСТРАЖИВАЊЕ ЗВЕЗДАНЕ И ЛАБОРАТОРИЈСКЕ ПЛАЗМЕ

МИЛАН С. ДИМИТРИЈЕВИЋ

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Резиме. Дат је преглед семикласичних истраживања параметара Штарковог ширења спектралних линија од интереса за истраживање звездане и лабораторијске плазме, при чему су разматрани различити семикласични методи и поређење теоријских резултата са критички одабраним експерименталним подацима и резултатима егзактнијег кванто - механичког метода јаке спреге. Такође су размотрени и приближни методи за прорачун параметара Штарковог ширења, који су нарочито корисни код таквих астрофизичких проблема код којих је неопходно извршити прорачун за велики број спектралних линија при чему је нарочито критична средња тачност а не толико тачност сваког појединачног резултата. Такође је описан и почетак и развој истраживања облика спектралних линија у Југославији.

Астрофизички аспекти истраживања Штарковог ширења спектралних линија

Тешко је генерално издвојити астрофизички значајне спектралне линије, с обзиром да хемијски састав неке звезде није a priori познат и постоје многе интересантне групе звезда чији је хемијски састав различит од сунчевог. Према томе, спектроскопија звезда зависи од података о великом броју спектралних линија различитих елемената, њихових атомских параметара и параметара ширења.

Интерес за велики број података о ширењу линија различитих емитера,

нарочито је порастао развојем космичке астрономије, што је омогућило прикупљање великог броја спектроскопских података у широком спектралном опсегу, од различитих небеских објеката, посебно стимулишући истраживање облика спектралних линија.

Ширење услед интеракције између емитера и наелектрисаних честица (Штарково ширење) доминантно је у неколико случајева од астрофизичког интереса. За $T_{\rm eff} > 10^4$K, водоник, главни конституент звездане атмосфере, углавном је јонизован па је међу механизмима ширења притиском доминантан Штарков ефекат. То је случај са белим патуљцима и топлим звездама O, B и A0 типа. Чак и код атмосфера хладнијих звезда као што је Сунце Штарково ширење може бити значајно. На пример, утицај Штарковог ширења у спектралној серији расте са порастом главног квантног броја горњег нивоа (Dimitrijević i Sahal-Bréchot 1984a,b; 1985a) па сходно томе допринос Штарковог ширења може бити значајан и у Сунчевом спектру (Vince i Dimitrijević 1985; Vince i dr. 1985a,b).

На пример чланови са великим главним квантним бројем у Балмеровој серији могу бити искоришћени као веома погодно средство за дијагностику приликом проучавања сунчеве атмосфере. Фелдман и Дошек (Feldman i Doshek, 1977) су искористили профиле линија Балмерове серије са главним квантним бројем n између 16 и 32 (на које снажно утиче Штарков ефекат) да би одредили концентрацију електрона и температуру у једној активној области на Сунцу.

Поуздани подаци о Штарковом ширењу спектралних линија потребни су такође за одређивање хемијске заступљености елемената, на основу еквивалентних ширина апсорпционих линија и за проучавање преноса зрачења кроз звездану плазму и то нарочито у субфотосферским слојевима, а осим тога потребни су и за прорачун непрозрачности плазме (опацитета). У таквом случају потребно је нарочито много података о спектралним линијама. Као добра илустрација може да послужи чланак о прорачуну непрозрачности код класичних модела цефеида (Iglesias i dr. 1990), где је узето у обзир 11,996.532 спектралних линија (45 линија H, 45 He, 638 C, 54 N, 2390 O, 16030 Ne, 50170 Na, 105700 Mg, 145200 Al, 133700 Si, 12560 Ar и 11,530.000 Fe), при чему је узето у обзир и њихово Штарково ширење.

Семикласичан метод

Упркос чињеници да је најегзактнији теоријски метод за проучавање Штарковог ширења квантно-механички метод јаке спреге, услед његове комплексности и нумеричких тешкоћа, постоји само мали број таквих прорачуна. На пример метод јаке спреге је примењен у случају линија Li I (2s – 2p) (Dimitrijević i dr. 1981), Ca II (4s – 4p и 3d – 4p) , (Barnes, 1971; Barnes i Peach, 1970) Mg II (3s – 3p) (Barnes, 1971; Bely i Griem, 1970) и Be II (2s – 2p) (Sanchez i dr., 1973). Ситон је извео прорачуне методом јаке спреге за 42 прелаза код Li–сличних јона Be II, B III, C IV, O VI, Ne VIII (Seaton, 1988) и за прелазе $2s^2\ {}^1S - 2s2p\,{}^1P^o$, $2s2p\,{}^3P^o - 2p^2\ {}^3P$ и $2s2p\,{}^1P^o - 2p^2\ {}^1D$ и ${}^1S$ код C III, O V и Ne VII (Seaton, 1987).

У многим случајевима као што су, на пример, комплексни спектри, тешки елементи или прелази између виших енергетских нивоа, егзактнији квантномеханички метод је веома тешко или чак и практично немогуће применити па у таквим случајевима семикласичан прилаз остаје најефикаснији метод за прорачун параметара Штарковог ширења.

Постојећи опсежни прорачуни параметара Штарковог ширења изведени су користећи три различита компјутерска програма које су развили (i) Џонс, Бенет и Грим (Jones i dr., 1971; Benett i Griem, 1971; Griem, 1974), (ii) Сахал-Брешо (1969a,б) и (iii) Басало, Катани и Валдер (1982).

У компјутерском програму који су развили Басало, Катани и Валдер, употребљена је такозвана конвергентна теорија коју су оригинално развили Вајнштајн и Собељман (1959). Користећи сличности између Дајсоновог низа за пертурбациони развој S матрице и Тејлоровог низа за развој експоненцијалне функције, овај метод избегава дивергенцију до које долази приликом интеграције по ударном параметру (ρ) када ρ тежи ка нули.

Опсежни прорачуни параметара Штарковог ширења линија не–водоничних неутрала и једноструко наелектрисаних јона (од хелијума до калцијума и цезијум), изведени уз помоћ компјутерског програма Џонса, Бенета и Грима објављени су 1971 и касније 1974 (Jones i dr., 1971; Benett i Griem, 1971; Griem, 1974). Користећи исти компјутерски програм (Griem, 1974) и верзију коју је Димитријевић прилагодио за случај вишеструко наелектрисаних јона, објављени су подаци за Br I, Ge I, Hg I, Pb I, Rb I, Cd I, Zn I (Dimitrijević i Konjević, 1983), O II (Dimitrijević, 1982a), O III (Dimitrijević, 1980a), C III (Dimitrijević, 1980b), C IV (Dimitrijević, 1980b; 1988a), N II, N III, N IV (Dimitrijević i Konjević, 1981a), S III, S IV, Cl III (Dimitrijević i Konjević, 1982) и Ti II, Mn II (Dimitrijević, 1982b).

Семикласични прорачуни на основу метода који је развила Сахал-Брешо (1969a,б) постоје за лакше елементе као што су C, N, Mg, Si (без доприноса резонанци [види, на пример, Сахал-Брешо и Сегре (1971) и наведене референце]. Подаци за јоне сличне алкалима Be II, Mg II, Ca II, Sr II и Ba II могу се наћи у раду Флориеа и др. (1977), док су у раду Лесажа и др. (1983) упоређени семикласични и експериментални подаци за линије Si II. Користећи овај компјутерски програм извршени су опсежни прорачуни за 79 мултиплета неутралног хелијума (Dimitrijević i Sahal-Bréchot, 1984a,b), 62 натријума (Dimitrijević i Sahal-Bréchot, 1985; 1990b,c), 51 калијума (Dimitrijević i Sahal-Bréchot, 1987; 1990d), 61 литијума (Dimitrijević i Sahal-Bréchot, 1991a,b), 25 алуминијума (Dimitrijević i Sahal-Bréchot, 1992a; 1994a), 24 рубидијума (Dimitrijević i Sahal-Bréchot, 1992b; 1994b), 3 паладијума (Dimitrijević 1993a), 19 берилијума (Dimitrijević i Sahal-Bréchot, 1992c), 270 магнезијума (Dimitrijević i Sahal-Bréchot, 1994c,d), 28 Ca II (Dimitrijević i Sahal-Bréchot, 1992d; 1993b), 30 Be II (Dimitrijević i Sahal-Bréchot, 1992e,f), 23 Al III (Dimitrijević i Sahal-Bréchot, 1993c,d), 10 Sc III, 10 Ti IV (Dimitrijević i Sahal-Bréchot, 1992g), 39 Si IV (Dimitrijević i dr., 1991a,b), 90 C IV (Dimitrijević i dr., 1991c,d; Dimitrijević i Sahal-Bréchot, 1992h), 30 N V (Dimitrijević i Sahal-Bréchot, 1992i), 30 O VI (Dimitrijević i Sahal-Bréchot, 1992j), 21 S VI (Dim-

itrijević i Sahal-Bréchot, 1993e), 10 F VII (Dimitrijević i Sahal-Bréchot, 1993f), 20 Ne VIII, 8 Na IX (Dimitrijević i Sahal-Bréchot, 1994e), 7 Al XI, и 9 Si XII (Dimitrijević i Sahal-Bréchot, 1994f) мултиплета. Такође постоје и подаци за појединачне линије F I (Vujnović i dr. 1983), Ar II (Dimitrijević i Truong-Bach, 1986), Ga II, Ga III (Dimitrijević i Artru, 1986), Si II (Lanz i dr., 1988), Cl I, Br I, I I (Djurović i dr., 1990), Cu I (Dimitrijević i Vujnović, 1990) и Hg II (Dimitrijević, 1992).

Објављен је такође опсежни прорачун линија He I, који су извршили Басало, Катани и Валдер користећи конвергентни семикласични метод.

Резултати сва три метода упоређени су са критички изабраним експерименталним подацима за 13 мултиплета He I (Dimitrijević i Sahal-Bréchot, 1985b). Слагање између експерименталних података и сва три семикласична прорачуна је у границама од ±20%, што је и предвиђена тачност семикласичног метода. (Griem, 1974).

Уопштено, подаци о ширини линије су много поузданији него подаци о помаку, с обзиром да је прорачун помака много осетљивији на мале промене различитих параметара. То је последица чињенице да су вредности помака мање од ширина и да су помаци настали услед деловања судара који су у просеку много дањи (минимални ударни параметар је много већи).

На крају, ако не постоје теоријски подаци, од велике помоћи могу бити прегледи критички изабраних експерименталних података (Konjević i Roberts, 1976; Konjević i Wiese, 1976; Konjević i dr., 1984a,b; Konjević i Wiese, 1990).

Приближни методи

Кадгод су потребни подаци о Штарковом ширењу за велики број спектралних линија, при чему висока тачност сваког појединачног резултата није посебно важна, просте приближне формуле чији резултати су добре тачности када се усредње, могу бити од велике користи. Осим тога, у случају комплекснијих атома или вишеструко наелектрисаних јона, услед недостатка довољно тачних атомских података неопходних за тачније прорачуне, поузданост семикласичних резултата опада. У таквим случајевима расте значај приближних метода.

Постојеће приближне методе за прорачун параметара Штарковог ширења можемо да поделимо у три групе. У првој су они методи где је најкомпликованији део прорачуна, прорачун пресека за диполне прелазе, избегнут коришћењем усредњених експерименталних (на пример (Griem, 1968; Dimitrijević i Konjević, 1980, 1981b,c; 1987; Dimitrijević i Kršljanin, 1986; Dimitrijević, 1988b; Hey i Bryan, 1977) или теоријских података (Seaton, 1987). У другу групу можемо да ставимо оне методе у којима се најкомпликованији део егзактне теорије упрошћава (на пример Griem, 1974) или се врши интерполација између теоријски једноставнијих граничних вредности (на пример Dimitrijević i Konjević, 1986). У трећој групи су могућности за интерполацију нових података уз помоћ регуларности и систематских трендова (на пример Wiese i Konjević,

1982; Dimitrijević i Peach, 1990; Dimitrijević, 1985; Dimitrijević i Popović, 1989; Purić i dr., 1980; 1991; Lakićević i Purić, 1983; Vitel i dr., 1988; Djeniže i dr., 1990).

Од нарочитог интереса за астрофизичке потребе може бити упрошћена семиемпиријска формула (Dimitrijević i Konjević, 1987) за Штаркове ширине изолованих линија једноструко и вишеструко наелектрисаних јона. Треба имати на уму да је ова формула применљива када је најближи атомски енергетски ниво (j'=i' или f') на који диполно дозвољени прелаз са почетног (и) или коначног нивоа разматране линије може да се деси, тако далеко да је задовољен услов $x_{jj'} = E/|E_{j'} - E_j| \leq 2$. У том случају пуна ширина на половини максималне висине је дата изразом (Dimitrijević i Konjević, 1987):

$$W(\text{Å}) = 2.2151\times10^{-8}\frac{\lambda^2(\text{cm})N(\text{cm}^{-3})}{T^{1/2}(\text{K})}(0.9-\frac{1.1}{Z})\sum_{j=i,f}(\frac{3n_j^*}{2Z})^2(n_j^{*2}-\ell_j^2-\ell-1) \quad (1)$$

Овде су N и T електронска концентрација и температура респективно, $E = 3kT/2$ је енергија пертурбујућег електрона, $Z-1$ је наелектрисање јона а n је ефективни главни квантни број. Овај израз је од значаја за одређивање заступљености хемијских елемената у звезданим атмосферама, као и за дијагностику звездане плазме, с обзиром да су услови за примену формуле у овим случајевима често задовољени.

Слично, у случају помака

$$\begin{aligned} d(\text{Å}) =& 1.1076\times10^{-8}\frac{\lambda^2(\text{cm})N(\text{cm}^{-3})}{T^{1/2}(\text{K})}(0.9-\frac{1.1}{Z})\frac{9}{4Z^2} \\ &\times\sum_{j=i,f}\frac{n_j^*\varepsilon_j^2}{2\ell_j+1}\{(\ell_j+1)[n_j^{*2}-(\ell_j+1)^2]-\ell_j(n_j^{*2}-\ell_j^2)\} \end{aligned}, \quad (2)$$

где је $\varepsilon = +1$ иако је $j = i$ а -1 ако је $j = f$.

Ако сви нивои $\ell_{i,f}\pm1$ постоје, може се извести додатно сумирање у једначини (2), па се добија

$$\begin{aligned} d(\text{Å}) =& 1.1076\times10^{-8}\frac{\lambda^2(\text{cm})N(\text{cm}^{-3})}{T^{1/2}(\text{K})}(0.9-\frac{1.1}{Z})\frac{9}{4Z^2} \\ &\times\sum_{j=i,f}\frac{n_j^*\varepsilon_j^2}{2\ell_j+1}(n_j^{*2}-3\ell_j^2-3\ell_j-1). \end{aligned} \quad (3)$$

Када упрошћена семиемпиријска формула није применљива, добре могућности пружа модификовани семиемпиријски метод (Dimitrijević i Konjević, 1980; 1981b; 1987; Dimitrijević i Kršljanin, 1986; Dimitrijević, 1988b). Да би се овај прилаз тестирао, изабрани експериментални подаци за 36 мултиплета (7 различитих врста јона) двоструко и троструко наелектрисаних јона упоређени су са теоријским ширинама линија. Усредњене вредности односа мерених и рачунатих ширина линија су следеће (Dimitrijević i Konjević, 1980): за

двоструко наелектрисане јоне 1.06±0.32 а за троструко наелектрисане 0.91±0.42. Модификовани семиемпиријски прилаз тестиран је више пута на бројним примерима (Dimitrijević, 1990). Објављени су подаци за најинтензивније линије следећих емитера: Be III, B III, B IV, C III, C IV, N III, N IV, O III, O IV, F III, Ne III, Ne IV, Na III, Mg IV, Al III, Si III, Si IV, P III, P IV, S III, S IV, Cl III, Cl IV, Ar III, Ar IV (Dimitrijević i Konjević, 1981b; Dimitrijević 1988b); C V, N VI, O V, F V, F VI, Ne V, Ne VI, Al V, Si V, Si VI, P VI, и Cl VI (Dimitrijević, 1993b). Осим тога, подаци о ширинама линија објављени су и за појединачне линије Ti II, Mn II (Dimitrijević, 1990), Fe II (Dimitrijević, 1988c), Cu IV (Dimitrijević i dr., 1989), Pt II (Dimitrijević, 1993c), Bi II (Dimitrijević, i Popović, 1994), Zn II, Cd II (Popović i dr., 1994) а подаци о помаку за Ar II линије (Kršljanin i Dimitrijević, 1989a,b).

Регуларности и систематски трендови

Када нема поузданих података, познавање регуларности и систематских трендова параметара ширења линија може бити употребљено за брзе процене нових података, нарочито када висока тачност сваког појединог податка није неопходна.

Регуларности и систематски трендови ширина изолованих неводоничних спектралних линија у плазми недавно су проучавани у низу чланака (види на пример Dimitrijević, 1982a; Wiese i Konjević, 1982; Dimitrijević i Peach, 1990; Dimitrijević, 1985; Dimitrijević i Popović, 1989; Purić i dr., 1980; 1991; Lakićević i Purić, 1983; Vitel i dr., 1988; Djeniže i dr., 1990; Konjević i Dimitrijević, 1981). Циљ оваквих проучавања је да се установи да ли регуларности и систематски трендови могу бити искоришћени за добијање нових вредности ширина линија и за критичку процену експерименталних података. На основу познавања регуларности и систематских трендова могли би смо на основу познатих експерименталних и теоријских вредности интерполацијом доћи до нових података потребних у спектроскопији звезда.

Ипак треба узети у обзир да систематски трендови и подаци о ширењу линија важе за услове у плазми за које су добијени и да екстраполације могу да доведу до грубих грешака.

Истраживања у Југославији

Први рад о профилима спектралних линија у старој Југославији објавио је 1962 године В. Вујновић из Загреба а у Србији 1964 године М. Д. Маринковић из Београда. До септембра 1993 године објављено је 869 библиографских јединица од укупно 127 југословенских аутора, од чега велики део у најпознатијим светским часописима као што су Astronomy and Astrophysics, Physical Review, Astrophysical Journal, Journal of Physics, Zeitschrift fuer Physik, Physics Letters, итд. Последњих година у просеку се објављује 60-так радова годишње што

сведочи о замаху ове области код нас.

Овако интензиван развој области и стварање праве југословенске школе, можда је највише последица чињенице да су неколицина сјајних истраживача из неколико наших градова и то Н. Коњевић и Ј. Лабат из Београда, М. Павлов из Новог сада и В. Вујновић из Загреба, радили на својим докторским дисертацијама у истом граду, у Ливерпулу, из сличних области и у исто време у лабораторијама професора Крегса и његових сарадника. У току дужег времена су били заједно и када су се вратили, у нашој земљи се брзо створило неколико центара у којима су на овој проблематици радили људи који су се међусобно познавали и дружили што је овој области брзо донело критичну масу, која је омогућавала инспиративну научну дискусију и плодотворну размену идеја. Они су били попут центара кристализације који су окупљали младе и способне људе уводећи их брзо у актуелне проблеме светске науке.

Први експериментални уређај за истраживање профила линија плазме, почели су у Београду да праве Јарослав Лабат и Љубомир Ћирковић. Њима се придружио тадашњи магистрант а садашњи редовни професор физичког факултета Јагош Пурић, а по повратку из Ливерпула и Никола Коњевић. Данас се у Београду на овим истраживањима ради у три институције. На физичком факултету, где су Јарослав Лабат, Јагош Пурић, Никола Коњевић, Михајло Платиша, Стеван Ђениже и њихови бројни сарадници, у Институту за физику у Земуну, где се експериментални рад одвија под руководством Николе Коњевића и, на Астрономској опсерваторији, где осим аутора раде на оваквим истраживањима и Иштван Винце, Владимир Кршљанин, Олга Атанацковић-Вукмановић, Слободан Јанков, Лука Поповић, Сања Еркапић и Дарко Јевремовић.

На овој проблематици остварена је интензивна и плодоносна међународна сарадња са Париском опсерваторијом, Институтом за астрофизику у Паризу, са САД, Енглеском, Немачком, Пољском и Тунисом. Бројност људи у нашој средини који се овом проблематиком баве на светском нивоу, ствара критичну масу са бројним међународним везама, што даје велику перспективу младима, да брзо достигну ниво који им омогућава проходност постигнутих резултата у најпознатије светске часописе.

Референце

Barnes, K. S.: 1971, *J. Phys. B*, **4**, 1377.

Barnes, K. S. & Peach, G.: 1970, *J. Phys. B*, **3**, 350.

Bassalo, J., Cattani, M. & Walder, W. S.: 1982, *JQSRT*, **28**, 75.

Bely, O. & Griem, H. R.: 1970, *Phys. Rev. A*, **1**, 97.

Benett, S. M. & Griem, H. R.: 1971, *Calculated Stark Broadening Parameters for Isolated Spectral Lines from the Atom Helium through Calcium and Cesium*, Univ. Maryland, Techn. Rep. No 71–097, College Park, Maryland.

Dimitrijević, M. S.: 1980a, *Publ. Obs. Astron. Sarajevo*, **1**, 215.

Dimitrijević, M. S.: 1980b, *V ESCAMPIG*, Dubrovnik p. 90.

Dimitrijević, M. S.: 1982a, *Astron. Astrophys.* **112**, 251.

Dimitrijević, M. S.: 1982b in *Sun and Planetary System*, eds. W. Fricke and G. Teleki, Astrophys. and Space Library 96, D. Reidel P. C., Dordrecht, Boston, London, p. 101.
Dimitrijević, M. S.: 1985, *Astron. Astrophys.* **145**, 439.
Dimitrijević, M. S.: 1988a, *Bull. Obs. Astron. Belgrade*, **139**, 31.
Dimitrijević, M. S.: 1988b, *Astron. Astrophys. Suppl. Series*, **76**, 53.
Dimitrijević, M. S.: 1988c, in *Physics of Formation of Fe II Lines Outside LTE*, eds. R. Viotti, A. Vitone, M. Friedjung, D. Reidel P. C. p. 211.
Dimitrijević, M. S.: 1990, in *Accuracy of Element Abundances from Stellar Atmospheres* ed. R. Wehrse, Lecture Notes in Physics 356, Springer, Berlin-Heidelberg p. 31.
Dimitrijević, M. S.: 1992, *JQSRT*, **47**, 315.
Dimitrijević, M. S.: 1993a, *Astron. Astrophys.* **100**, 237.
Dimitrijević, M. S.: 1993b, *Astrophys. Lett. Communications*, **28**, 381.
Dimitrijević, M. S. & Artru M. C.: 1986, *XIII Symp. Phys. Ioniz. Gases*, Šibenik, p. 317.
Dimitrijević, M. S., Djurić, Z. & Mihajlov, A. A.: 1989, *J. Phys. Coll. C 1, Suppl. au No 1*, 50, C1-623.
Dimitrijević, M. S., Djurić, Z. & Mihajlov, A. A.: 1994, *J. Phys. D*, **27**, 247.
Dimitrijević, M. S., Feautrier, N. & Sahal–Bréchot, S.: 1981, *J. Phys. B*, **14**, 2559.
Dimitrijević, M. S., & Konjević, N.: 1980, *JQSRT*, **24**, 451.
Dimitrijević, M. S., & Konjević, N.: 1981a, *JQSRT*, **25**, 387.
Dimitrijević, M. S. & Konjević, N.: 1981b in *Spectral Line Shapes*, Ed. B. Wende, W. de Gruyter, Berlin, New York p. 211.
Dimitrijević, M. S. & Konjević, N.: 1981c, *Astron. Astrophys.*, **102**, 93.
Dimitrijević, M. S. & Konjević, N.: 1982, *JQSRT*, **27**, 203.
Dimitrijević, M. S. & Konjević, N.: 1986, *Astron. Astrophys.* **163**, 297.
Dimitrijević, M. S. & Konjević, N.: 1987, *Astron. Astrophys.* **172**, 345.
Dimitrijević, M. S. & Kršljanin, V.: 1986, *Astron. Astrophys.* **165**, 269.
Dimitrijević, M. S. & Peach, G.: 1990, *Astron. Astrophys.* **236**, 261.
Dimitrijević, M. S., & Popović, M. M.: 1989, *Astron. Astrophys.* **217**, 201.
Dimitrijević, M. S. & Sahal-Bréchot, S.: 1984a, *JQSRT*, **31**, 301.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1984b, *Astron. Astrophys.* **136**, 289.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1985a, *JQSRT*, 34, **149**.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1985b, *Phys. Rev. A*, **31**, 316.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1987, *JQSRT*, **38**, 37.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1989, *Bull. Obs. Astron. Belgrade*, **141**, 57.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1990a, *Astron. Astrophys. Suppl. Series*, **82**, 519.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1990b, *JQSRT*, **44**, 421.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1990c, *Bull. Obs. Astron. Belgrade*, **142**, 59.

Dimitrijević, M. S. & Sahal–Bréchot, S.: 1990d, *Bull. Obs. Astron. Belgrade*, **142**, 29.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1991a, *JQSRT*, **40**, 41.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1991b, *Bull. Obs. Astron. Belgrade*, **143**, 29.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1992a, *Bull. Obs. Astron. Belgrade*, **146**, 83.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1992b, *Bull. Obs. Astron. Belgrade*, **146**, 97.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1992c, *Bull. Obs. Astron. Belgrade*, **146**, 73.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1992d, *Bull. Astron. Belgrade*, **145**, 81.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1992e, *JQSRT*, **48**, 397.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1992f, *Bull. Astron. Belgrade*, **145**, 65.
Dimitrijević, M. S. & Sahal-Bréchot, S.: 1992g, *Astron. Astrophys. Suppl. Series*, **95**, 121.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1992h, *Astron. Astrophys. Suppl. Series*, **96**, 613.
Dimitrijević, M. S. & Sahal-Bréchot, S.: 1992i, *Astron. Astrophys. Suppl. Series*, **95**, 109.
Dimitrijević, M. S. & Sahal-Bréchot, S.: 1992j, *Astron. Astrophys. Suppl. Series*, **93**, 359.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1993a, *Astron. Astrophys. Suppl. Series*, **100**, 593.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1993b, *JQSRT*, **49**, 157.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1993c, *Astron. Astrophys. Suppl. Series*, **99**, 585.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1993d, *Bull. Astron. Belgrade*, **147**, 35.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1993e, *Astron. Astrophys. Suppl. Series*, **100**, 91.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1993f, *Astron. Astrophys. Suppl. Series*, **101**, 587.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1994a, *Physica Scripta*, **49**, 34.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1994b, *Physica Scripta*, **49**, 661.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1994c, *Bull. Astron. Belgrade*, **149**, 31. (**150**, 121).
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1994d, *Bull. Astron. Belgrade*, **150**, 47.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1994e, *Astron. Astrophys. Suppl. Series*, **107**, 349.
Dimitrijević, M. S. & Sahal–Bréchot, S.: 1994f, *Astron. Astrophys. Suppl. Series*, **105**, 245.
Dimitrijević, M.S., Sahal-Bréchot, S. & Bommier, V.: 1991a, *Astron. Astrophys. Suppl. Series* **89**, 581.
Dimitrijević, M.S., Sahal-Bréchot, S. & Bommier, V.: 1991b, *Bull. Obs. Astron. Belgrade*, **144**, 65.

Dimitrijević, M.S., Sahal-Bréchot, S. & Bommier, V.: 1991c, *Astron. Astrophys. Suppl. Series* **89**, 591.

Dimitrijević, M.S. Sahal-Bréchot, S. & Bommier, V.: 1991d, *Bull. Obs. Astron. Belgrade*, **144**, 81.

Dimitrijević, M. S. & Truong–Bach: 1986, *Z. Naturforsch.* **41a**, 772.

Dimitrijević, M. S. & Vujnović, V.: 1990 *Proc. XV SPIG*, Dubrovnik, 241.

Djeniže S., Srećković, A., Platiša, M., Konjević, R., Labat, J., Purić, J.: 1990, *Phys. Rev. A*, **42**, 2379.

Djurović, S., Konjević, N. & Dimitrijević, M. S.: 1990, *Z. Phys. D*, **16**, 255.

Feldman, U. & Doschek, G. A.: 1977, *Astrophys. J.* **212**, 913.

Fleurier, C., Sahal–Bréchot, S. & Chapelle, J.: 1977, *JQSRT*, **17**, 595.

Griem, H. R.: 1968, *Phys.Rev.*, **165**, 258.

Griem, H. R.: 1974, *Spectral Line Broadening by Plasmas*, Academic Press, New York & London.

Hey, J. D. & Bryan, R. J.: 1977, *JQSRT*, **17**, 221.

Iglesias, C. A., Rogers, F. J. & Wilson, B. G.: 1990, *Astrophys. J.*, **360**, 221.

Jones, W. W. Benett, S. M. & Griem, H. R.: 1971, *Calculated Electron Impact Broadening Parameters for Isolated Spectral Lines from Singly Charged Ions Lithium through Calcium*, Univ. Maryland , Techn. Rep. No 71–128, College Park, Maryland.

Konjević, N. & Dimitrijević, M. S.: 1981 in *Spectral Line Shapes I* ed. B.Wende, W.de Gruyter, Berlin, New York p. 211.

Konjević, N., Dimitrijević, M. S. & Wiese W. L.: 1984a, *J. Phys. Chem. Ref. Data*, **13**, 619.

Konjević, N., Dimitrijević, M. S. & Wiese, W. L.: 1984b, *J. Phys. Chem. Ref. Data*, **13**, 649.

Konjević, N. & Roberts, D. E.: 1976, *J. Phys. Chem. Ref. Data*, **5**, 209.

Konjević, N. & Wiese, W. L.: 1976, *J. Phys. Chem. Ref. Data*, **5**, 259.

Konjević, & Wiese, W. L.: 1990, *J. Phys. Chem. Ref. Data*, **19**, 1307.

Kršljanin, V. & Dimitrijević, M. S.: 1989a, *Bull. Obs. Astron. Belgrade*, **140**, 7.

Kršljanin, V. & Dimitrijević, M. S.: 1989b, *Z. Phys. D*, **14**, 273.

Lakićević, I. S. & Purić, J.: 1983 in *Spectral Line Shapes II*, ed. K. Burnett, W. de Gruyter, Berlin, New York, p 147.

Lanz, T., Dimitrijević, M.S. & Artru M.-C.: 1988, *Astron.Astrophys.*, **192**, 249.

Lesage, A., Rathore, B. A., Lakićević, I. S. & Purić, J.: 1983, *Phys.Rev.A*, **28**, 2264.

Popović, L. Č. Vince, I. Dimitrijević, M. S.: 1994, *Astron. Astrophys. Suppl. Series*, **102**, 17.

Purić, J., Ćuk, M., Dimitrijević, M. S. & Lesage, A.: 1991, *Astrophys. J.*, **382**, 353.

Purić, J., Lakićević, I. & Glavonjić, V. : 1980, *Phys. Lett.*, **76a**, 128.

Sahal-Bréchot, S.: 1969a, *Astron. Astrophys.*, **1**, 91.

Sahal-Bréchot, S.: 1969b, *Astron. Astrophys.*, **2**, 322.

Sahal–Bréchot, S. & Segre S.: 1971, in *Highlights of Astronomy 2*, ed. C. de Jager, p. 566.

Sanchez A., Blaha M. & Jones W. W.: 1973, *Phys.Rev.A* **8**, 774.
Seaton, M. J.: 1987, *J. Phys. B*, **20**, 6431.
Seaton, M. J.: 1988, *J. Phys. B*, **21**, 3033.
Vainshtein, L. A. & Sobel'man, I. I.: 1959, *Opt. Spektrosk.*, **6**, 279.
Vince, I. & Dimitrijević, M. S.: 1985, *Publ. Obs. Astron. Belgrade*, **33**, 15.
Vince, I., Dimitrijević, M. S. & Kršljanin, V.: 1985a in *Spectral Line Shapes III*, ed. F. Rostas, W. de Gruyter, Berlin, New York, p. 649.
Vince, I., Dimitrijević, M. S. & Kršljanin, V.: 1985a in *Progress in Stellar Spectral Line Formation Theory*, eds. J. Beckman & L. Crivelari, D. Reidel, Dordrecht, Boston, Lancaster, p. 373.
Vitel, Y., Skowronek, M., Dimitrijević, M. S. & Popović, M. M: 1988, *Astron. Astrophys.*, **200**, 285.
Vujnović, V., Vadla, Č., Lokner, V. & Dimitrijević, M. S.: 1983, *Astron. Astrophys.*, **123**, 249.
Wiese, W. L. & Konjević, N.: 1982, *JQSRT* **28**, 185.

ON SPECTRAL LINE STARK BROADENING PARAMETERS NEEDED FOR STELLAR AND LABORATORY PLASMA INVESTIGATIONS

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Abstract. Stellar spectroscopy depends on very extensive list of elements and line transitions with their atomic and line broadening parameters. It is difficult to state in general terms which are the relevant transitions since the atmospheric composition of a star is not known a priori, and many interesting groups of stars exist with very peculiar abundances as compared to the Sun.

The interest for a very extensive list of line broadening data is additionally stimulated by spectroscopy from space. In such a manner an extensive amount of spectroscopic information over large spectral regions of all kind of celestial objects has been and will be collected, stimulating the spectral–line–shape research.

Here is presented a review of semiclassical calculations of Stark broadening parameters and comparison of different semiclassical procedures is discussed, as well as the agreement with critically selected experimental data and more sophysticated, close coupling calculations. Approximate methods for the calculation of Stark broadening parameters, usefull especially in such astrophysical problems where large scale calculations and analyses must be performed and where a good average accuracy is expected, have also been discussed.

The begining and developement of line shapes investigations in Yugoslavia has been described as well.

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ON THE IONIZED IRON LINES STARK BROADENING IN STELLAR SPECTRA

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Abstract. Stark broadening parameters for singly-ionized iron a^6D - z^6P^o, a^6D - z^6D^o and a^6D - z^6F^o multiplets, have been calculated by using the semiclassical-perturbation approach. The obtained results have been compared with experimental data and simpler estimates.

1. INTRODUCTION

The research of neutral and ionized iron spectra is of great astrophysical importance due to high abundance of this element and its role in various processes in stellar plasma. Fe II lines are present in solar and stellar spectra and for their analysis or the calculations of synthetic spectra corresponding Stark broadening data are of importance. In spite of the astrophysical meaning of iron, we found only two published experimental investigations of Stark broadening parameters of Fe II lines. Manning *et al.* (1990) have investigated shifts of Fe II a^4D - z^4F^o 2755.73 Å line and Purić *et al.* (1993) widths of 14 lines from a^6D - z^6D^o and a^6D - z^6F^o multiplets. Electron-impact widths for 3 solar multiplets (a^4H - z^4F^o, a^6D - z^6D^o and a^4F - z^4F^o) and 3 multiplets observed in the spectrum of 15 Vulpeculae (Yo-ichi Takeda, 1984) b^4P - z^4F^o, b^4F - z^4D^o and b^4P - z^4D^o), have been calculated by Dimitrijević (1988) within the modified semiempirical approach (Dimitrijević and Konjević, 1980). Simple estimates based on the regularities and systematic trends, by Lakićević (1983) and Purić *et al.* (1993) exist as well.

The strongest Fe II lines correspond to 4s-4p and 3d-4p transitions in $3d^6nl$ and $3d^54snl$ configurations, covering some 1500 observed lines and accounting for the main part of the intensity of the Fe II spectrum (Johanson, 1984). However, if one wishes to perform a more sophisticated calculations it is not easy to collect the sufficiently complete energy level set and to avoid the additional difficulties due to configuration interaction and violation of the LS selection rules. The best situation is just with 4s-4p sextets, measured by Purić *et al.* (1993), where the sufficiently complete energy level set exists and there is not pronounced configuration interactions or critical violations of the LS selection rules (Fawcet, 1987), so that the semiclassical calculations may provide more reliable Stark broadening parameters.

By using the semiclassical-perturbation formalism (Sahal-Bréchot 1969ab), we have calculated Stark broadening parameters for singly-ionized iron $a^6D - z^6P^o$, $a^6D - z^6D^o$ and $a^6D - z^6F^o$ multiplets. Perturbers are electrons, protons and a singly charged perturber with the mass equal to 35 a.u. corresponding to the averaged mass of perturbing ions in Solar atmosphere. A summary of the formalism is given in Dimitrijević *et al.* (1991). The obtained results have been compared with experimental data and simpler evaluations.

2. RESULTS AND DISCUSSION

All details of calculations and results for $a^6D - z^6P^o$, $a^6D - z^6D^o$ and $a^6D - z^6F^o$ multiplets, covering 34 lines within 2328.11-2632.108 Å range, will be published in Dimitrijević (1995), for a perturber density of $10^{17}cm^{-3}$ and temperatures T = 5,000 - 150,000 K.

In Table 1 the present theoretical full half-widths have been compared with experimental results (Purić *et al.* 1993a) as well as with the calculations of Dimitrijević (1988) performed by using the modified semiempirical approach (1980) and with simple theoretical estimates of Purić *et al.* (1993b) based on regularities and systematic trends. For the experiment of Purić *et al.* (1993a) SF_6 has been used as a working gas. At T = 3O,OOO K and electron density of $10^{17}cm^{-3}$ full half width for F II-impact broadening of Fe II 2392.9 Å line is 0.00606Å and for S II-impact broadening 0.00618Å. Since the difference is negligible in comparison with electron-impact broadening, and since the ionized sulphur has the lower ionization potential and the corresponding linewidth is larger, full half width due to S II- impacts has been presented in Table 1 as an upper limit of ion broadening contribution. We can see that semiclassical calculations with the ion broadening contribution included, give larger widths than experiment but within the error bars of theory and experiment. Taking into account the complexity of the Fe II spectrum, the results (Dimitrijević, 1988) obtained by using the modified semiempirical method (Dimitrijević and Konjević, 1980) are in satisfactory agreement with the experimental values. The agreement of simple estimates of Purić *et al.* (1993b) with experimental and semiclassical values is encouraging as well. Simple estimate of Lakićević (1983) gives for $a^6D - z^6D^o$ Fe II multiplet for a perturber density of $10^{17}cm^{-3}$ and the temperature of 20,000 K, full width = 0.068 Å which is in encouraging agreement with experimental and semiclassical results. On the other hand the shift of 0.032 Å has the different sign. New experimental data for Fe II Stark broadening parameters will be of interest for astrophysics as well as for theoretical investigations of Stark broadening for complex spectra.

TABLE I

Comparison of experimental and theoretical Stark widths (FWHM) at corresponding electron densities N, and temperatures T. WM - experimental widths(FWHM) of Purić *et al.* 1993a; We - present semiclassical widths(FWHM) for electron-impact broadening; WSII - present semiclassical widths (FWHM) for SII- impact broadening; WDK - Dimitrijević (1988); WP - Purić *et al.* 1993b.

Transition	Wavelength [A]	T [10^4K]	N [10^{17}cm^{-3}]	W_M[A]	W_e[A]	W_{SII} A]	W_{DK}[A]	W_P[A]
a^6D-z^6D^o	2598.37	3.00	1.95	0.070	0.117	0.0130	0.068	0.126
		2.90	1.64	0.058	0.100	0.0109	0.059	0.108
		2.80	1.06	0.044	0.066	0.0070	0.038	0.072
	2607.52	3.00	1.95	0.100	0.117	0.0130	0.068	0.126
		2.90	1.64	0.076	0.100	0.0109	0.059	0.108
		2.90	1.27	0.058	0.077	0.0084	0.045	0.084
	2611.87	3.00	1.95	0.096	0.117	0.0130	0.068	0.126
		2.90	1.64	0.090	0.100	0.0109	0.059	0.108
		2.80	1.06	0.072	0.066	0.0070	0.038	0.070
	2613.82	3.00	1.95	0.088	0.117	0.0130	0.068	0.126
		2.90	1.64	0.072	0.100	0.0109	0.059	0.108
		2.80	1.06	0.044	0.066	0.0070	0.038	0.070
	2617.62	3.00	1.95	0.084	0.117	0.0130	0.068	0.126
		2.90	1.64	0.072	0.100	0.0109	0.059	0.108
		2.80	1.06	0.050	0.066	0.0070	0.038	0.070
a^6D-z^6F^o	2373.74	2.80	1.06	0.062	0.057	0.0065	0.034	0.064
	2382.04	3.00	1.95	0.090	0.101	0.0121	0.060	0.114
		2.90	1.64	0.080	0.086	0.0101	0.051	0.098
		2.80	1.06	0.048	0.057	0.0065	0.034	0.064
	2388.63	3.00	1.95	0.076	0.101	0.0121	0.060	0.114
		2.80	1.06	0.044	0.057	0.0065	0.034	0.064
	2404.43	2.70	0.63	0.030	0.034	0.0038	0.020	0.038
	2404.89	3.00	1.95	0.086	0.101	0.0121	0.060	0.112
		2.90	1.64	0.066	0.086	0.0101	0.051	0.096
		2.80	1.06	0.042	0.057	0.0065	0.034	0.064

References

Dimitrijević, M. S. : 1988, in *Physics of Formation of Fe II Lines Outside LTE*, eds. R. Viotti, A. Vittone, M. Friedjung, Astrophysics and Space Science Library, Vol. 138, D.Reidel P.C., p. 211.
Dimitrijević, M. S. : 1995, *Astron. Astrophys. Suppl. Series*, submitted.
Dimitrijević, M. S. and Konjević, N. : 1980, *JQSRT*, **24**, 451.
Dimitrijević, M. S., Sahal-Bréchot, S. and Bommier, V. : 1991, *Astron. Astrophys. Suppl. Series*, **89**, 581.
Johansson, S. : 1984, *Physica Scripta*, **T8**, 63.
Lakićević, I. S. : 1983, *Astron. Astrophys.* **127**, 37.
Manning, J. T., Winefordner, J. D., Palmer, B. A. and Hof, D. E. : 1990, *Spectrochim. Acta*, **45B**, 1031.
Purić, J., Djeniže, S., Srećković, A., Bukvić, S., Pivalica, S. and Labat, J. : 1993a, *Astron. Astrophys. Suppl. Series*, **102**, 607.
Purić, J., Miller, M. H., and Lesage, A. : 1993b, *Astrophys. J.* **416**, 825.
Sahal-Bréchot, S. : 1969a, *Astron. Astrophys.* **1**, 91.
Sahal-Bréchot, S. : 1969b, *Astron. Astrophys.* **2**, 322.
Yo-ichi Takeda : 1984, *Publ. Astron. Soc. Japan* **36**, 149.

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THE INFLUENCE OF COLLISIONS WITH CHARGED PARTICLES ON STELLAR LINE SPECTRA

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Abstract. The astrophysical importance of the line broadening due to the interaction between emitter(absorber) and charged particles (Stark broadening) is discussed. A review of semiclassical calculations of Stark broadening parameters and comparison of different semiclassical procedures is presented too, as well as the comparison with critically selected experimental data and more sophisticated, close coupling calculations. Approximate methods for the calculation of Stark broadening parameters, useful especially in such astrophysical problems where large scale calculations and analyses must be performed and where a good average accuracy is expected, have also been discussed.

Among the various pressure broadening mechanisms, broadening due to interaction between emitter and charged particles (Stark broadening) is dominant in several cases. For $T_{eff} > 10^4$K, hydrogen, the main constituent of a stellar atmosphere is mainly ionized, and the main collisional broadening mechanism for spectral lines is the Stark effect. This is the case for white dwarfs and hot stars of O, B and A0 type. Even in cooler star atmospheres as e.g. Solar one, Stark broadening may be important. For example, the influence of Stark broadening within a spectral series increases with the increase of the principal quantum number of the upper level and consequently,Stark broadening contribution may become significant even in the Solar spectrum.

An important problem where we need reliable Stark broadening data is also the determination of chemical abundances of elements from equivalent widths of absorption lines. Stark broadening data are also required for the estimation of the radiative transfer through the stellar plasmas, especially in subphotospheric layers and for opacity calculations. In such a case data for especially large numbers of lines are needed. An illustrative example might be the article on the calculation of opacities for classical cepheid models (Iglesias *et al.* 1990), where 11,996,532 spectral lines have been taken into account, and where Stark broadening is important.

Stellar spectroscopy depends on very extensive list of elements and line transitions with their atomic and line broadening parameters. It is difficult to state in general terms which are the relevant transitions since the atmospheric composition of a star is not known a priori, and many interesting groups of stars exist with very peculiar abundances as compared to the Sun.

The interest for a very extensive list of line broadening data is additionally stimulated by spectroscopy from space. In such a manner an extensive amount of spectro-

scopic information over large spectral regions of all kind of celestial objects has been and will be collected, stimulating the spectral–line–shape research.

The most sophisticated theoretical method for the calculation of a Stark broadened line profile is of course the quantum mechanical strong coupling approach. However, due to its complexity and numerical difficulties, only a small number of such calculations exist. In a lot of cases such as e.g. complex spectra, heavy elements or transitions between more excited energy levels, the more sophisticated quantum mechanical approach is very difficult or even practically impossible to use and, in such cases, the semiclassical approach remains the most efficient method for Stark broadening calculations.

Here is presented a review of semiclassical calculations of Stark broadening parameters and comparison of different semiclassical procedures is discussed, as well as the agreement with critically selected experimental data and more sophisticated, close coupling calculations. Approximate methods for the calculation of Stark broadening parameters, useful especially in such astrophysical problems where large scale calculations and analyses must be performed and where a good average accuracy is expected, have also been discussed.

References

Iglesias, C. A., Rogers, F. J. and Wilson, B. G. : 1990, *Astrophys. J.* **360**, 221.

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THE ANALYSIS OF THE SIMPLIFIED FORMULA FOR THE STARK BROADENING OF NEUTRAL ATOM LINES

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Abstract. The approximate semiclassical formula of Dimitrijević and Konjević for isolated neutral atom spectral lines has been applied to neutral helium lines. The desagreements with the more sophisticated full semiclassical calculations of Griem are within 20 per cents. It is demonstrated as well how one can introduce simple corrections in order to achieve even better agreement. With such corrections the largest desagreement is 2 percents.

1. INTRODUCTION

Starting from the semiclassical approach for Stark broadening parameters of neutral atom lines, in the version adapted for practical calculations by Griem, Jones and Benett (see *e.g.* Griem, 1974), Freundenstein and Cooper (1978) developed a simple approximate method for line width (w) calculation. This method has been improved and adapted as well for the shift (d) by Dimitrijević and Konjević (1986). Our objective here is to analyse the applicability of this method. Since the method has been derrived from the more sophisticated Griem's semiclassical approach, we will compare results obtained by both methods in order to see desagreements due to the additional simplifications introduced in the approach of Dimitrijević and Konjević (1986). The neutral helium lines have been choosen first of all since Stark broadening of neutral helium lines is well described within the semiclassical theory (Griem, 1974), and a comprehensive set of theoretical data checked by numerous experiments exists (see *e.g.* Griem, 1974)

2. RESULTS AND DISCUSSION

By using the methods of Freundenstein and Cooper (1978) (FC) and Dimitrijević and Konjević (1986) (DK), Stark broadening widths (w_{FC}, w_{DK}) and shifts (d_{DK}) for 12 neutral helium multiplets have been calculated at an electron density $N_e = 10^{16}$ cm^{-3} and temperatures 5000 - 40000 K.The ratios of obtained results and Griem's (1974) values (w_G, d_G) are shown in Table 1 for the width and in Table 2 for the shift. The corresponding averaged values denoted as $(...)_{av}$ are shown as well One can see in Tables 1 and 2 that the desagreements with the more sophisticated full semiclassical calculations of Griem are within 20 per cents. Since the error bars of the semiclassical

method are estimated on 30 per cents (Griem, 1974), the corresponding error bars of the approach of Dimitrijević and Konjević (1986) may be estimated as 50 percents which is in accordance with the estimated error bars for the semiempirical method (see *e.g.* Griem, 1974).

TABLE 1

Ratios w_{DK}/w_G and w_{FC}/w_G for neutral helium spectral line widths (w) for an electron density of $N_e = 10^{16}$ cm^{-3}. DK - present calculations by using the method of Dimitrijević and Konjević (1986); FC - present calculations by using the method of Freundenstein and Cooper (1978); G - Griem (1974)

SINGLETS			
	T [K]	w_{DK}/w_G	w_{FC}/w_G
2s - 3p $\lambda = 501,7$ nm	5000	1,248	2,103
	10000	1,278	1,947
	20000	1,275	1,808
	40000	1,242	1,624
2s - 4p $\lambda = 396,5$ nm	5000	1,184	1,720
	10000	1,190	1,590
	20000	1,163	1,500
	40000	1,118	1,390
2p - 4s $\lambda = 504,8$ nm	5000	1,038	1,000
	10000	1,148	1,110
	20000	1,178	1,140
	40000	1,121	1,090
2p - 5s $\lambda = 443,8$ nm	5000	1,056	1,030
	10000	1,152	1,130
	20000	1,145	1,130
	40000	1,080	1,070
2p - 3d $\lambda = 667,8$ nm	5000	1,156	2,430
	10000	1,199	2,320
	20000	1,232	2,200
	40000	1,252	1,980
2p - 4d $\lambda = 492,2$ nm	5000	1,060	1,660
	10000	1,045	1,770
	20000	1,042	1,570
	40000	1,029	1,480
2p - 5d $\lambda = 438,8$ nm	5000	0,996	1,400
	10000	0,984	1,330
	20000	0,976	1,280
	40000	0,965	1,220

Table 1 (continued)

TRIPLETS			
	T [K]	w_{DK}/w_G	w_{FC}/w_G
2s - 3p $\lambda = 388,9$ nm	5000	1,529	1,910
	10000	1,526	1,930
	20000	1,470	1,790
	40000	1,384	1,640
2s - 4p $\lambda = 318,8$ nm	5000	1,438	1,690
	10000	1,402	1,670
	20000	1,326	1,530
	40000	1,246	1,390
2s - 5p $\lambda = 294,5$ nm	5000	1,398	
	10000	1,354	
	20000	1,260	
	40000	1,177	
2p - 4s $\lambda = 471,3$ nm	5000	1,000	
	10000	1,009	
	20000	1,185	
	40000	1,165	
2p - 5s $\lambda = 412,1$ nm	5000	1,029	
	10000	1,137	
	20000	1,189	
	40000	1,138	

T [K]	$(w_{DK}/w_G)_{av}$	$(w_{FC}/w_G)_{av}$
5000	$1,178 \pm 0,177$	$1,660 \pm 0,664$
10000	$1,210 \pm 0,148$	$1,644 \pm 0,380$
20000	$1,204 \pm 0,122$	$1,550 \pm 0,330$
40000	$1,160 \pm 0,107$	$1,430 \pm 0,280$

TABLE 2

Ratios d_{DK}/d_G for neutral helium spectral line shifts (d) for an electron density of $N_e = 10^{16}$ cm^{-3}. DK - present calculations by using the method of Dimitrijević and Konjević (1986); G - Griem (1974)

λ	d_{DK}/d_G			
(nm)	5000 K	10000 K	20000 K	40000 K
501,7	0,892	0,830	0,763	0,720
396,5	1,178	0,786	0,732	0,722
504,8	1,222	1,112	0,972	0,849
443,8	1,172	1,063	0,919	0,823
667,8	0,992	0,969	0,913	0,851
492,2	0,885	0,877	0,856	0,818
438,8	0,845	0,834	0,818	0,794
388,9	1,040	0,912	0,823	0,772
318,8	1,032	0,920	0,858	0,826
294,5	0,988	0,888	0,839	0,818
471,3	1,231	1,129	1,023	0,892
412,1	1,170	1,082	0,968	0,854

$(d_{DK}/d_G)_{av}$			
5000 K	10000 K	20000 K	40000 K
1,054 ± 0,132	0,950 ± 0,114	0,873 ± 0,084	0,812 ± 0,049

The accuracy of an approximate method may be improved if we have a set of theoretical or experimental data of higher accuracy, like the Griem's (1974) semiclassical calculations in the considered case. We will take into account that the ratios of corrected values w_c, d_c and the corresponding Griem's values must be close to unity, and we will search correction functions $f_w(n,T)$ and $f_d(n,T)$ such that $w_c = f_w(n,T)w_{DK}$ and $d_c = f_d(n,T)d_{DK}$, where the principal quantum number is denoted with n The obtained corrected width is

$$w_c = \frac{aT^m + C_1 \ln T + C_2}{(w_{DK}/w_G)_m} \cdot w_{DK} \quad .$$

Since $aT^m + C_1 \ln T + C_2 \approx 1$ one can also use the approximation $f_w(n,T) \approx \frac{1}{(w_{DK}/w_G)_m}$, so we have $w_c \approx \frac{w_{DK}}{(w_{DK}/w_G)_m}$. Here $(w_{DK}/w_G)_m$ is the mean value formed by grouping results for similar transitions on the same temperature. For the shift one obtains the completely analogous expression. For width we obtain a = 1.407, m = -0.039, C_1 = 0.038, and C_2 = -0.330 and for shift a = 3.88, m = -0.139, C_1 = 0.145 and C_2 = -1.419.

TABLE 3

Ratio of our corrected (w_c) and Griem's (w_G) width values at different temperatures for He I spectral lines ($N_e = 10^{16}$ cm^{-3}).

λ	w_c/w_G			
(nm)	5000 K	10000 K	20000 K	40000 K
501,7	1,042	1,078	1,057	1,029
396,5	0,990	1,004	0,964	0,928
504,8	1,008	0,969	0,978	0,930
443,8	1,026	0,973	0,950	1,054
667,8	0,967	1,010	1,020	1,038
492,2	1,030	1,005	1,032	1,000
438,8	0,967	0,946	0,966	0,942
388,9	1,049	1,063	1,042	1,145
318,8	0,987	0,979	0,947	1,033
294,5	0,960	0,945	1,046	0,976
471,3	0,971	1,056	0,982	0,967
412,1	1,000	0,958	0,987	0,944

$(w_c/w_G)_{av}$			
5000 K	10000 K	20000 K	40000 K
0,999 ± 0,103	0,999 ± 0,040	0,998 ± 0,038	0,999 ± 0,060

TABLE 4

Ratio of our corrected (d_c) and Griem's (d_G) shift values at different temperatures for He I spectral lines ($N_e = 10^{16}$ cm^{-3}).

λ	d_c/d_G			
(nm)	5000 K	10000 K	20000 K	40000 K
501,7	1,024	0,980	0,868	0,892
396,5	0,712	0,926	0,834	0,902
504,8	1,026	0,986	1,108	1,052
443,8	0,984	1,068	1,047	1,020
667,8	0,982	0,974	1,041	1,049
492,2	1,020	1,035	0,976	1,014
438,8	0,968	0,984	0,933	0,984
388,9	1,027	0,916	0,935	0,970
318,8	1,018	0,926	0,977	1,029
294,5	0,979	1,048	0,958	1,012
471,3	1,035	1,002	1,164	1,104
412,1	0,983	1,087	1,103	1,058

$(d_c/d_G)_{av}$			
5000 K	10000 K	20000 K	40000 K
0,980 ± 0,084	0,994 ± 0,053	1,000 ± 0,100	1,007 ± 0,060

In tables 3 and 4, ratios of corrected values for widths and shifts and the corresponding Griem's values are shown, as well as the averaged values. One can see that the largest desagreement now is 2 per cents.

References

Dimitrijević, M. S., Konjević, N. : 1986, *Astron. Astrophys.* **163**, 297.
Freundenstein, S. A., Cooper, J. : 1978, *Astrophys. J.* **224**, 1079.
Griem, H. R. : 1974, Spectral Line Broadenintg by Plasmas, Academic Press, New York.

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MODIFIED SEMIEMPIRICAL METHOD 1980 - 2000

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It is more than twenty years from the formulation of the modified semiempirical (MSE) approach (Dimitrijević and Konjević, 1980) for the calculation of Stark broadening parameters for non-hydrogenic ion spectral lines. Within this period the considered method has been applied succesfully many times for different problems in astrophysics and physics. Besides the Stark broadening investigation of particular spectral lines in laboratory and astrophysical plasmas, the considered method has been succesfully applied e.g. for the research of elemental abundances in normal late-B and HgMn stars (Smith, 1993) and hot white dwarfs (Chayer et al, 1995b), investigations of abundance anomalies in stars (Michaud and Richer, 1992), radiative acceleration calculation in stellar envelopes (Gonzales et al., 1995), consideration of radiative levitation in hot white dwarfs (Chayer et al 1995ab), opacities for classical cepheid models (Iglesias et al., 1990), design of new lasers (Decker and London, 1998), spectroscopic diagnostics of railgun plasma armatures (Bakshi et al., 1993)... The MSE method entered in computer codes, as e. g. OPAL opacity code (Rogers and Iglesias, 1995), handbooks (Vogt, 1996) and monographies (Gray, 1992; Griem, 1997).

In comparison with the full semiclasical perturbation approach and the Griem's (1968) semiempirical approach who need practically the same set of atomic data, the modified semiempirical approach needs a considerably smaller number of such data. In fact, if there are not perturbing levels strongly violating the assumed approximation, for *e.g.* the line width calculations, we need only the energy levels with $\Delta n = 0$ and $\ell_{if} = \ell_i \pm 1$, since all perturbing levels with $\Delta n \neq 0$, needed for a full semiclasical investigation or an investigation within the Griem's (1968) semiempirical approach, are lumped together and approximately estimated. Here, n is the principal and ℓ the orbital angular momentum quantum numbers of the optical electron and with i and f are denoted the initial and final state of the considered transition.

Due to the considerably smaller set of needed atomic data in comparison with the complete semiclassical or Griem's (1968) semiempirical method, the MSE method is particularly useful for stellar spectroscopy depending on very extensive list of elements and line transitions with their atomic and line broadening parameters where it is not possible to use sophysticated theoretical approaches in all cases of interest.

The MSE method is also very useful whenever line broadening data for a large number of lines are required, and the high precision of every particular result is not so important like e.g. for opacity calculations or plasma modeling. Moreover, in

the case of more complex atoms or multiply charged ions the lack of the accurate atomic data needed for more sophysticated calculations, makes that the reliability of the semiclassical results decreases. In such cases the MSE method might be very interesting as well.

In order to complete as much as possible the available Stark broadening data for astrophysical, laboratory, laser produced and technological plasmas investigation and modeling Belgrade group (Milan Dimitrijević, Luka Popović, Vladimir Kršljanin, Nenad Milovanović, Dragana Tankosić) has applied the MSE method (Dimitrijević and Konjević, 1980, 1981; 1987; Dimitrijević and Kršljanin, 1986; Dimitrijević, 1988ab; Popović and Dimitrijević, 1997) for spectral lines Stark broadening parameters, when there is not a sufficiently complete set of reliable perturbing energy levels, for a more sophysticated semiclassical approach.

The Stark broadening data for the most intensive lines for the following atom and ion species are availlable:

Ar II, Fe II, Pt II, Bi II, Zn II, Cd II, As II, Br II, Sb II, I II, Xe II, La II, Au II, Eu II, Ti II, Kr II, Na II, Y II, Zr II, Sc II, Ra II, Be III, B III, C III, N III, O III, F III, Ne III, Na III, Al III, Si III, P III, S III, Cl III, Ar III, Mn III, Ga III, Ge III, As III, Se III, Zn III, Mg III, La III, V III, Ti III, Bi III, Sr III, Cu III, Co III, Zr III, B IV, Cu IV, Ge IV, C IV, N IV, O IV, Ne IV, Mg IV, Si IV, P IV, S IV, Cl IV, Ar IV, V IV, Ge IV, C V, O V, F V, Ne V, Al V, Si V, N VI, F VI, Ne VI, Si VI, P VI, and Cl VI.

In order to make the use of these data easier we are organizing them now in a database BELDATA.

For the astrophysical purposes, of particular interest might be as well the symplified version of the Modified semiempirical formula (Dimitrijević and Konjević, 1987) for Stark widths of isolated, singly, and multiply charged ion lines applicable in the cases when the nearest atomic energy level ($j' = i$ 'or f') where a dipolly allowed transition can occur from or to initial (i) or final (f) energy level of the considered line, is so far, that the condition $x_{jj'} = E/|E_{j'} - E_j| \leq 2$ is satisfied. Here, E is the energy of the perturbing electron and $E_{j,j'}$ energies of the initial ($j = i$) or final ($j = f$) levels and the corresponding the nearest perturbing level (j').

The modified semiempirical approach has been tested several times on numerous examples (Dimitrijević, 1990). The assumed accuracy of the MSE approximation is about $\pm 50\%$, but it has been shown in Popović and Dimitrijevic (1996, 1998) that the MSE approach, even in the case of the emitters with very complex spectra (e.g. Xe II and Kr II), gives very good agreement with experimental measurements (in the interval $\pm 30\%$). For example for Xe II, $6s - 6p$ transitions, the averaged ratio between experimental and theoretical widths is 1.15 ± 0.5 (Popović and Dimitrijević 1996).

In order to test the modified semiempirical approach, selected experimental data for 36 multiplets (7 different ion species) of triply–charged ions were compared with theoretical linewidths. The averaged values of the ratios of measured to calculated widths are as follows (Dimitrijević and Konjević, 1980): for doubly charged ions 1.06 ± 0.32 and for triply–charged ions 0.91 ± 0.42.

References

Bakshi, V., Barett, B.D., Boone, T.D.Jr., Nunnally, W.C.: 1993, *IEEE Transactions on Magnetics*, **29**, 1097.

Chayer, P., Fontaine, G., Wesemael, F.: 1995a, *Astrophys. J. Suppl. Series*, **99**, 189.

Chayer, P., Vennes, S., Pradhan, A.K., Thejll, P., Beauchamp, A., Fontaine, G., Wesemael, F.: 1995b, *Astrophys. J.*, **454**, 429.

Decker, C. D., London, R. A.: 1998, *Phys. Rev. A*, **57**, 1395.

Dimitrijević, M. S.: 1988a, *Bull.Obs.Astron.Belgrade*, **139**, 31.

Dimitrijević, M. S.: 1988b, *Astron. Astrophys. Suppl. Series*, **76**, 53.

Dimitrijević, M. S.: 1990 in *Accuracy of Element Abundances from Stellar Atmospheres* ed. R.Wehrse, Lecture Notes in Physics 356, Springer, Berlin-Heidelberg p. 31.

Dimitrijević, M.S., Konjević, N.: 1980, *JQSRT*, **24**, 451.

Dimitrijević, M. S., Konjević, N.:1981 in*Spectral Line Shapes* Ed. B.Wende, W. de Gruyter, Berlin, New York p. 211.

Dimitrijević, M.S., Konjević, N.: 1987, *Astron. Astrophys.*, **172**, 345.

Dimitrijević, M.S., Kršljanin, V.: 1986, *Astron.Astrophys.*, **165**, 269.

Gonzales, J.F., LeBlanc, F., Artru, M.-C., Michaud, G.: 1995, *Astron. Astrophys.*, **297**, 223.

Gray, D.F.: 1992, *The Observation and Analysis of Stellar Photospheres*, Cambridge University Press, Cambridge.

Griem, H. R.: 1968, *Phys.Rev.*, **165**, 258.

Griem, H. R.: 1997, *Principles of Plasma Spectroscopy*, Cambridge Monographs of Plasma Physics 2, Cambridge University Press.

Iglesias,C.A., Rogers, F.J.: 1992, *Revista Mexicana de Astronomia y Astrofisica*, **23**, 161.

Iglesias C.A., Rogers F.J., Wilson B.G.: 1990, *Astrophys. J.*, **360**, 221.

Michaud, G., Richer, J.: 1997, in *Spectral Line Shapes*, **9**, eds. M. Zoppi, L. Ulivi, *AIP Conf. Proc.*, **386**, 397.

Popović, L.Č., and Dimitrijević, M. S.: 1996, *Astron. Astrophys. Suppl. Series*, **116**, 359.

Popović, L.Č., and Dimitrijević, M. S.: 1997, in The Physics of Ionized Gas, eds. B. Vujičić, S. Djurović and J. Purić, Institute of Physics, Novi Sad, p. 477.

Popović, L.Č., and Dimitrijević, M. S.: 1998, *Astron. Astrophys. Suppl. Series*, **127**, 295.

Rogers, F.J., Iglesias, C.A.: 1995, in *Astrophysical Applications of Powerful Databases*, eds. S.J. Adelman, W.L. Wiese, ASP Conf. Series **78**, 31.

Smith,K.C.: 1993, *Astron. Astrophys.*, **276**. 393.

Vogt, H. H. editor: 1996, Stellar atmospheres: Atomic and molecular data, Astronomy and Astrophysics, Extension and Supplement to Vol. 2, Subvolume B, Stars and Star Clusters, Landolt-Boernstein, Group VI: Astron. Astrophys. Volume 3, Springer, 57.

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THE GREATEST BYZANTINE ASTRONOMER NICEPHOROS GREGORAS AND SERBS

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Abstract. Nicephoros Gregoras (1295-1360) is considered along with his teacher, Theodoros Metochites, as the most significant scholar and the greatest astronomer of Byzantium. Gregoras was the first to propose, in 1324, a correction to the calculation of Easter, and the reform of the Julian calendar similar to the one adopted later, in 1582, by the Pope Gregory XIII. His famous book "Byzantine history" is an important source for the researches on medieval Serbia. He was also in a diplomatic mission on the court of Serbian king Stefan Dečanski.

1. LIFE AND WORKS OF NICEPHOROS GREGORAS

The greatest Byzantine astronomer Nicephoros Gregoras (1295-1360) was born in Heracleia of Pontus, where he obtained the basic education. He was raised by his uncle John (1249-1328), Bishop of Heracleia. John educated Nicephoros and introduced him to the ancient Greek writers, especially to Plato. At the age of twenty, he was sent by his uncle to Constantinople to continue his studies. Patriarch John XIII "the Sweet" (1315-1328) taught him Aristotelian logic. At about the same time, Nicephoros met the most eminent Platonist philosopher and Great Logothetes (a kind of Prime Minister) of the Byzantine Empire Theodoros Metochites (1260-1332), considered as the one of the greatest forerunners of the Renaissance in the Greek world. Metochites taught Nicephoros philosophy, astronomy and mathematics. He proved to be worth of his teacher, "having no other superior, neither in the East nor in the West". Moreover, he had a common interest with him: politics.

In 1320 Theodoros Metochites presented his superb student to the Emperor Andronicus II Palaeologus (1282-1328), who won his trust owing to his abilities and his intelligence.

Gregoras founded the "Mone tes Choras" ("Monastery of the Country"), a distinguished School where he started to teach philosophy, mathematics and astronomy to a large number of Byzantine and European students. The large body of his works covers various disciplines such as history, theology, philosophy, astronomy, and others, almost all the branches of knowledge in Byzantium. He was the homo universalis of his epoch. His "Roman History", i.e. Byzantine History, composed of 37 books, is considered especially important. Its 7 leading chapters give a short account of the events from 1204 to 1320, while the remaining 30 cover extensively the period from 1320 up to 1359.

In his philosophical works the influence of his teacher, Theodoros Metochites, is evident. Gregoras, probably due to his studies of mathematics, became a supporter of the Platonic and an opponent of the Aristotelian philosophy, another element of differentiation of the Byzantine scholars from their counterparts in the West. However, Nicephoros Gregoras distinguished himself mainly as an astronomer, continuing the astronomical work of Metochites "Elements of the Astronomical Science", which in essence is an Introduction to the Ptolemy's "Syntaxis". Of great value are his astronomical works: "About the Revilers of Astronomy", "Entreaties For Astronomy", "How Should an Astrolabe Be Constructed" and others. His very important contribution is the proposal to the emperor Andronicus II in 1324, more than 250 years before Gregory XIII, of the calendar reform and of the plan for more correct Easter calculation. As an astronomer, he is superior to those who were doing astronomy in his era, in both East and West.

Later on, after the abdication of his protector Andronicus II in 1328, Gregoras fell into disfavor, lost his property and retired from the public life. In 1330 the Patriarch of Constantinople Isaiah (1323-1332) nominated Gregoras as the head of the delegation of the Orthodox Church in the dialog for the unification of the Churches, for both his debating ability and his theological knowledge. Gregoras faced the delegates of Pope John XXII (1316-1334) without retreating an inch to their claims concerning the Papal Primacy. The same year, Gregoras started to fight against the heretic Greek Aristotelian philosopher and monk Barlaam (1290-1348). Gregoras came back into public life in 1331 with a public debate with Barlaam, which he won. He was restored by the new Emperor Andronicus III (1328-1341) at the Office of the Great Teacher of the Empire.

After 1349, Nicephoros Gregoras took active part in the reaction against the Hesychasts, the followers of Gregorios Palamas. The Hesychasm was a movement created in the ranks of the monks, aiming to their spiritual completion through the incessant praying and silence, hence the name of the movement (hesychia = silence). Palamas, the leader of the Hesychasts (1296-1360), even wrote a counter-speech against Gregoras entitled: "Regarding the false writings as well as the impiety of Gregoras". Unfortunately for Gregoras, Eastern Orthodox Church adopted the movement of Hesychasm and canonized Gregorios Palamas. Gregoras fell into disfavour and the Holy Synod of Vlahernae in 1351 condamned his ideas, and he was confined in the "Mone tes Choras" by the Emperor John Cantacuzen (1347-1355), without possibility to communicate with his followers. These were the years when the "Roman History" was written, along with many rhetorical, poetical and philosophical works, poems,

speeches and 161 letters. Gregoras was liberated when the next Emperor, John V Palaeologue, ascended to the Throne once again in 1355.

Nicephoros Gregoras deceased in the beginning of 1360, without renouncing his ideas. The fanatic crowd desacrated his body. The intense battle of ideas of that time increased fanatism and restricted prudence.

2. ON THE IMPORTANCE OF NICEPHOROS GREGORAS FOR SERBS

The capital work of Nicephoros Gregoras, The "Roman History" ("Byzantinae Historiae" in the "Patrologia Graeca" series of Migne, 1857-1866) is the very important source for the Serbian medieval history. In its 37 volumes the writer exposes the events that took place from 1204 to 1359, interlaced with astronomical, geographical and theological informations. The considered period covers in Serbia the time from Stefan Prvovenčani to the beginning of the epoch of emperor Uroš V. The "History" is written by a contemporaneous participant who was also on the court of Serbian king Stefan Uroš III Dečanski and his son "young king", the future Emperor of Serbs and Greeks Stefan Dušan.

Of particular astronomical interest is the Gregoras' description of the battle at Velbužd on 28th July 1330, between Serbian army led by the king Stefan Uroš III Dečanski and Bulgarian one, headed by the emperor Michael Shishman, where he gives a detailed description of the Solar eclipse of 16th July of the same year (see e.g. Ćirković and Ferjančić, 1968, pp. 208-209), dating precisely the battle with the help of astronomical evidences.

In the spring of 1327, Gregoras takes part in a diplomatic mission on the court of Serbian king Stefan Uroš III Dečanski, whose second wife was Marry Palaeologue the daughter of John Palaeologue, the son of the brother of emperor Andronicus II and Irina, the daughter of Theodoros Metochites. Together with his son in law, Serbian king, John Palaeologue started to fight against Andronicus II and died in Skoplje at the end of 1326 or beginning of 1327. His widow Irina, the daughter of the great logotetes Metochites, refused to came back to Constantinople. Metochites asked the emperor to send Gregoras, the former teacher of Irina, with a diplomatic mission on the court of Stefan Dečanski in Skoplje, to persuade his daughter to come to Constantinople. Gregoras did it with success and he described in details his journey to Serbia in his letter to Andronikos Zarida (see e.g. Ćirković and Ferjančić, 1968, p. 147) which was almost completely included in "Byzantine history".

The astronomer Gregoras could be recognized from the following passage of the description of his journey: "... *And we wandered as some planets, entrusting us to God and vagues expectations. The night came down; "resigned the Sun and the darkness came down to the roads"*[1], *and, it has not been the Moon. Since before it was full, now the Moon was out of the center relative to the Earth and relative to the Sun was in quadrangle position and in the beginning of the night did not gift us his rays. It is why we walked through a deep darkness like those who walked beside*

[1] Homer's Odyssey II, 388.



Figure 1: Dinar of the emperor of Serbs and Greeks Dušan from the collection of Sergije Dimitrijević (Dimitrijević, 2001). On this, so called "corronation dinar", issued after the coronation of Stefan Dušan for the Emperor of Serbs and Greeks (Imperator Rascianorum et Romaiorum or *Βασιλευσ και αυτοκρατωρ Σερβιας και Ρωμανιας*) on 16th April 1346 in Skoplje, one can see two angels putting the imperial crown (stema) on his head. The cyrilic inscription is S[TE]F[AN] C[A]R - STEFAN THE EMPEROR.



Figure 2: Dinar of the Serbian king Stefan Uroš III Dečanski from the collection of Sergije Dimitrijević (Dimitrijević, 2001). The Cyrilic inscription STEFAN UROSH TPHTH (H was pronounced as Greek η, at that time)- STEFAN UROSH THE THIRD.

Tenaros to Hades or like those who walked for the underground profecy of Trofonios.[2] *To this moonless night joined the shadow of neighbouring mountains. They were so high that covered the sky so that it was not possible, according to the sentence "to direct rightly by stars" this unhappy travel"* (translated from Serbian from Radošević, 1968).

In any case, Nicephoros Gregoras was an exceptional scientific personality and a very prolific writer, important also for the serbian history and the history of serbian astronomy, together with his teacher Theodoros Metochites (see e.g. Vlahakos, 2003; Wolf, 1877).

References

Ćirković, Sima, Ferjančić, Božidar: 1968, Nicephoros Gregoras (Nićifor Grigora), in Serbian, Byzantine Sources for the History of Peoples of Yugoslavia (Vizantijski izvori za istoriju naroda Jugoslavije), **VI**, 145.

Dimitrijević, Sergije: 2001, Catalogue of the Serbian Medieval Coins (Katalog srpskog srednjovekovnog novca), in Serbian, Serbian Academy of Sciences and Arts and "'Zavod za udžbenike i nastavna sredstva"', Belgrade.

Migne, J.-P.: 1857-1866, Patrologia Graeca (P.G.), Patrologiae cursus completus, series graeca, Turnholti, Belgium. Typographi Brepols Editores Pontificii, **148, 149**.

Radošević, Nikola: 1968, Nicephoros Gregoras takes part in a diplomatic mission in Serbia (Nićifor Grigora učestvuje u poslanstvu u Srbiju), in Serbian, Byzantine Sources for the History of Peoples of Yugoslavia (Vizantijski izvori za istoriju naroda Jugoslavije), **VI**, 620.

Vlahakos, P.: 2003, Nicephoros Gregoras, Zetros editions, Thessaloniki (in Greek).

Wolf, R.: 1877, Geschichte der Astronomie, München, pp. 162-166

[2]At Tenaros on the south of Peloponnesos was the mythic entrance in Hades, while the underground profecy of Trofonios was in Boetia

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ЂОРЂЕ СТАНОЈЕВИЋ ПРВИ СРПСКИ АСТРОФИЗИЧАР

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Слика 1. *Ђорђе Станојевић.*

Ђорђе Станојевић, први српски астрофизичар, други руководилац Астрономске и метеоролошке опсерваторије, рођен је у Неготину 7. априла 1858. године. У родном граду, где је завршио основну школу и нижу гимназију, данас постоји његова спомен соба. У Београд прелази 1874. године и у Првој београдској гимназији полаже испит зрелости септембра 1877. године (Трифуновић, 1976). Исте године уписује се на Природно-математички одсек Филозофског факултета Велике школе у Београду, опредељујући се у току студија за физику. Студије завршава 1881. године, а Коста Алковић, који је на Великој школи предавао физику, њему као и оснивачу Астрономске опсерваторије Милану Недељковићу, задржава га као асистента приправника на Катедри за физику, где следеће 1882. године бива постављен за његовог асистента (Мушицки и Басарић, 1987). Станојевић је 1883. године постављен за професора физике у Првој београдској гимназији.

Као питомац Министарства војног у периоду од 1883. до 1887. био је на студијама, специјализацији и раду на најпознатијим астрономским и метеоролошким опсерваторијама Европе у Берлину (Универзитет), Потсдаму (астрофизичка опсерваторија), Хамбургу (метеоролошка централа),

Паризу (Сорбона), Медону (Париска опсерваторија за физичку астрономију), Гриничу, Кју-у и Пулкову (Симовљевић, 1987; Мушицки и Басарић, 1987). У овом периоду, Станојевић се опредељује за астрофизику и бира физику Сунца за своју научну област.

Године 1887, по повратку у земљу, постаје професор физике и механике на Војној академији, а 1893. године, после пензионисања Косте Алковића, професор експерименталне физике на Великој школи где постаје директор Физичког института. У периоду од 1909. до 1913. био је декан Филозофског факултета, а од 1913. до 1921. године ректор Универзитета у Београду. На улици у Паризу, где борави ради проучавања неких решења у ваздухопловној техници, умире изненада услед срчаног удара 24. децембра 1921. године.

Када је Милан Недељковић први пут био у пензији од 5. јула 1899. до 31. октобра 1900. године (Ђурковић, 1968), Управник Београдске опсерваторије постаје Ђорђе Станојевић. Њему је поверена и катедра за астрономију са метеорологијом. Њу је на Великој школи до тада држао Недељковић, који је по Уредби из 1896. године предавао астрономију као стручни предмет у Математичко-физичком одсеку. Према усменом саопштењу оснивача Сеизмолошког завода Јеленка Михајловића (објављено у Јанковић, 1989) Станојевић није држао предавања из астрономије у време док је Недељковић био удаљен, а астрономија сведена на помоћну науку и изостављена из професорских испита изменом Уредбе од 30. 09. 1900. године.

У Медону ради код оснивача ове опсерваторије, чувеног астрофизичара Жансена, који је открио хелијум на Сунцу и ту почиње да се бави озбиљним научним радом на пољу физике Сунца и спектроскопије. Године 1885. објављује свој први прави научни рад *Спектрална анализа елемената у Земљиној атмосфери* (Станојевић, 1885) у часопису Париске академије наука. Следеће 1886. године, у овом реномираном научном часопису излазе његови радови *О пореклу фотосферске мреже на Сунцу* (Станојевић, 1886а) и *О спектру апсорпције кисеоника* (Станојевић, 1886б). Године 1887. излази научни рад *О директној фотографији барометарског стања атмосфере Сунца* (Станојевић, 1887б). Ови његови научни радови из астрофизике објављени у издањима Париске академије наука су први прави научни радови из астрофизике код Срба (Јанковић, 1986).

При крају свога боравка у Паризу, августа 1987, учествује као изасланик Париске опсерваторије (Трифуновић, 1976) у експедицији за посматрање потпуног помрачења Сунца 19. августа 1887. године у Русији (Петровск), о чему објављује извештај у часопису Париске академије (Станојевић, 1888а). Временске прилике му нису ишле на руку, па се потпуно помрачење могло видети само 20 - 25 секунди. После његовог повратка у Србију, Париска опсерваторија позива младог професора физике и механике на Војној академији, да учествује у француској експедицији која ће испитивати Сунце у Сахари, где остаје три месеца (1891-1892).

Његови научни резултати су толико изнад нивоа тадашње научне јавности у Србији, да тек основана Српска краљевска академија одбија да публикује његове радове из физике Сунца (Станојевић, 1888б). Разочаран он практично напушта научни рад на пољу астрофизике. У издањима Париске академије објављује још само прегледни чланак „Садашње стање фотографије Сунца“ (Станојевић, 1889). Библиографију његових радова у астрономским наукама објавио је Трифуновић (1994), а целокупну библиографију Трифуновић и Димић (1976).

У каснијем раду се опредељује за физику и практичне проблеме електрификације и индустријализације Србије. Он изводи електрификацију Београда, Ужица, Лесковца, Чачка (Трифуновић, 1976). Учествује у изградњи прве хидроцентрале у Србији код Ужица. На Великој школи организује ремонтну службу за електромоторе (Трифуновић, 1976). У Србији покреће индустрију ледара и од 1907. године је на челу тада основане Комисије за индустрију хладноће. Уводи код нас фотографију у боји и објављује књигу са оваквим фотографијама *Србија у сликама* (Станојевић, 1901в). Наставља да се бави озбиљним научним радом у физици, па му после прекида од девет година поново почињу да излазе научни радови у часопису Париске академије наука, али из експерименталне физике. У периоду од 1898. до 1920. објављује у часопису Париске академије наука седам научних радова (Станојевић, 1898, 1900, 1901аб, 1902, 1905а, 1920).

Станојевић се поново враћа астрономији у своме раду на реформи Јулијанског календара. Наиме Станојевић предлаже Српској православној цркви да се сваке 128. године избацује по један дан, односно да се свака 128. година рачуна као проста ма да је дељива са четири (Станојевић, 1908), па би по Јулијанском календару требала да буде преступна. Такав предлог, Српска црква је упутила руском Светом синоду и Цариградској патријаршији али он није прихваћен (Јанковић, 1985)

Очаран лепотама ноћног неба пише научно популарну књигу *Звездано небо независне Србије* (Станојевић, 1882). У предговору, млади Станојевић наш први велики популаризатор астрономије у модерном, а не у просветитељском „Доситејевском“ духу, излаже свој *кредо* речима: „Ништа није грешније него знати неку истину, а не хтети је казати и другоме, који је не зна и у свом незнању лута тамо амо, машајући се често и за највећу погрешку.“ (Станојевић, 1882 стр. VI). Популаризацијом астрономије почиње да се бави још као студент па у периоду од 1880. до 1883. године објављује деветнаест научно популарних чланака из астрономије у Просветном гласнику (9), Васпитачу (5), Побратимству (3), Србадији (1) и Отаџбини (1) (Трифуновић, 1994). Године 1887. објављује научно - популарну књижицу *Васионска енергија и модерна физика* (Станојевић, 1887а) а 1888. године у Отаџбини велики чланак *Небо и његов склоп* (Станојевић, 1888в). У *Шематизму Краљевине Србије* за 1891. и 1892. годину пише одељак *Небо у години*, као и у *Државном календару Краљевине Србије* за 1894. и 1895. годину. У овој публикацији у периоду од 1901. до 1914. године, редовно пише прилог *Стари и нови календар и година*. Популаризацији астрономије

враћа се 1910. године када пише књижицу *Халејева комета и Земља* (Станојевић, 1910).

Ђорђе Станојевић, први српски астрофизичар, други руководилац Астрономске опсерваторије, ректор Универзитета у Београду, велики популаризатор астрономије и науке уопште, човек који је подарио светлост Београду, Ужицу, Лесковцу, Чачку, градитељ прве српске хидроцентрале, пионир индустрије расхладних уређаја и фотографије у боји има велико и значајно место у историји науке, технике и културе српског народа.

Референце

Ђурковић Перо: 1968, Седамдесет пет година рада Астрономске опсерваторије у Београду, *Publ. Obs. Astron. Belgrade*, **12**, 15.

Јанковић Ђ. Ненад: 1985, Став Срба према реформи календара, Зборник радова VII Националне конференције астронома Југославије, Публикације Астрономског друштва „Руђер Бошковић“ Но. 4, Београд, 25.

Јанковић Ђ. Ненад: 1986, Преглед историје астрономије у Југословенским земљама, у: Историја астрономске науке од Њутновог доба до наших дана (Б.М. Шеварлић), Универзитет у Београду, Београд, 143.

Јанковић Ђ. Ненад: 1989, Милан Недељковић, професор Велике школе и оснивач њене Опсерваторије, у: Сто година Астрономске опсерваторије у Београду, *Publ. Obs. Astron. Belgrade*, **36**, 107.

Мушицки Ђорђе, Басарић Ђорђе: 1987, Физика, у: Четрдесет година Природно – Математичког факултета у Београду, Београд, 196.

Симовљевић Јован: 1987, Астрономија, у: Четрдесет година Природно – Математичког факултета у Београду, Београд, 166.

Станојевић М. Ђорђе: 1882, Звездано небо независне Србије, стр. VIII + 59 + (3); са једном звезданом картом, Београд.

Stanojević M. Djordje: 1885, Analyse spectrale des éléments de l'atmosphere terestre, Communication à l'Academie des Sciences de Paris, **100**, 752.

Stanojević M. Djordje: 1886a, Sur l'origine du résau photosphérique Solaire, Communication à l'Academie des Sciences de Paris, **102**, 853.

Stanojević M. Djordje: 1886b, Sur le spectre d'absorption de l'Oxygéne, Communication à l'Academie des Sciences de Paris, **102**, 1024.

Станојевић М. Ђорђе: 1887а, Васионска енергија и модерна физика, стр. 68, Београд.

Stanojević M. Djordje: 1887b, Sur la photographie directe de l'état barometrique de l'atmosphère Solaire, Communication à l'Academie des Sciences de Paris, **104**, 1263.

Stanojević M. Djordje: 1888a, L'éclipse totale du Soleil du 19 août 1887, observé en Russie (Pétrowsk), Communication à l'Academie des Sciences de Paris, **106**, 43.

Станојевић М. Ђорђе: 1888б, Сунчеве фотосферске мреже пред Краљевско - Српском Академијом природних наука, Београд.

Станојевић М. Ђорђе: 1888в, Небо и његов склоп, Отаџбина, **7**, књ. 19, 1-22.

Stanojević M. Djordje: 1889, L'état actuel de la photographie du Soleil, Communication à l'Academie des Sciences de Paris, **108**, 724.

Stanojević M. Djordje: 1898, Les lignes de forces et les surfaces équipotentielles dans la nature, Communication à l'Academie des Sciences de Paris, **126**, 640.

Stanojević M. Djordje: 1900, Les lignes de forces dans les plantes, Communication à l'Academie des Sciences de Paris, **131**.

Stanojević M. Djordje: 1901a, Méthode éléctro - sonore pour combattre la grêle, Communication à l'Academie des Sciences de Paris, **133**, 373.

Stanojević M. Djordje: 1901b, Photomètre physiologique, Communication à l'Academie des Sciences de Paris, **133**, 351.

Станојевић М. Ђорђе: 1901в, Србија у сликама (фотографски снимци), књ. I, стр. 28, (са предговором др Богдана Поповића), Београд.
Stanojević M. Djordje: 1902, Photomètre physiologique, Communication à l'Academie des Sciences de Paris, **134**, 1457.
Stanojević M. Djordje: 1905a, Paratonnerre â cornes dentelées, Communication à l'Academie des Sciences de Paris, **141**, 1.
Станојевић М. Ђорђе: 1905б, Београдска опсерваторија и њен извештај за 1899 – 1903. год., стр. 32, Београд.
Станојевић М. Ђорђе: 1908, Нетачно празновање васкрсења у православној цркви и реформа календара, стр. 84, Београд.
Stanojević M. Djordje: 1908, Le calendrier normal, str. 15 + (1), Paris.
Станојевић М. Ђорђе: 1910, Халејева комета и Земља, стр. 29 + (3), Београд.
Stanojević M. Djordje: 1920, L'aéroplane et la grêle, Communication à l'Academie des Sciences de Paris, **170**, 1590.
Трифуновић Драган: 1976, Дело Ђорђа М. Станојевића у светлу открића Николе Тесле, у: Никола Тесла и његова открића (Ђорђе М. Станојевић), Београд.
Трифуновић Драган: 1994, Стваралаштво Ђорђа Станојевића у астрономским наукама, *Васиона*, **XLII**, No. 1-2, 23.
Трифуновић Драган: 1997, Ђорђе Станојевић професор и ректор Универзитета у Београду – Живот и дело, Свеске књ. 1, Д. Трифуновић, Београд.
Трифуновић Д., Димић М.: 1976, Библиографија радова Ђорђа М. Станојевића, у: Никола Тесла и његова открића (Ђорђе М. Станојевић), Београд.

DJORDJE STANOJEVIĆ – THE FIRST SERBIAN ASTROPHYSICIST

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Abstract. Life and scientific activities of Djordje M. Stanojević (1858-1921), the first Serbian astrophysicist, rector of Belgrade University (1913-1921) and Director of Belgrade Astronomical Observatory (1899-1900) are presented.

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РАЗВОЈ АСТРОНОМИЈЕ КОД СРБА ОД ПОЧЕТКА XVIII ВЕКА ДО ПРВОГ СВЕТСКОГ РАТА

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1. ОСАМНАЕСТИ ВЕК

У осамнаестом веку од Срба се једино Руђер Бошковић, бави као научник астрономијом. Он изучава различите астрономске проблеме, разрађује своју теорију о атомима и оснива Опсерваторију Брера у Милану. Године 1739. пише *De novo telescopii usu ad objectes coelestis determinanda.* Пише расправе из оптике као и о конструкцији и коришћењу оптичких инструмената, дурбина, хелиостата, дотеривању окулара, одређивању меридијана, грешкама меридијанског инструмента итд.

Осим теоријског рада на пољу астрономије, Руђер Бошковић се бави и посматрањима. Тако објављује резултате своја два посматрања проласка Меркура преко Сунчевог диска у расправама *De Mercurii novissimo infra Solem transitu*, 1737. (О најновијем пролазу Меркура испод Сунца) и *Osservazioni dell'ultimo passagio di Mercurio sotto il Sole*, (Посматрања последњег пролаза Меркура испод Сунца), 1753. (Јанковић, 1986). Он мери два степена меридијана између Рима и Римини ја, заједно са Мером да би тачније одредио облик Земље и мапу Ватиканске државе. Резултате рада објавили су у књизи *De litteraria expeditione per pontificiam ditionem ad dimentiendos duos meridiani gradus et corrigendam mappam geographicam*, 1755. (О научном путовању кроз Папску државу ради мерења два степена меридијана и исправљању географске карте). Бошковић пише и о Сунчевим пегама и њиховом посматрању, 1736. године, *De maculis Solaribus* (О Сунчевим пегама). Касније, 1777., он посматра пеге из Француске, те пише о методама посматрања и својим запажањима о природи Сунца.

Комете такође привлаче његову пажњу па посматра комету из 1744. и поводом ње пише 1746. расправу *De cometis.* Поводом комете из 1774. објављује методу за одређивање путање комете на основу посматрања у три мало међусобно удаљена положаја. Када је Хершел објавио откриће новог небеског тела 1781. године, Бошковић је покушао да својом методом одреди његову путању и установио је да је то елипса. Мада је Бошковић своје елиптичне елементе Уранове орбите објавио шест месеци пре Лапласа и

Лексела, обично се њима приписује прво израчунавање елемената путање нове планете.

Поменимо још и Бошковићева дела о годишњим аберацијама некретница, о нестајању и појављивању Сатурновог прстена, о налажењу путања планета геометријском конструкцијом ако су познати сила, брзина и правац кретања у једној тачки, о посматрању Месечевих фаза приликом помрачења, о облику Земље итд. Године 1785. издаје своја сабрана дела *Opera pertinentia ad opticam et astronomiam* (Дела о оптици и астрономији) у пет томова.

Бошковић се бави и популаризацијом. Тако је његов спев *De Solis, ac Lunae defectibus* (О помрачењима Сунца и Месеца), штампан 1760., 1761., и 1767., преведен на француски 1779. (Јанковић, 1986) и препеван на српски 1996. Године 1785. објављује *Notice abrégée de l'astronomie pour un marin* (Скраћена белешка из астрономије за једног поморца), која треба заповедника флоте да упути у најосновнија знања из астрономије, потребна поморцу.

Остали прегаоци баве се овим наукама у осамнаестом веку у просветитељском, Доситејевском смислу, док се у првој половини деветнаестог века постављају основе за развој природних наука: физике, астрономије и метеорологије код Срба. У то време развој астрономије је од превасходног интереса пре свега за поморство па није чудно да најпознатије опсерваторије граде управо и велике поморске силе, па се на пример, једна од најпознатијих у Америци и зове Поморска опсерваторија. У нашим крајевима подстицај за интерес према астрономији и метеорологији пружа пољопривреда, па код нашег народа, који се у овом сложеном историјском периоду бори за опстанак, ослобођење и стварање своје државе, астрономски садржаји доминирају у природним наукама, нарочито у осамнаестом веку управо због интереса пољопривредно оријентисаног становништва за календар, смену годишњих доба и појаве на небу.

У овом периоду у нашим крајевима врши астрономска посматрања болоњски гроф Алојзије Фердинанд Марсиљи (Luigi [Aloysius] Ferdinandus Marsigli) (1658-1730) (Wurzbach, 1867, стр. 16). Војник по професији, а научник по вокацији, изузетни човек универзалног духа, плодове својих истраживања објављује у Амстердаму 1726. године у монументалном шестотомном делу *Danubius Pannonico – Mysicus, observationibus geographicis, astronomicis, hydrographicis, historicis, physicis*. На 35 страна у другом делу првог тома описује, уз подробне цртеже, резултате својих астрономских посматрања, обављених код нас у јуну и јулу 1696. године. На ушћу Драве у Дунав и у тврђави у Тителу одредио је – користећи астрономске методе – месне географске ширине, висине Сунца у меридијану, посматрао Јупитер и његова четири сателита, скицирао тадашњи изглед Месеца. Са моста на Црној Бари, код Бачког Градишта, посматрао је Јупитер и његове пратиоце, нацртао карту тада видљивог дела Месеца. Код Сенте је опет посматрао Јупитер са сателитима, док је у Жабљу поново нацртао карту Месеца у фази (Јовановић, 1985а). Дело грофа Марсиљија, човека енциклопедијске ширине, сврстава га у ред личности од изузетног значаја за историју науке

у XVIII веку на нашим просторима.

Као прво „астрономско“ занимање у Београду, може се навести посао мувекита, верског службеника који се стара о тачном времену за молитве и одређује правац ка Меки. У мувекитханама (сахатницама) које су оснивали или вакуфи или богати султанови намесници, тачно време се одређивало мерењем висине Сунца помоћу астролаб-квадранта (руб'тахта) (Мулаомеровић, 1985). Мувекит ради у Београду од 1741. у џамији султана Махмуда у Горњем граду уз коју је била медреса са библиотеком, а касније бива премештен у Хусеин Ћехајину џамију (Тричковић, 1974).

У исто време, у латинској школи у Сремским Карловцима, велики путник, песник и богослов, а на крају архимандрит Јован Рајић (11. XI 1726 – 11. XII 1801) предаје астрономију од 1749. до 1768. године, а сачувана су и његова скрипта за тај предмет (Јанковић, 1985). Он се бави и посматрачким радом па је сачуван његов опис посматрања комете из 1769. године. Интересантно је напоменути да у то време Руђер Бошковић предаје астрономију у Римском колегијуму и да је рукопис предавања одржаних школске 1754/55. године сачуван и налази се у Централној националној библиотеци Виторио Емануело у Риму (Мартиновић, 1985). У српској православној великој гимназији у Сремским Карловцима предаје се астрономија од 1798. до 1825. године по Валховом уџбенику из 1794. године, написаном на немачком језику а елементи астрономије налазе се и у математичкој географији и физици (Јовановић, 1990).

2. КАЛЕНДАРИ

О интересу за астрономију сведоче такође разни преводи или прераде текстова из ове науке. Осим тога астрономски садржаји налазе се и у календарима који на српском језику почињу да се штампају у другој половини XVIII века. Почев од 1765. па до краја XVIII века има их једва дванаестак, док се средином XIX века само у једној години штампа толики број различитих календара (Јанковић, 1994).

Први српски календари, месецослови, штампају се у Млецима, Бечу, Будиму и Темишвару, а тек тридесетих година XIX века Милошева Србија добија штампарије па се на насловним странама календара почињу јављати и Београд и Крагујевац. Овакви календари су ширили и популарисали астрономска знања у нашем народу, објављујући не само времена изласка и заласка Сунца, дужину дана, Месечеве мене, почетак годишњих доба и видљивост планета, него и чланке о небеским појавама и другим астрономским темама који се на другом месту нису могли наћи на српском језику.

У Млецима Павле Соларић штампа свој календар 1813. године, а Захарије Орфелин (1726-1785) објављује Вечити календар 1783. године (Јовановић, 1985а) у Бечу. Поред астрономског дела он садржи и 182 странице посвећене физици. Астрономски и физички део писан је према уџбенику Адама Данијела Рихтера, директора гимназије у Цитави, *Lehrbuch einer für*

Schulen fasslichen Naturlehre, zum Gebrauch bey Vorlesungen, Фулда 1776. (Јовановић, 1985а, Јанковић, 1994). У Бечу 1792. године свој календар објављује и Стефан Новаковић (Јанковић, 1994). Велики број календара на српском језику штампан је и у Будиму, почевши од 1799. када је у Писмени славеносербскија печатни при Краљевском Университету, штампан *Месјацослов*. У Будиму је штампан 1801. *Календар или Прогностикон* у преводу Государа Дамијана Каулицијa, Месјацослов митрополита Стратимировића (1807) и други (Јанковић, 1994).

Међу првим календарима у Београду налазе се *Забавник* (1833) Димитрија Давидовића и *Београдска лира* (1833). Давидовићев забавник се штампа у разним местима са прекидима од 1815. до 1836. године. Он први међу календарима употребљава (1815) народне називе за Венеру (Даница, Зорњача, Вечерњача), а у једном од издања (1820) јавља се чланак *Астрономија*, у коме је дат кратак преглед небеских тела (Јанковић, 1994). Атанасије Николић (Бачки Брестовац 1803. – Београд 1882) покреће 1831. године календар *Ружицу*, а од 1831. до 1837. године издаје *Домовни и обштеполезни календар* (Јовановић, 1985а). Од 1836. године па до 1850., „при Књажевско – Србској типографији“ штампа се *Месецослов*, а у Новом Саду се појављује „печатан код г. Павла Јанковића“ а после код његове удовице *Ружични венац* (1839) (Јанковић, 1985).

Од 1826. до 1834. са прекидом од 1830. до 1833. године Вук Стефановић Караџић издаје *Даницу* са занимљивим календарским делом. Димитрије Пантелеон Тирол (Чаково 1793 – Темишвар 1857) објављује 1837. и 1838. године у Београду *Уранију* заједно са „сотрудницима“ Јованом С. Поповићем, Јованом Стејићем и Симом Милутиновићем. У Темишвару, Тирол објављује *Банатски алманах* (1827 и 1828). Осим тога он објављује и Месецослове за 1836., 1837. и 1842. годину (Јовановић, 1985а). Александар Андрић од 1846. до 1859. године уређује и издаје календар *Зимзелен* у коме саопштава где ће се која планета налазити.

На Цетињу, Димитрије Милаковић издаје календар *Грлицу* 1835-1839, с тим што је 1837. године уредник био Петроније Лујановић. У првој књизи овог календара за 1835. годину налази се саопштење о Халејевој комети.

Мада многи календари не прате увек довољно развој астрономских знања, има и много супротних примера који су омогућили нашим људима да прате напредак астрономије и буду правовремено обавештени о значајним појавама на небу. Тако је долазак Халејеве комете најављен 1835. године на време. Српска јавност је 1836. године упозната и са Енкеовом кометом, а и Нептун откривен 1846. нашао се убрзо на страницама календара.

У другој половини XIX века издавачка делатност се шири и низ календара, алманаха и часописа доноси прилоге из астрономије, који имају едукативну и популаризаторску функцију.

3. ПРОСВЕТИТЕЉИ И ПОПУЛАРИЗАТОРИ

Научни живот на нашим просторима на крају осамнаестог и почетком деветнаестог века, обележен је просветитељским духом Доситеја Обрадовића, за кога је наука била првенствено средство које је користио у циљу просвећивања народа и сузбијања сујеверја и различитих заблуда.

Најзначајнији међу писцима који су следили овакав доситејевски дух био је Атанасије Стојковић (1733-1832) доктор филозофије и члан немачких учених друштава. Мада је на нашем подручју деловао веома кратко, од 1799. када се враћа са студија у Немачкој до свога одласка у Русију 1804., где постаје професор Универзитета у Харкову (Деретић, 1973), оставио нам је поред неколико полукласичних ода и четири прозна дела (*Кандор или откровеније египетских таин, Аристид и Наталија, Сербски секретар* и *Fisika*), међу којима је најзначајнија и најпознатија тротомна *Fisika*.

Ово капитално дело писано славеносербским језиком остало је дуго времена непревазиђено и донело Стојковићу славу и ауторитет које није помрачила ни његова борба против Вука. Фисика даје систематско излагање о природним појавама и законима. Осим физике обухвата и све друге природне науке осим хемије па се у њој налазе и поглавља посвећена астрономији.

Текстове у којима се јављају и астрономски садржаји објављују Павле Соларић (1781 – 1821) (*Ново грађанско землеописаније*, 1804), Василије Булић (1785 или 1786 – 1826) (*Земљеописаније* – 1824), Павле Кенгелац (Кикинда 1766 – Темишвар 1834) *Јестествословије* (Будим 1811), Пантелејмон Михајловић, *Енкиклопедија* (Будим 1818) и други. Занимљиво је да се и један свештеник, Ђорђе (Гаврило) Поповић (Баја 1811 – Београд 1871) бавио популарисањем астрономије. Године 1850. издао је књигу *Астрономија или наука о звездама*. Јанковић (1955) наводи да се „по који астрономски чланак може наћи и у популарним делима“ *Огледи умне науке* од Јована Петрова и *Општа знања сваком човеку нуждна*, од Петра Радовановића. У Црној Гори, у часопису Луча (јануар 1896., год. II, св. II, стр. 32-35), Душан В. Тодоровић, студент Петроградског универзитета, објављује чланак *Неколико ријечи о животу на другим свјетилима*.

Као једног од првих астронома аматера у нашим крајевима, можемо сматрати Јована (Јулијана) Чокора (Баја, 21. I / 2. II 1810 – Сремски Карловци, 10. или 13. VI 1871) (Јанковић, 1955). Он је у Сремским Карловцима направио малу опсерваторију, а израђивао је и сунчане сатове. Аматерски су се бавили астрономијом и Ђорђе Максимовић (1838 – 1881), лекар, Петар Манојловић Селим, официр и дипломата, Лазар Комарчић, књижевник и писац нашег првог научно фантастичног романа (Комарчић, 1902), Сретен Хаџић, педагог и други (Јанковић, 1955).

4. РЕФОРМА КАЛЕНДАРА

Православни Срби нису усвојили Грегоријански календар, који је у Аустрију и Мађарску увео цар Рудолф II, као ни друге православне земље све

до почетка XX века. У средњем веку су године рачунате по цариградској ери, од стварања света, а почињале су 1. септембра или ређе 1. марта. Татомир Миловук у књижици *План најновији и општи један свију христијана вселенски календар*, Нови Сад, 1865., предлаже да се у јулијанском календару месецима са 31 даном одузме један дан, а месецима са 30 дана у грегоријанском календару дода по један дан – фебруару два, па би разлика која постоји нестала. Овај наивни план остаје без одјека, али Мојсије Пајић у три предавања у Бечу 1866. године, предлаже да година почиње равнодневицом, сваке године на подневку који је 87 или 87,2 степена западније од оног од претходне године, тако да свака година има 366 дана али последњи дан траје само $5^h\ 48^m$ или $5^h\ 49^m$ (Јанковић, 1985б).

Крајем XIX века, у Србији предлаже реформу Јулијанског календара Ђорђе Станојевић 1892. године, али је његов предлог да се сваке 128. године изостави по један дан остао без подршке. У књизи објављеној у Београду 1898. године, *Предлог за изравнање јулијанског и грегоријанског календара и сметње томе*, Љубомир Узун-Мирковић (1832 – 1905) предлаже изједначавање грегоријанског и јулијанског календара, тако што би се у току 1898. и 1899. од јула одузела 2 дана, а од августа, септембра, октобра и децембра по један дан, што би уклонило разлику која је у то време износила 12 дана.

Од 1900. до 1921. године, професор гимназије Максим Трпковић (Орланци код Кичева, 15. XI 1864 – Београд 3 / 16. XII 1924) објављује низ радова у којима установљава да се разлика између јулијанске и тропске године (време између два узастопна проласка Земље кроз пролећну или гама тачку) повећа за 7 дана у току 900 година. Да би се овај вишак дана елиминисао он предлаже да преступне буду само оне године са две нуле на крају које подељене са 9 дају остатак 0 или 4. Он 1900. године штампа у Београду књигу *Реформа календара*. Такође у Годишњем извештају Реалке за 1894 – 1895 (Београд, 1895, 25-40) објављује: *Нешто о даљинама звезда (некретница) и склопу васионе*.

Године 1900. Недељковић објављује свој рад *Projet de reforme du calendrier* (Предлог за реформу календара). Осим усклађивања календара са тропском годином, он жели и да пролеће увек почиње 21. марта а уколико би оно почињало 22. марта он би ту годину учинио преступном и тако почетак пролећа вратио на 21. Таквим рачуном добија низ преступних година: 1900, 1904, 1908, 1913, 1921,... Он увиђаману оваквог рачунања, да преступне године нису у правилним размацима, па даје и други предлог у коме је свака четврта година преступна. Да би то постигао он претвара из преступних у просте године које се завршавају са две нуле, осим оних које је израчунао до 12000. године, али сада почетак пролећа не пада увек 21. марта.

5. ДЕВЕТНАЕСТИ ВЕК

У време када је на Лицеју предавања из физике држао (1843 – 1849) Јанко Шафарик, професор словенске филологије и историје, од 1847. године у збирци физичких инструмената постоји и астрономски дурбин

(Симовљевић, 1987), који је Лицеју поклонио енглески конзул (усмено саопштење Д. Трифуновића). Године 1849. долази по позиву за професора Вук Маринковић (1807-1859). Он предаје физику од 1849. до 1859. године и први од професора физике на Лицеју, пише свој уџбеник, *Начела физике*, који објављује 1851. године, а где се налазе и астрономски садржаји. У наставном плану Лицеја из 1844. године нема астрономије, али је вероватно већ од 1849. године, Вук Маринковић предаје уз физичку географију.

За историју астрономије важни су и Милован Спасић (1817 – 1908) и Константин Бранковић (1814 – 1865) (Јанковић, 1955). Астрономски садржаји налазе се и у уџбеницима *Прва початија исчислителного јестествената земљеписанија*, Јована Стерије Поповића из 1845. и *Астрономија или наука о звездама*, Гаврила Поповића из 1850. Међу писцима који састављају уџбенике за гимназије са укљученим астрономским садржајем налази се Емилијан Берберовић (1849 – 1889), који је у својој *Календарографији или науци о календару* објавио 1881. године корисна упутства о састављању календара (Јанковић, 1986). Проблеме у вези са састављањем календара са низом таблица и упутстава за практичну примену излаже и Јован Драгашевић (1836 – 1915) у уџбенику *Кронографија* објављеном 1874. године. Он 1875. године објављује и уџбеник *Космометрија* у коме се описује како се одређује време, географске координате и магнетска деклинација, а намењен је слушаоцима војне академије и техничког факултета. Астрономски дурбин који од 1847. године постоји у збирци физичких инструмената на Лицеју вероватно је коришћен за изучавање астрономских садржаја.

У другој половини XIX века појављују се и прави научни радови из астрономије. Ђорђе Станојевић, први српски астрофизичар објављује низ научних радова из физике Сунца и спектроскопије у часопису Париске академије наука (види у овом зборнику Димитријевић, 1997а). Треба поменути и рад: *Соко-Бања, први метеорит у Србији*, од Јосифа Панчића (Гласник Српског ученог друштва, 1880, XLVIII), *Јелички метеорит*, од Јована Жујовића (Геолошки анали, 1890), као и чланке о спектроскопији, фотометрији и фотографији у астрономији од Јеленка Михајловића (Јанковић, 1955).

6. ОСНИВАЊЕ АСТРОНОМСКЕ И МЕТЕОРОЛОШКЕ ОПСЕРВАТОРИЈЕ И КАТЕДРЕ ЗА АСТРОНОМИЈУ СА МЕТЕОРОЛОГИЈОМ

Милан Недељковић (Београд, 27. IX 1857 – Београд, 21. XII 1950), као „приправник за физику и математику на Великој школи“ подноси 16. VIII 1878. године Министарству просвете молбу да студије завршене у земљи настави у иностранству и то физику и астрономију, а осим тога аналитичку или рационалну механику и математику. Министар Бошковић тражи од ректора мишљење које стиже 12. VI 1879. План студија према овом мишљењу је следећи: „1) да у Паризу слуша две године предавања из инфинитезималног рачуна, рачуна вероватноће, математичке физике, метеорологије,

рационалне и аналитичке механике, више геодезије и астрономије; 2) треће године да се вежба на Париској астрономској и метеоролошкој опсерваторији и слуша специјална предавања из астрономије и метеорологије, поглавито о теорији и употреби астрономских и метеоролошких инструмената; 3) прву половину четврте године да пробави у Лондону, а другу половину у путовању, обилазећи најважније астрономске и метеоролошке станице.“ Ово мишљење су потписали Јосиф Панчић, Коста Алковић, Сима Лозанић, Љубомир Клерић, Димитрије Нешић и Димитрије Стојановић (Јанковић, 1989). Тиме га ово мишљење усмерава у ствари на студије астрономије и метеорологије и ради њих је као државни питомац послат у Француску.

Године 1863., законом о устројству Велике школе, астрономија је забораваљена, али је изменама и допунама овог закона 1880. године уведена као посебан предмет на Природнословно – математичком одсеку Филозофског факултета Велике школе, а требало је да је слушају и студенти технике. Ова одлука је спроведена у дело тек 1884. године, када се Милан Недељковић, вратио са школовања у Француској, на коме је био од јуна 1879. до јула 1884. Управо 17. VII 1884. године, министар правде Димитрије Маринковић (1835 – 1911), у својству заступника министра просвете и црквених дела, саопштава одлуку Главног просветног савета „да се космографија у строжијем, научном смислу одвоји од географије и пренесе као засебан предмет у VII разред гимназија и реалака.“ Милан Андоновић, професор Велике школе (1849 – 1926) и Јован Ђорђевић, професор Учитељске школе, задужени су да саставе програм. Године 1888. М. Андоновић је написао Космографију, уџбеник за овај предмет. Она је у једном периоду била најпотпунији уџбеник за овакво градиво.

После повратка са школовања, Милан Недељковић је краљевим указом од 21. X 1884. године постављен за суплента за астрономију и метеорологију и поверена му је катедра за астрономију са метеорологијом Велике школе, коју држи пуних четрдесет година, до свог другог пензионисања 1924. године. Једини прекид био је када је Милан Недељковић први пут био у пензији од 5. јула 1899. до 31. октобра 1900. године (Ђурковић, 1968), када је катедра за астрономију са метеорологијом, поверена Ђорђу Станојевићу. Недељковић је по Уредби из 1896. године предавао астрономију као стручни предмет у Математичко – физичком одсеку. Астрономија је сведена на помоћну науку и изостављена из професорских испита изменом Уредбе од 30. 09. 1900. године. Ништа се не мења ни оснивањем Универзитета 1905. године. Од 1906. астрономија је помоћни предмет I студијске групе Филозофског факултета, а М. Недељковић је ванредни професор. Године 1909. за ванредног професора примењене математике, по позиву долази из Беча, доктор технике, грађевински инжењер Милутин Миланковић (Даљ, 28. V 1879 – Београд, 12. XII 1958), који је први код нас, у оквиру овог предмета, започео наставу из небеске механике.

Недељковић није написао уџбеник за астрономију, већ су студенти користили *Космографију* Милана Андоновића (Јанковић, 1986). У рукопису

је остала *Практична астрономија за ученике Велике школе*, и преводи метеорологије од Van Bebber-a (1885 – 1886), астрономије од Wolf-a (1877), Теоријске астрономије од Watson-a (1868) и Теоријске метеорологије од W. Ferrel-a (Јанковић, 1989), као и делимични превод Secchi-јеве књиге о звезданој астрономији. Поред поменутих радова о реформи календара сумираних у чланку *О календару* из 1923., треба поменути и популарну књижицу *Свет и Халејева комета*, издату 1910. године.

Недељковић покушава да оснује и Опсерваторију али до 1887. није могао ништа да уради. Те године, министар просвете и црквених дела, песник Милан Кујунџић Абердар (1842 – 1893), у писму ректору Велике школе од 21. јануара, пита „може ли наша држава ступити у коло осталих земаља на основу споразума Међународне геодетске конференције у Берлину?“ Одговор Љ. Клерића био је да је крајње време за то, а радови би се могли поверити професорима геодезије и астрономије. Пошто је то сматрао као повољну прилику, Недељковић 2. III 1887 подноси предлог за оснивање Опсерваторије. Изузетно брзо, 26. III / 7. IV 1887. Милан Кујунџић Абердар потписује акт о оснивању Астрономске и метеоролошке опсерваторије, чију реализацију поверава Милану Недељковићу. Оснивањем ове установе (оснивање и развој су описани у Димитријевић, 1997б), која је представљала основну базу за развој астрономске науке код нас, дат је снажан подстрек и постављене су основе за развој ове науке.

Референце

Деретић Јован: 1973, Славеносербски списатељ Атанасије Стојковић, Атанасије Стојковић: Аристид и Наталија, Фисика, Нолит, Београд.

Димитријевић Милан С.: 1995, Астрономија и физика у Србији у XVIII и првој половини XIX века, Зборник радова научног скупа „Природне и математичке науке у Срба у 18. и у првој половини 19. века“, САНУ Огранак у Новом Саду, Универзитет у Новом Саду, Матица Српска, Нови Сад, 25.

Димитријевић Милан С.: 1997а, Ђорђе Станојевић – први српски астрофизичар, у овој публикацији.

Димитријевић Милан С.: 1997б, 110 година Астрономске опсерваторије, у овој публикацији.

Ђурковић Перо: 1968, Седамдесет пет година рада Астрономске опсерваторије у Београду, *Publ. Obs. Astron. Belgrade*, **12**, 15.

Francisty Jaroslav: 1985, Астрономска посматрања грофа L. F. Marsigli-ја са територије Војводине у току лета 1696. год., Зборник радова VII Националне конференције астронома Југославије, Публикације Астрономског друштва „Руђер Бошковић“ No. 4, Београд, 67.

Гледић Војислав: 1985, Биљешке о астрономији у Црној Гори у XIX вијеку, Зборник радова VII Националне конференције астронома Југославије, Публикације Астрономског друштва „Руђер Бошковић“ No. 4, Београд, 123.

Јанковић Ненад: 1955, Астрономија код Срба, Енциклопедија Југославије I, Лексикографски завод ФНРЈ, Загреб, 223.

Јанковић Ненад: 1985а, Астрономија у делима Јована Рајића, Зборник радова VII Националне конференције астронома Југославије, Публикације Астрономског друштва „Руђер Бошковић“ No. 4, Београд, 77.

Јанковић Ненад: 1985б, Став срба према реформи календара, Зборник радова VII Националне конференције астронома Југославије, Публикације Астрономског друштва „Руђер Бошковић“ No. 4, Београд, 103.

Јанковић Ђ. Ненад: 1986, Преглед историје астрономије у Југословенским земљама, у: Историја астрономске науке од Њутновог доба до наших дана (Б.М. Шеварлић), Универзитет у Београду, Београд, 143.
Јанковић Ђ. Ненад: 1989, Милан Недељковић, професор Велике школе и оснивач њене Опсерваторије, у: Сто година Астрономске опсерваторије у Београду, *Publ. Obs. Astron. Belgrade*, **36**, 107.
Јанковић Ненад Ђ.: 1994, Астрономија у српским штампаним календарима до 1900., САНУ Посебна издања DCXXVIII, Одељење Природно – математичких наука, књ. 70, Београд.
Јовановић Божидар Д.: 1985а, Војводина и војвођани у популаризацији астрономије до 1941. године, Зборник радова VII Националне конференције астронома Југославије, Публикације Астрономског друштва „Руђер Бошковић“ No. 4, Београд, 117.
Јовановић Божидар Д.: 1985б, Живот и рад Јована (Јулијана) Чокора, Зборник радова VII Националне конференције астронома Југославије, Публикације Астрономског друштва „Руђер Бошковић“ No. 4, Београд, 117.
Јовановић Божидар: 1990, Нећемо корачати у XVIII век, Дневник, 14. јули стр. 2.
Комарчић Лазар: 1902, Једна угашена звезда, Штампарија Д. Димитријевића, Београд.
Мартиновић Ивица: 1985, Биљешке Бошковићевих предавања из астрономије академске године 1754/1755, Зборник радова VII Националне конференције астронома Југославије, Публикације Астрономског друштва „Руђер Бошковић“ No. 4, Београд, 91.
Мулаомеровић Јасминко: 1985, Мувекитхане – прве астрономске институције у Босни и Херцеговини, Зборник радова VII Националне конференције астронома Југославије, Публикације Астрономског друштва „Руђер Бошковић“ No. 4, Београд, 25.
Мушицки Ђорђе, Басарић Ђорђе: 1987, Физика, у: Четрдесет година Природно - математичког факултета у Београду, Београд, 196.
Secchi A.: 1879, Les étoiles, essai d'astronomie sidérale, Paris.
Симовљевић Јован: 1987, Астрономија, у: Четрдесет година Природно - математичког факултета у Београду, Београд, 166.
Тричковић Радмила: 1974, Варош после 1740. године, Историја Београда I, уредник В. Чубриловић, Просвета, Београд, 668.
Van Bebber W.J.: 1885-1886, Handbuch der ausübenden Witterungskunde, Stuttgart.
Von Wurzbach Constantin: 1867, Biographisches Lexikon, 17, Theil, Wien, 16.
Watson J.C.: 1868, Theoretical Astronomy, Philadelphia.
Wolf Rudolf: 1877, Geschichte der Astronomie neuerer Zeit, München.

DEVELOPMENT OF ASTRONOMY AMONG SERBS FROM THE BEGINNING OF THE 18th CENTURY TO THE FIRST WORLD WAR

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Abstract. A short history of the developement of astronomy among Serbs from the beginning of the 18th century to the beginning of the First World War.

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Астрономска опсерваторија у Београду је једна од најстаријих научних установа у Србији, која је за сто десет година деловања постала важан део историје науке и културе на овим просторима. Акт о оснивању, потписао је министар просвете и црквених дела Краљевине Србије Милан Кујунџић 26. марта (7. априла) 1887. године, на иницијативу Милана Недељковића (Београд, 27. IX 1857 – Београд, 21. XII 1950), професора Велике школе, који је и одређен за првог управника Астрономске и метеоролошке опсерваторије.

Првог маја 1887. године, Недељковић почиње са радом у Провизорној опсерваторији у закупљеној кући породице Гајзлер, данас на углу улица Светозара Марковића и Војводе Миленка. Овде је Опсерваторија радила до првог маја 1891. године, када се преселила у за то време довршену сопствену зграду, данашњу Метеоролошку опсерваторију у Карађорђевом парку, у чијем се мањем музејском простору, од прославе стогодишњице оснивања 1987. године, налази једна соба посвећена почецима астрономске науке код нас. У оно време земљиште Опсерваторије обухватало је не само данашњи Карађорђев парк, него и место на коме се данас налази Дечја клиника.

Недељковић је на челу Опсерваторије од 26. марта (7. априла) 1887. године до 30. јануара 1924. године. Изузетак представља само период од 5. јула 1899. до 31. октобра 1900. године, када је био у пензији због политичких разлога, тј. због Ивандањског атентата на краља Милана, који је краљ Александар искористио за обрачун са својим политичким противницима. У то време на његовом месту био је Ђорђе Станојевић (Неготин, 7. IV 1858 – Париз, 24. XII 1921), први српски астрофизичар, други руководилац Астрономске и метеоролошке опсерваторије, ректор Универзитета у Београду, велики популаризатор астрономије и науке уопште, човек који је увео електрично осветљење у Београду, Ужицу, Лесковцу, Чачку, дарујући тако тим градовима светлост, градитељ прве српске хидроцентрале, пионир индустрије расхладних уређаја, иницијатор организовања

комитета за хладноћу и међународне организације за технику хлађења у Паризу 1903. године, пионир фотографије у боји код нас. Његов албум *Србија у сликама* са оваквим фотографијама у боји о историјским споменицима, ношњи и пределима у Србији и Црној Гори из 1901. године је први овакве врсте код нас.

Осим свог значаја за метеорологију, Астрономска и метеоролошка опсерваторија Милана Недељковића, колевка је и сеизмолошких и геомагнетских истраживања код Срба. Крајем 1903. године, Недељковић позајмљује инструменте за геомагнетска мерења од Теге Миклош Конкоља, оснивача Астрономске опсерваторије у Будимпешти и гради земномагнетски павиљон. Он почиње са земномагнетским мерењима која од 1907. године изводи Неша Петровић. Захваљујући Конкољу, Недељковић 1903. године добија и сеизмограф, који следеће године поставља у посебан павиљон. Посматрања се обављају редовно и за ове потребе подиже се на Ташмајдану зграда данашњег Сеизмолошког завода 1906. године. Ову активност преузима Недељковићев помоћник Јеленко Михајловић (Врбица, 11. I 1869 – Београд, 10. X 1956), који од 1896. године ради на Опсерваторији.

За време друге аустроугарске окупације у Првом светском рату, Опсерваторију води Виктор Конрад из Беча. Приликом бекства из Србије, Аустријанци су однели или уништили све инструменте.

Захваљујући свом огромном залагању и стручности, Милан Недељковић набавља у Немачкој на име ратних репарација телескопе и пратећу опрему за нову опсерваторију.

Инструменти које је набавио Недељковић и данас су практично једина посматрачка база Опсерваторије, иако су неке Немци однели у II светском рату, осим тога два су однета у Љубљану, два у Загреб (види Ђурковић, 1968), а неки мањи нису монтирани ни до данас. Највећи од инструмената, Велики рефрактор, био је тада четврти по величини у Европи, а до данас је највећи у нашој земљи.

Данас су монтирани у павиљонима следећи инструменти које је набавио Недељковић:

1. Велики рефрактор – екваторијал „Zeiss“ 650/10550 mm.
2. Сунчани спектрограф (монохроматор) типа Littrow, 9000mm/100000, изграђен адаптацијом екваторијала „Zeiss“ 200/3020 mm са две астрокамере „Tessar“ и „Petzval“ 160/800 mm.
3. Велики меридијански круг „Askania“ 190/2578 mm.
4. Велики пасажни инструмент „Askania“ 190/2578 mm са системом вакуумских мира.
5. Велики вертикални круг „Askania“ 190/2578 mm.
6. Астрограф „Zeiss“ 160/800 mm.
7. Фотовизуелни рефрактор „Askania“ 135/1000 и 125/1000 mm.
8. Зенит телескоп „Askania“ 110/1287 mm.
9. Пасажни инструмент „Bamberg“ 100/1000 mm.

Док је Недељковић водио борбу за нову Опсерваторију на којој би били постављени набављени инструменти и почела астрономска посматрања, из-

ненада је пензионисан 30. јануара 1924. године. Одлуком Факултетског савета, те године се Опсерваторија дели у две посебне установе: Метеоролошку и Астрономску опсерваторију Универзитета у Београду.

Године 1925. на чело Астрономске опсерваторије бива постављен Војислав В. Мишковић (Фужине, 18. I 1892 – Београд, 25. XI 1976), који је у то време афирмисани астроном запослен на Опсерваторији у Ници. Он је студије астрономије започео у Будимпешти и Гетингену пред први светски рат, а после демобилисања крајем 1918. године послат је у Француску да заврши студије. Дипломирао је 1919. године и постављен за асистента Астрономске опсерваторије у Марсељу. У Ници ради као астроном од 1922. године а 1924. докторира на Универзитету у Монпељеу. Године 1925. добио је награду Француске академије наука за студије из звездане статистике. У француским научним часописима, у периоду од 1919. до 1925. године објављује двадесетак радова, посвећених посматрањима малих планета и комета, као и одређивањима њихових путања. У Београд долази 1926. године и осим Астрономске опсерваторије, преузима и новоосновану Катедру теоријске и практичне астрономије на Филозофском факултету где је изабран за ванредног професора. Године 1929. изабран је и за дописног члана Српске краљевске академије а 1939. године за редовног. Он у знатној мери делатност установе усмерава ка математичко-нумеричким пословима, који дају више вредних резултата. Значајни су нумерички радови везани за Математичку климатологију М. Миланковића и Мишковићеве Прецесионе таблице.

Када је Опсерваторија подељена на Метеоролошку и Астрономску, привременој Астрономској опсерваторији Универзитета додељен је део земљишта Опсерваторије на коме је данас Дечја клиника. Ту су биле барака са канцеларијама и слушаоницом, барака са станом за управника, дрвени павиљони за пасажни инструмент и мали астролаб, као и павиљон алтазимута. Током 1928. године сазидан је павиљон екваторијала и то на спрат са терасом око куполе. Убрзо затим, 7. октобра 1929. године, Мишковић успева да добије средства за изградњу нове опсерваторије, 6 км југоисточно од Теразија, на површини од 4.5 ha, на коти 253 m, на брду Велики Врачар, које од тада, као и читав део града, носи назив Звездара.

Изузетан и веома вредан архитектонски комплекс Астрономске опсерваторије, пројектовао је Јан Дубови, члан Групе архитеката модерног правца (ГАМП) основане 1928. године. Захваљујући управо овом остварењу, Јан Дубови је у Прагу проглашен за доктора наука. Грађевински радови извођени су од 1930. до 1932. године, а током наредне две године монтирани су инструменти.

Мишковић започиње и са издавањем научног часописа *Mémoires de l'Obs. Astr. Belgrade* (штампано пет свезака за 1932., 1933., 1936., 1938. и 1949. годину), *Annuaire de l'Obs. Astr. Belgrade* (издато шест свезака за 1929. – 1934. године), који је садржао звездано време и краткопериодичне чланове нутације, средње и привидне положаје 189 звезда, ново-откривене астероиде и објашњења за употребу, *Наутичког годишњака,* (за године од 1934.

до 1941.) за потребе навигације у морнарици, те *Годишњака нашег неба,* астрономског календара на српском језику, који је излазио од 1930. до 1941. и од 1948. до 1952. године (број за 1948. годину уредио је Ф. Доминко а за 1949., 1950. и 1951. годину Божидар Поповић).

Године 1935. Перо М. Ђурковић (Српска Трнова, 1908 – Београд, 5. I 1981) и Фран Доминко (Водњан 26. VII 1903 – Љубљана 22. II 1987) организују службу времена и дужине, и те године Ђурковић одређује провизорну географску дужину Опсерваторије. Она је тачније одређена 1938. године под руководством В. Мишковића а у сарадњи са Војно – географским институтом који се тада налазио на Калимегдану.

Године 1936. Милорад Протић организује службу малих планета и посматрања Сунца. Исте године П. Ђурковић открива на опсерваторији у Иклу (Uccle – Белгија), малу планету (планетоид, данас се обично употребљава назив астероид) која касније добија име 1605 Миланковић, а М. Протић у Београду, малу планету 1564 Србија, чиме започиње рад на проналажењу нових малих планета. Укупно су сарадници Опсерваторије открили 43 мале планете од којих су 12 добиле име, а три открића су накнадно приписана другим ауторима. Сам Протић је у периоду од 1936. до 1956. открио 33 мале планете. Осим мале планете 1564 Србија, он је добио право да да име малим планетама 1517 Београд, 1550 Тито, 1554 Југославија, 1605 Миланковић, 1675 Симонида, 1724 Владимир (по унуку М. Протића Владимиру Бенишеку), 2244 Тесла и 2348 Мишковић. Ђурковић је открио пет малих планета у периоду од 1936. до 1941. године, а име је дао малој планети 1700 Звездара. Године 1980, Зоран Кнежевић открива на фотоплочама које су по његовом упутству снимљене на опсерваторији Piszkestetö у Мађарској, четири мале планете од којих једна добија име 3276 Paolicchi, по његовом сараднику из Италије. Године 1991. у знак почасти, једној малој планети је додељено име 3900 Кнежевић, према овом астроному. За српски народ је везана и мала планета 1555 Дејан названа по сину П. Ђурковића.

Године 1936, оснивањем Службе малих планета и посматрања Сунца, завршена је организација посматрачких радова на новој Опсерваторији. Те године Мишковић покреће *Bulletin de l'Observatoire astronomique de Belgrade*, научни часопис који од броја 145 за 1992. годину излази под именом *Bulletin astronomique de Belgrade*. Уредници овог часописа били су В. В. Мишковић (за године 1936 – 1940, 1943 – 1948 и 1952 –1956), М. Б. Протић (за године 1941 – 1942, 1955 – 1960, као и 1971-1975), Б. Поповић (за годину 1950.), В. Оскањан (1964), П. М. Ђурковић (за године 1964 – 1970), М. Мијатов (Nos. 127 – 131, 1976 –1981), Д. Зулевић (Nos. 132 – 133, 1982 – 1983), Ђ. Телеки (134 –136, 1984 – 1986) и М. С. Димитријевић (137 –, 1987 –).

Од јула 1941. године на Опсерваторији се налази немачка војска а Вермахт доводи професоре Гротријана и Кипенхојера из Потсдама, који пописују инструменте као немачку имовину а спектрохелиограф и тражиоц комета шаљу у Немачку. На терасама управне зграде и резервоара за воду сагрђени су бункери за управљање артиљеријском ватром, а библиотека је

претворена у официрску кантину. Приликом борби за ослобођење Београда, нарочито су тешко оштећени централна зграда, зграда резервоара за воду и павиљон Великог рефрактора.

После рата започиње обнова Опсерваторије. Мишковић остаје на дужности директора до марта 1946. када подноси оставку, која је прихваћена тек маја 1948. године. За то време опсерваторијом руководи М. Б. Протић. Захваљујући залагању М. Протића, П. Ђурковића, Б. Шеварлића, као и способностима Љ. Пауновића, шефа техничке службе, чија су креативна решења унапредила рад већине опсерваторијских инструмената, ратна оштећења су санирана у првим послератним годинама.

Године 1945. Перо М. Ђурковић покреће и уређује стручни часопис *Астрономска и метеоролошка саопштења*, који Астрономска опсерваторија издаје од 1945. до 1950. године (7 бројева). Опсерваторија покреће 1947. године серију издања *Публикације Астрономске опсерваторије у Београду*. На месту главног и одговорног уредника били су В. Оскањан (No. 10), П. М. Ђурковић (Nos. 12-16), М. Б. Протић (Nos. 17-19, 21-22), Ђ. Телеки (Nos. 20, 26, 32, 34, 35), М. Мијатов (Nos. 24, 25, 27-31), Г. М. Поповић (No. 33), М. С. Димитријевић (Nos. 36-56).

Током 1947. године, П. Ђурковић, Б. Шеварлић и Захарије Бркић (Пољна код Трстеника, 8. XI 1910 – Београд, 24. IV 1979) организују службу географске ширине, коју 1956. Шеварлић и Ђорђе Телеки (Сента, 20. VIII 1928 – Београд, 23. II 1987) укључују у Међународну брзу службу ширина, у коју је примљена 7. октобра те године. После Шеварлића, који се у овој Служби задржава до 1963. године, на њеном челу су Ђ. Телеки до 1968, Владета Миловановић до 1972, а од тада до пензионисања Радомир Грујић.

До 1. јула 1948, Опсерваторија је као и пре рата била под Универзитетом, а од 1. јула 1948. до 18. децембра 1950. године, када долази под јурисдикцију Српске академије наука, она је под Комитетом за научне установе, Универзитет и високе школе НР Србије. Под Српском академијом наука Опсерваторија је до 27. марта 1954. године, када постаје установа са самосталним финансирањем при Извршном већу НР Србије, а 9. VIII 1985. године постаје самосталан научно – истраживачки институт са Извршним већем Скупштине СР Србије као оснивачем и мења назив у Астрономска опсерваторија – Институт за астрономска истраживања. Тада је финансира Републичка заједница наука СР Србије, а по њеном укидању, Републички фонд за науку Србије преко научног пројекта „Физика и кретање небеских тела и вештачких Земљиних сателита“ (1985 – 1990), чији су руководиоци били Ђ. Телеки (1985 – 1987), А. Кубичела (1987 – 1989) и М. Димитријевић (1990). Пројекат за период 1991 – 1995 носи назив „Физика и кретање небеских тела“ а њиме руководе М. Димитријевић (1991 – 1993) и З. Кнежевић (1993 – 1995). Службе за време и географску ширину су финансиране директно из средстава буџета СР Србије. 12. V 1992. Астрономска опсерваторија постаје научни институт, који се финансира преко поменутог научног пројекта код Републичког министарства за науку и технологију, а

оснивач установе је Влада Републике Србије. 20. XII 1994. Опсерваторија се региструје поново као научни институт и враћа стари назив. За период 1996 – 2000, научни пројекат има назив „Астрометријска, астродинамичка и астрофизичка истраживања“, а руководиоц је З. Кнежевић.

Када је маја 1948. године прихваћена оставка Војислава Мишковића на положај директора, за директора Опсерваторије бива именован академик Милутин Миланковић (Даљ, 28. V 1879 – Београд, 12. XII 1958), који је у историју науке ушао као човек који је објаснио појаву ледених доба, спорим променама у осунчавању Земље услед различитих утицаја због којих се мења нагиб Земљине осе и карактеристике њеног кретања око Сунца. Миланковић је растумачио и историју климе на Земљи и другим планетама и творац је математичке теорије климе и теорије о померању Земљиних полова. Управа Опсерваторије поверена је Савету Опсерваторије, на чијем челу је директор и председник савета М. Миланковић, а чланови су Антон Билимовић, В. Мишковић и Павле Савић (Поповић, 1951). Десетог јуна 1948. Миланковић у својству директора Опсерваторије, овлашћује секретара у лицу Милорада Протића (Астрономска опсерваторија Универзитета у Београду бр. 197, 10. VI 1948) „да може вршити наредбодавна права са извршењем предрачуна Астрономске опсерваторије, потписивати сва рачунска документа и сва званична административна акта“ (захваљујем се М. Ђокићу, који ми је на ово скренуо пажњу). Миланковић је хонорарни директор Опсерваторије до 27. јануара 1951. када постаје директор са пуним радним временом и на овом положају остаје до 26. јуна 1951.

Године 1949. завршен је геодетски павиљон започет још пре другог светског рата у који су постављени пасажни инструмент (отвор 10/100 cm), зенит телескоп (отвор 11/110 cm), мали астролаб са призмом и универзални инструмент (отвор (7/70 cm). Те године је павиљон у коме су до тада били пасажни инструменти назван „школски“, пошто је стављен на располагање студентима астрономије и геодезије.

Године 1951. П. Ђурковић организује службу двојних звезда. У служби, доцније Групи, откривено је до данас преко двеста нових двојних и вишеструких звезда, чему је највећи допринос дао Георгије Поповић, који је у групи од 1960. а на њеном челу од 1976. године. У раду групе су учествовали и Љубомир Дачић и Вера Ерцег (од 1967), а на овој проблематици раде и Данило Зулевић (од 1961), Драгомир Олевић (на Опсерваторију долази 1964. у групу за мале планете, комете и сателите, а једно време ради као сарадник групе за двојне звезде), Раде Павловић (од 1994) и Весна Живков (од 1996).

Исте године Василије Оскањан организује службу променљивих звезда. На овом послу му се придружују Александар Кубичела и Јелисавета Арсенијевић (која на Опсерваторији ради од 1956), чиме започиње буран развој астрофизичких истраживања, која се касније усмеравају на физику звезда, Сунца и астрономску спектроскопију. У почетку развија се фотометрија еруптивних звезда, а после 1959. после повратка В. Оскањана са специјализације из Совјетског савеза почиње се са радом у области по-

лариметрије еруптивних звезда. Формално, група за астрофизику је основана 1960. године. У групи је 1969. и 1970. године радио и Трајко Ангелов, а 1985 – 1996. Владимир Кршљанин. У групу долазе 1972. Иштван Винце, 1980. Гојко Ђурашевић, 1983. Слободан Јанков, 1984. Милан Димитријевић, 1989 – 1996. Олга Атанацковић-Вукмановић (која на Опсерваторију долази 1982. у групу за апсолутне деклинације), 1992. Лука Поповић, 1994. Дарко Јевремовић, 1995. Силвана Николић, 1996. заснива стални радни однос Сања Еркапић, која је до тада била на постдипломским студијама уз повремени рад на одређено време у групи, а 1997. у групу долази Милан Ћирковић. Треба поменути успешну експедицију групе на Хвар, ради посматрања тоталног помрачења Сунца 15. II 1961. Године 1966. групу напушта В. Оскањан, а 1972. – 1973. А. Кубичела, чијој се инвентивности има захвалити за постојање свих савремених астрофизичких мерних инструмената на Астрономској опсерваторији, конструише Сунчев спектрограф на подлози дотадашњег малог рефрактора – екваторијала и започиње истраживања фотосферских кретања великих размера на Сунцу. А. Кубичела, Ј. Арсенијевић и И. Винце организују 1980. године експедицију која прати потпуно помрачење Сунца у Индији, са три истраживачка програма. Од 1969. године Ј. Арсенијевић почиње да изучава поларизацију зрачења хладних суперџинова. Од 1973. започиње се и са проучавањем дугорочних промена поларизације код звезда са емисионим линијама (Ве звезде), у циљу изучавања физичких карактеристика атмосфера и омотача таквих објеката. Од 1984. године започиње се са радом на спектроскопији астрофизичке плазме са посебним нагласком на утицају ударних процеса на облике линија у спектрима Сунца и звезда. Године 1987. започет је програм праћења изабраних спектралних линија Сунца у току једног Сунчевог циклуса. Од 1985. Г. Ђурашевић започиње са радом на моделирању активних тесних двојних звезда. С. Јанков започиње и рад на методама реконструкције површинског сјаја на диску звезде на основу спектроскопских и фотометријских посматрања, а 1995. почиње се са радом на спектрима активних галаксија.

Од 26. VI 1951. до 27. III 1954. године директор Опсерваторије је поново В. Мишковић. После његовог одласка у пензију, на челу Опсерваторије је М. Протић у функцији заменика директора, а од 21. XI 1956. до 21. XI 1960. године у функцији директора.

Године 1953. Под руководством Захарија Бркића служба времена бива укључена у Међународну службу времена. Научна истраживања започета у овом периоду крунисана су докторским дисертацијама З. Бркића (26. IX 1958) и Љ. Митића (20. VI 1959), првим послератним докторатима из астрономије. Служба времена од 1962. године сарађује са Међународном службом за кретање пола, а од 1971. са Совјетском службом времена. Године 1963. на основу споразума са Војно-географским институтом Астрономска опсерваторија добија батерију кварцних часовника са пратећим приборима, чиме се делатност службе времена подиже на виши ниво, тако да се Опсерваторија сврстава међу првих десет у овој служби у Европи. На

основу споразума са Савезним заводом за мере и драгоцене метале од 1991. године, а после припремних грађевинских радова, у изолованој комори, 10 m под земљом, у трећем подруму централне зграде Опсерваторије, били су до 1997. године смештени цезијумски атомски и кварцни часовник Завода, помоћу којих се у једном периоду на Опсерваторији остваривао југословенски еталон времена.

Године 1956. Ружица Митриновић оснива Службу идентификације малих планета и рад на одређивању орбита малих планета. Од 1957. до 1959. Астрономска опсерваторија успешно учествује у радовима у оквиру Међународне геофизичке године на посматрањима Сунца и истраживањима у области Земљине ротације и географских координата.

Од краја 1957. године до краја 1959., изграђени су павиљони у које су постављена, после 34 године, три велика фундаментална астрометријска инструмента, што је учинило Опсерваторију једном од најопремљенијих у свету за истраживања у области фундаменталне астрометрије. Поред овога, изграђени су још неколико помоћних објеката, стамбена зграда и пут, а круг Опсерваторије је проширен на садашњих око 10 ha. Укупна улагања чине око трећине вредности грађевинских радова из 1929/30. год. То доводи до оснивања три нове научне групе: Групе за релативне координате (Велики меридијански круг, Љ. Дачић), Групе за апсолутне ректасцензије (Велики пасажни инструмент, Љ. Митић) и Групе за апсолутне деклинације (Велики вертикални круг, Ђ. Телеки). Од тог времена, научни рад у области астрометрије, достигао је, под руководством Љ. Митића, Ђ. Телекија, Б. Шеварлића и С. Саџаков, светски ниво. На Меридијанском кругу, за последњих тридесет година је урађено седам посматрачких каталога положаја звезда, под руководством Софије Саџаков, а сви су били део међународних посматрачких програма. За оваква достигнућа године 1990. С. Саџаков и М. Дачић постају добитници Октобарске награде града Београда. Софија Саџаков која је на Опсерваторију дошла 1962. године, од 1972. је шеф групе за релативне координате. У ову групу 1962. године долази и Иван Паквор који касније прелази у групу за апсолутне координате. Године 1970. долази Миодраг Дачић, а 1984. Зорица Станчић, удата Цветковић. Године 1989. под руководством С. Саџаков и Астрономске опсерваторије започињу координирана мултидисциплинарна истраживања промена средњих географских координата Београда на Астрономској опсерваторији и у више института из области геомагнетизма, геофизике и сеизмологије.

Групом за апсолутне деклинације небеских тела руководио је Ђ. Телеки од њеног оснивања 1960. до своје смрти 1987. године, са изузетком 1984. године, када је на овој дужности била С. Саџаков. У групи су сарађивали и М. Мијатов, Б. Кубичела, Ђура Божичковић, Веселка Трајковска и О. Атанацковић-Вукмановић.

Године 1970. по замисли Љ. Митића и залагањем И. Паквора, Велики пасажни инструмент је добио систем вакуумских мира, јединствен у свету, који је знатно повисио тачност апсолутних мерења на овом инструменту, на

коме је урађен први апсолутни каталог ректасцензија Београдске опсерваторије, који је садржао 308 звезда. Каталог апсолутних деклинација ових 308 звезда урађен је на Вертикалном кругу.

После М. Протића на челу установе је Василије Оскањан, прво од 1960. као вршилац дужности, а од 1964. до 1965. као директор. После њега од 9. VII 1965. до 1970. директор је Перо Ђурковић, када на овај положај, у периоду од 1971. до 1975. опет долази М. Протић. Од 1975. прво као вршилац дужности, а од 13. VII 1977. до септембра 1981. на челу установе је Милан Мијатов (Београд, 3. VII 1933 – Београд, 19. XI 1996). На положају директора је од 1982. до 1989. Миодраг Митровић, од 1990. до 1993. Иштван Винце, а од 21. XI 1994. Милан Димитријевић.

Године 1986. Од стране Скупштине СР Србије и РИВа усвојен је пројекат и одобрена су средства за изградњу астрофизичке посматрачке станице на Ргајској планини код Прокупља. Због обустављања инвестиција у Републици пројекат до данас није реализован.

Године 1987. У присуству више државника и угледних гостију из земље и иностранства, у сали Скупштине Србије свечано је обележена стогодишњица оснивања Опсерваторије. Поводом овог јубилеја у Београду су одржане три међународне и једна југословенска научна конференција, и то Колоквијум 100 Међународне астрономске уније „Фундаментална астрометрија“ (8 - 11. IX – Председник научног комитета H. Eichorn iz Gainsville-a USA), Међународни скуп о астрономској рефракцији посвећен успомени на Ђ. Телекија, председника радне групе за астрономску рефракцију Међународне астрономске уније (3 - 4. IX – Председник научног комитета В. Миловановић), Други међународни скуп о катастрофалним сударима малих тела Сунчевог система (8 - 11. IX – Председник научног комитета, V. Zappala, Италија) и Други семинар „Астрофизика у Југославији“ (8 - 10. IX – Председник научног комитета М. Димитријевић). Поводом прославе стогодишњице, у старој згради Опсерваторије у Карађорђевом парку, отворен је мали музеј у коме је једна соба посвећена развоју Астрономске опсерваторије.

Године 1994. долази до реорганизације унутрашње структуре Опсерваторије, тако да се формирају одсек за астрофизику, одсек за динамичку астрономију и одсек за астрометрију.

Године 1995. Опсерваторија учествује у организацији Међународне Руско – Југословенске конференције „Њукомб и фундаментална астрометрија“ у Ст. Петерсбургу, I Мађарско – Југословенске конференције у Бају, I Румунско – Југословенског округлог стола о сарадњи у астрономији у Темишвару и организује I Југословенску конференцију о облицима спектралних линија у Кривају.

Прошле године (1996.) Опсерваторија организује II Румунско – Југословенски округли сто о сарадњи у астрономији у Београду и астрофизичку секцију на XVIII Међународном симпозијуму о физици јонизованих гасова у Котору. Опсерваторија учествује у организовању I Белоруско – Југословенске конференције о физици и дијагностици лабораторијске и

астрофизичке плазме у Минску. Сарадници излажу своје резултате на 13 међународних конференција и 6 националних. Сарадници Опсерваторије објављују 129 библиографских јединица, од којих су 16 у најреномиранијим међународним часописима. Издају се четири публикације монографског типа и два броја часописа Bull. Astron. Belgrade. На Астрономској опсерваторији данас ради 40 запослених од којих су 26 астрономи.

У току протеклих 110 година Астрономска опсерваторија је постала установа од великог значаја за историју науке и културе српског народа, и то не само на подручју астрономије већ и метеорологије, сеизмологије и геомагнетских истраживања. За ову установу се везује низ славних личности из историје наше науке, који су допринели да Опсерваторија и научна достигнућа српских астронома стекну углед у међународној научној јавности, а млади перспективу да се у нашој земљи могу бавити овом лепом и изазовном науком и имати научно окружење које им омогућава да постижу резултате који се могу публиковати и у најпознатијим светским научним часописима..

Референце

***: 1989, Сто година Астрономске опсерваторије у Београду, *Publ. Obs. Astron. Belgrade*, **36**.

Андрић Слободанка: 1997, Једанаест деценија Астрономске и метеоролошке опсерваторије. „Падежи“ за временску прогнозу, Политика, 19. XII 1997, 19.

Димитријевић Милан С.: 1996, Београдска Астрономска опсерваторија у 1995, Belgrade Astronomical observatory in 1995, *Publ. Obs. Astron. Belgrade*, **52**.

Димитријевић Милан С.: 1997, Београдска Астрономска опсерваторија у 1996, Belgrade Astronomical observatory in 1996, *Publ. Obs. Astron. Belgrade*, **55**.

Ђокић Милорад: 1989, Архивска грађа о Опсерваторији Велике школе и Универзитета у Београду у времену од 1887. до 1924. године, у: Сто година Астрономске опсерваторије у Београду, *Publ. Obs. Astron. Belgrade*, **36**, 177.

Ђурковић Перо: 1968, Седамдесет пет година рада Астрономске опсерваторије у Београду, *Publ. Obs. Astron. Belgrade*, **12**, 15.

Djurković P.: 1969, Rapport sur l'activité de l'Observatoire Astronomique de Belgrade de 1966 á 1969, *Bull. Obs. Astron. Belgrade*, **XXII**, No 2, 143.

Djurković P.: 1970, Rapport sur l'activité de l'Observatoire Astronomique de Belgrade en 1970, *Bull. Obs. Astron. Belgrade*, **124**, 195.

Иванишевић Г., Ђокић Н.: 1989, Библиографија издања Астрономске опсерваторије у Београду, у: Сто година Астрономске опсерваторије у Београду, *Publ. Obs. Astron. Belgrade*, **36**, 107.

Јанковић Ђ. Ненад: 1986, Преглед историје астрономије у Југословенским земљама, у: Историја астрономске науке од Њутновог доба до наших дана (Б. М. Шеварлић), Универзитет у Београду, Београд, 143.

Јанковић Ђ. Ненад: 1989, Милан Недељковић, професор Велике школе и оснивач њене Опсерваторије, у: Сто година Астрономске опсерваторије у Београду, *Publ. Obs. Astron. Belgrade*, **36**, 107.

Јеличић Милан: 1987, Провизорна Астрономска и метеоролошка опсерваторија у Београду, *Васиона*, **XXXV**, No 3-4, 78.

Јеличић Милан: 1991, Мала планета 3900 Кнежевић, *Васиона*, **XXXIX**, No 5, 69.

Јеличић Милан: 1997, Затворена и кафана „Мала астрономија“, Политика, 18. II 1997, 12.

Michkovitch V.V.: 1930, Rapport annuel sur l'état et les travaux de l'Observatoire Astronomique de Belgrade pour l'année 1929, Annuaire pour l'an 1930, 125.

Michkovitch V.V.: 1931, Rapport annuel sur l'état et les travaux de l'Observatoire Astronomique de Belgrade pour l'année 1930, Annuaire pour l'an 1931, 133.
Michkovitch V.V.: 1932, Rapport annuel pour l'année 1931 sur l'état et les travaux de l'Observatoire Astronomique de l'Université de Belgrade, Mémoires I, 38.
Michkovitch V.V.: 1941, Services et travaux d'observations en 1939 á l'Observatoire Astronomique de l'Université de Belgrade, *Bull. Obs. Astron. Belgrade*, **V**, No 1-2, 1.
Michkovitch V.V.: 1950, Services et travaux d'observations en 1940 á l'Observatoire Astronomique de l'Université de Belgrade, *Bull. Obs. Astron. Belgrade*, **VI**, No 1-2, 1.
Michkovitch V.V.: 1952, Rapport annuel présenté à l'Academie des sciences Serbe, sur l'état et l'activité de l'Observatoire en 1951, *Bull. Obs. Astron. Belgrade*, **XVI**, No 1-4, 1.
Мушицки Ђорђе, Басарић Ђорђе: 1987, Физика, Четрдесет година Природно - Математичког факултета у Београду, Београд, 196.
Недељковић Милан: 1904, Извештај Опсерваторије Велике школе и њених метеоролошких стација, 1899-1903, Државна штампарија, Београд.
Недељковић Милан: 1905, Извештај Опсерваторије и Метеоролошких стација, 1904, Државна штампарија, Београд.
Недељковић Милан: 1907, Извештај Опсерваторије и Метеоролошких стација, 1905-1906, Штампарија Давидовић, Београд.
Недељковић Милан: 1908, Извештај Опсерваторије и Метеоролошких стација, 1907, Државна штампарија, Београд.
Недељковић Милан: 1909, Извештај Опсерваторије и Метеоролошких стација, 1908-1909, Државна штампарија, Београд.
Недељковић Милан: 1910, Извештај Опсерваторије и Метеоролошких стација, 1910, Државна штампарија, Београд.
Недељковић Милан: 1914, Извештај Опсерваторије и Метеоролошких стација, 1911-1912, Меркур, Београд.
Недељковић Милан: 1923, Извештај Опсерваторије, за 1919-1920, 1922 и 1923, Београдска опсерваторија, Београд.
Недељковић Милан: 1925, Извештај Опсерваторије, за 1924, Београдска опсерваторија, Београд.
Popović B.: 1950, Services et travaux d'observations en 1949 á l'Observatoire astronomique de l'Université de Belgrade, *Bull. Obs. Astron. Belgrade*, **XIV - 1949**, VII.
Popović B.: 1951, Rapport annuel sur l'état et l'activité de l'Observatoire astronomique de Belgrade en 1950, *Bull. Obs. Astron. Belgrade* **XV – 1950**, VII.
Поповић, С.: 1994, Астрономска опсерваторија за докторат, Београдске новине, 12. VIII 1994, 11.
Протић, М.: 1975, Извештај о раду Астрономске опсерваторије у Београду током 1973. године, *Publ. Obs. Astron. Belgrade*, **20**, 231.
Протић-Бенишек Војислава: 1987, Један век Астрономске опсерваторије у Београду, *Васиона*, **XXXV**, No 3-4, 64.
Protitch M.: 1950, Services et travaux d'observations en 1941 á l'Observatoire astronomique de l'Université de Belgrade, *Bull. Obs. Astron. Belgrade*, **VII – 1942**, 1.
Protitch M.: 1956, Rapport annuel sur l'état et les travaux de l'Observatoire en 1955, *Bull. Obs. Astron. Belgrade*, **XX**, No 3-4, 16.
Protitch M.: 1960, Rapport annuel sur l'état et les travaux de l'Observatoire en 1959, *Bull. Obs. Astron. Belgrade*, **XXIV**, No 3-4, 42.
Симовљевић Јован: 1987, Астрономија, Четрдесет година Природно - Математичког факултета у Београду, Београд, 166.
Станојевић М. Ђорђе: 1905, Београдска опсерваторија и њен извештај за 1899 – 1903. год., стр. 32, Београд.

110 YEARS OF THE BELGRADE ASTRONOMICAL OBSERVATORY

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Abstract. A short history of Belgrade Astronomical Observatory with the bibliography of the most important articles on its history, is presented.

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АСТРОНОМИЈА У СРБИЈИ

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1. Милан Недељковић и оснивање Астрономске опсерваторије и катедре за астрономију

Ма да је Законом о измени и допуни Закона о Великој школи, донетим 1880. године предвиђено је да се астрономија изучава заједно са метеорологијом, па се та година сматра годином оснивања Катедре за астрономију у Београду, прва предавања из астрономије почињу 1884. године, када се Милан Недељковић (Београд, 27. IX. 1857 - Београд, 21. XII. 1950) вратио са школовања у Француској и био изабран за суплента за овај предмет. Он је за професора изабран 1886., и на челу Катедре за астрономију и метеорологију остаје до пензионисања 1924. године.

Недељковић почиње и борбу за оснивање Астрономске и метеоролошке опсерваторије, подухват који је, уочивши за њега повољне околности, крунисао успехом. Акт о оснивању, потписао је министар просвете и црквених дела Краљевине Србије Милан Кујунџић 26. марта (7. априла) 1887. године, а Милан Недељковић је одређен за првог управника Астрономске и метеоролошке опсерваторије. Овај датум, узима се као датум оснивања Астрономске опсерваторије у Београду, једне од најстаријих научних установа у Србији и јединог самосталног астрономског института у Југославији, а историја њеног развоја је важан део историје науке и културе на овим просторима.

Првог маја 1887. године, Недељковић почиње са радом у Провизорној опсерваторији у закупљеној кући породице Гајзлер. Овде је Опсерваторија радила до првог маја 1891. године, када се преселила у за то време довршену сопствену зграду, данашњу Метеоролошку опсерваторију у Карађорђевом парку, у чијем се мањем музејском простору, од прославе стогодишњице оснивања 1987. године, налази једна соба посвећена почецима астрономске науке у Југославији.

Недељковић је на челу Опсерваторије од 26 марта (7 априла) 1887. године до 30 јануара 1924. године. Изузетак представља само период од 5 јула 1899. до 31. октобра 1900. године, када је био у пензији због политичких разлога, т.ј. због Ивандањског атентата на краља Милана, који је краљ Александар искористио за обрачун са својим политичким противницима. У то време на његовом месту био је Ђорђе Станојевић (Неготин, 7.IV.1858 - Париз, 24.XII.1921), први српски астрофизичар, други руководилац Астрономске и метеоролошке опсерваторије, ректор Универзитета у Београду, велики популаризатор астрономије и науке уопште, човек који је увео електрично осветљење у Београду, Ужицу, Лесковцу, Чачку, дарујући тако тим градовима светлост, градитељ прве српске хидроцентрале, пионир индустрије рашладних уређаја, иницијатор организовања комитета за хладноћу и међународне организације за технику хлађења у Паризу 1903. године. Он је и пионир фотографије у боји у Србији.

Осим свог значаја за метеорологију, Астрономска и метеоролошка опсерваторија Милана Недељковића, колевка је и сеизмолошких и геомагнетских истраживања код Срба. Крајем 1903. године, Недељковић позајмљује инструменте за геомагнетска мерења од Теге Миклош Конколја, оснивача Астрономске опсерваторије у Будимпешти и гради земномагнетски павиљон. Захваљујући Конколју, Недељковић 1903. године добија и сеизмограф, који следеће године поставља у посебан павиљон. Посматрања се обављају редовно и за ове потребе подиже се на Ташмајдану зграда данашњег Сеизмолошког завода 1906. године. Ову активност преузима Недељковићев помоћник Јеленко Михајловић (Врбица, 11. I. 1869 - Београд, 10. X. 1956), који од 1896. године ради на Опсерваторији.

За време друге аустроугарске окупације у Првом светском рату, Опсерваторију води Виктор Конрад из Беча. Приликом бегства из Србије, Аустријанци су однели или уништили све инструменте. Захваљујући свом огромном залагању и стручности, Милан Недељковић успева да после рата набави у Немачкој на име ратних репарација, телескопе и пратећу опрему за нову опсерваторију.

Инструменти које је набавио Недељковић и данас су практично једина посматрачка база Опсерваторије, иако су неке Немци однели у II светском рату, два су однета у љубљану, два у Загреб (види Ђурковић, 1968), а неки мањи нису монтирани ни до данас.

Данас су монтирани у павиљонима следећи инструменти које је набавио Недељковић:

1. Велики рефрактор - екваторијал "Zeiss" 650/10550 mm.
2. Сунчани спектрограф (монохроматор) типа Littrow, 9000mm/100,000, изграђен адаптацијом екваторијала "Zeiss" 200/3020 mm са две астрокамере "Tessar" и "Petzval" 160/800 mm.

3. Велики меридијански круг "Askania" 190/2578 mm.
4. Велики пасажни инструмент "Askania" 190/2578 mm са системом вакуумских мира.
5. Велики вертикални круг "Askania" 190/2578 mm.
6. Астрограф "Zeiss" 160/800 mm.
7. Фотовизуелни рефрактор "Askania" 135/1000 и 125/1000 mm.
8. Зенит телескоп "Askania" 110/1287 mm.
9. Пасажни инструмент "Bamberg" 100/1000 mm.

Док је Недељковић водио борбу за нову Опсерваторију на којој би били постављени набављени инструменти и почела астрономска посматрања, изненада је пензионисан 30 јануара 1924. године. Одлуком Факултетског савета, те године се Опсерваторија дели у две посебне установе: Метеоролошку и Астрономску опсерваторију Универзитета у Београду. Истовремено и Катедра за астрономију се одваја од метеорологије, као посебна катедра на Филозофском факултету, где је астрономија од оснивања Универзитета 1905. године.

2. Изградња нове Астрономске опсерваторије и њен развој

Године 1925. на чело Астрономске опсерваторије бива постављен Војислав В. Мишковић (Фужине, 18. I. 1892 - Београд, 25. XI. 1976), који је у то време афирмисани астроном запослен на Опсерваторији у Ници. Он је студије астрономије започео у Будимпешти и Гетингену пред први светски рат, а после демобилисања крајем 1918. године послат је у Француску да заврши студије. Дипломирао је 1919. године и постављен за асистента Астрономске опсерваторије у Марсељу. У Ници ради као астроном од 1922. године а 1924. докторира на Универзитету у Монпељеу. Године 1925. добио је награду Француске академије наука за студије из звездане статистике. У француским научним часописима, у периоду од 1919 до 1925 године објављује двадесетак радова, посвећених посматрањима малих планета и комета, као и одређивањима њихових путања. У Београд долази 1926. године и осим Астрономске опсерваторије, преузима и Катедру астрономије. Године 1927. установљена је посебна студијска група за астрономију. Она је добила назив III група наука и садржала је Практичну и теоријску астрономију, Небеску механику, Теоријску математику, Рационалну механику, Физику и Метеорологију. Мишковић је изабран за ванредног професора теоријске и практичне астрономије на Филозофском факултету. Године 1929. изабран је и за дописног члана Српске краљевске академије а 1939. године за редовног. Он у знатној мери делатност установе усмерава ка математичко-нумеричким пословима, који дају више вредних резултата. Значајни су нумерички радови везани за Математичку климатологију М.Миланковића и Мишковићеве Прецесионе таблице.

Године 1929., Мишковић успева да добије средства за изградњу нове, модерне опсерваторије, 6 км југоисточно од Теразија, на површини од 4.5 ха, на коти 253 м, на брду Велики Врачар, које од тада, као и читав део града, носи назив Звездара.

Изузетан и веома вредан архитектонски комплекс Астрономске опсерваторије, пројектовао је Јан Дубови, члан Групе архитеката модерног правца (ГАМП) основане 1928. године. Захваљујући управо овом остварењу, Јан Дубови је у Прагу проглашен за доктора наука. Грађевински радови извођени су од 1930. до 1932. године, а током наредне две године монтирани су инструменти.

Мишковић започиње и са издавањем научног часописа *Mémoires de l'Obs. Astr. Belgrade* (штампано пет свезака за 1932., 1933., 1936., 1938. и 1949. годину), *Annuaire de l'Obs. Astr. Belgrade* (издато шест свезака за 1929. - 1934. године), који је садржао звездано време и краткопериодичне чланове нутације, средње и привидне положаје 189 звезда, ново-откривене астероиде и објашњења за употребу. *Наутичког годишњака,* (за године од 1934. до 1941.) за потребе навигације у морнарици, те *Годишњака нашег неба,* астрономског календара на српском језику, који је излазио од 1930. до 1941. и од 1948. до 1952. године (број за 1948. годину уредио је Ф. Доминко а за 1949., 1950. и 1951. годину Божидар Поповић).

Године 1936. Мишковић уз помоћ Милорада Протића организује службу малих планета и посматрања Сунца. Исте године П. Ђурковић открива на опсерваторији у Иклу (Uccle - Белгија), малу планету (планетоид, данас се обично употребљава назив астероид) која касније добија име 1605 Миланковић а М. Протић у Београду, малу планету 1564 Србија, чиме започиње рад на проналажењу нових малих планета. Укупно су сарадници Опсерваторије открили 43 малих планета од којих су 12 добиле име а три открића су накнадно приписана другим ауторима. Сам Протић је у периоду од 1936. до 1956. открио 33 мале планете. Осим мале планете 1564 Србија, он је добио право да да име малим планетама 1517 Београд, 1550 Тито, 1554 Југославија, 1605 Миланковић, 1675 Симонида, 1724 Владимир (по унуку М. Протића Владимиру Бенишеку), 2244 Тесла и 2348 Мишковић. Ђурковић је открио пет малих планета у периоду од 1936. до 1941. године а име је дао малој планети 1700 Звездара. Године 1980, Зоран Кнежевић (који на Астрономској опсерваторији ради од 1974. године) открива на фотоплочама које су по његовом упутству снимљене на опсерваторији Писзкестетѳ у Мађарској, четири мале планете од којих једна добија име 3276 Паолицчи, по његовом сараднику из Италије. Године 1991. у знак почасти, једној малој планети је додељено име 3900 Кнежевић, према овом астроному. За српски народ је везана и мала планета 1555 Дејан названа по сину П. Ђурковића. На овим пословима од 1972. године на Опсерваторији почиње да ради Војислава Протић - Бенишек.

Године 1936., Мишковић покреће *Bulletin de l'Observatoire astronomique de Belgrade*, научни часопис који од броја 145 за 1992. годину излази под именом *Bulletin astronomique de Belgrade*, а од 157 за 1998. годину под именом *Serbian Astronomical Journal*. Уредници овог часописа били су В. В. Мишковић (за године 1936 - 1940, 1943 - 1948 и 1952 -1956), М. Б. Протић (за године 1941 - 1942, 1955 - 1960, као и 1971-1975), Б. Поповић (за годину 1950.), В. Оскањан (1964), П. М. Ђурковић (за године 1964 - 1970), М. Мијатов (Nos. 127 - 131, 1976 -1981), Д. Зулевић (Nos. 132 - 133, 1982 - 1983), Ђ. Телеки (134 -136, 1984 - 1986) и М. С. Димитријевић (137 -, 1987 -).

Од јула 1941. године на Опсерваторији се налази немачка војска. Приликом борби за ослобођење Београда, нарочито су тешко оштећени централна зграда, зграда резервоара за воду и павиљон Великог рефрактора. После рата започиње обнова Опсерваторије. Мишковић остаје на дужности директора до марта 1946. када подноси оставку, која је прихваћена тек маја 1948. године.

Године 1945. Перо М. Ђурковић покреће и уређује стручни часопис *Астрономска и метеоролошка саопштења*, који Астрономска опсерваторија издаје од 1945. до 1950. године (7 бројева). Опсерваторија покреће 1947. године серију издања *Публикације Астрономске опсерваторије у Београду*. На месту главног и одговорног уредника били су В. Оскањан (No. 10), П. М. Ђурковић (Nos. 12-16), М.Б. Протић (Nos. 17-19, 21-22), Ђ. Телеки (Nos. 20, 26, 32, 34, 35), М. Мијатов (Nos. 24, 25, 27-31), Г.М. Поповић (No. 33), М.С. Димитријевић (Nos. 36-61 и даље).

Када је маја 1948. године прихваћена оставка Војислава Мишковића на положај директора, за директора Опсерваторије бива именован академик Милутин Миланковић (Даљ, 28. V. 1879 - Београд, 12. XII. 1958), који је у историју науке ушао као човек који је објаснио појаву ледених доба, спорим променама у осунчавању Земље услед услед различитих утицаја услед којих се мења нагиб Земљине осе и карактеристике њеног кретања око Сунца. Миланковић је растумачио и историју климе на Земљи и другим планетама и творац је математичке теорије климе и теорије о померању Земљиних полова. Миланковић је у Београд дошао из Беча, на позив Београдског Универзитета, на коме је 1909. године био изабран за професора Небеске механике. Овај предмет је држао све до пензионисања 1955. године.

Управа Опсерваторије поверена је Савету Опсерваторије, на чијем челу је директор и председник савета М. Миланковић, а чланови су Антон Билимовић, В. Мишковић и Павле Савић (Поповић, 1951). Миланковић на овом положају остаје до 26. јуна 1951.

Године 1951. П.Ђурковић организује службу двојних звезда. У служби, доцније Групи, откривено је до данас преко двеста нових двојних и

вишеструких звезда, чему је највећи допринос дао Георгије Поповић, који је у групи од 1960. У раду групе су учествовали и љубомир Дачић и Вера Ерцег (од 1967), Данило Зулевић (од 1961), Драгомир Олевић (на Опсерваторију долази 1964. у групу за мале планете, комете и сателите а једно време ради као сарадник групе за двојне звезде), Слободан Нинковић (од 1986.), Раде Павловић (од 1994) и Весна Живков (од 1996).

Исте године Василије Оскањан организује службу променљивих звезда. На овом послу му се придружују Александар Кубичела и Јелисавета Арсенијевић, (која на Опсерваторији ради од 1956) чиме започиње буран развој астрофицичких истраживања, која се касније усмеравају на физику звезда, Сунца и астрономску спектроскопију. У почетку развија се фотометрија еруптивних звезда, а после 1959. после повратка В. Оскањана са специјализације из Совјетског савеза почиње се са радом у области полариметрије еруптивних звезда. Формално, група за астрофизику је основана 1960. године. У групи је 1969. и 1970. године радио и Трајко Ангелов а 1985. - 1996. Владимир Кршљанин. У групу долазе 1972. Иштван Винце, 1980. Гојко Ђурашевић, 1983. Слободан Јанков, 1984. Милан Димитријевић, 1989 - 1996 Олга Атанацковић - Вукмановић (која на Опсерваторију долази 1982. у групу за апсолутне деклинације), 1992. Лука Поповић, 1993. љиљана Скуљан, 1994. Дарко Јевремовић, 1995. Силвана Николић, 1996. заснива стални радни однос Сања Еркапић, која је до тада била на постдипломским студијама уз повремени рад на одређено време у групи, 1997. Милан Ћирковић а 1998. Наташа Трајковић, Драгана Танкосић, Еди Бон и Десанка Шулић. Треба поменути успешну експедицију групе на Хвар, ради посматрања потпуног помрачења Сунца 15.II. 1961. Године 1966. групу напушта В. Оскањан а 1972-1973. А. Кубичела, чијој се инвентивности има захвалити за постојање свих савремених астрофизичких мерних инструмената на Астрономској опсерваторији, конструише Сунчев спектрограф на подлози дотадашњег малог рефрактора - екваторијала и започиње истраживања фотосферских кретања великих размера на Сунцу. А. Кубичела, Ј. Арсенијевић и И. Винце организују 1980. године експедицију која прати потпуно помрачење Сунца у Индији, са три истраживачка програма. Од 1969. године Ј. Арсенијевић почиње да изучава поларизацију зрачења хладних суперцинова. Од 1973. започиње се и са проучавањем дугорочних промена поларизације код звезда са емисионим линијама (Бе звезде), у циљу изучавања физичких карактеристика атмосфера и омотача таквих објеката. Од 1984. године започиње се са радом на спектроскопији астрофизичке плазме са посебним нагласком на утицају ударних процеса на облике линија у спектрима Сунца и звезда. Године 1987. започет је програм праћења изабраних спектралних линија Сунца уу току једног Сунчевог циклуса. Од 1985. Г. Ђурашевић започиње са радом на моделирању активних тесних двојних звезда. С. Јанков започиње и рад на методама реконструкције површинског сјаја на диску звезде на основу спектроскопских и фотометријских посматрања.

Од 26.VI. 1951. до 27.III. 1954. године директор Опсерваторије је поново В. Мишковић. После његовог одласка у пензију, на челу Опсерваторије је М. Протић у функцији заменика директора а од 21.XI.1956. до 21.XI.1960. године у функцији директора.

Године 1953. Под руководством Захарија Бркића служба времена бива укључена у Међународну службу времена. Научна истраживања започета у овом периоду крунисана су докторским дисертацијама З. Бркића (26.IX.1958) и Љ. Митића (20.VI.1959), првим послератним докторатима из астрономије. Служба времена од 1962. године сарађује са Међународном службом за кретање пола а од 1971. са Совјетском службом времена. После одласка у пензију Милутина Јовановића 1997. године, руководилац Службе за време и одређивање географских координата постаје Горан Дамљановић, који на Астрономској опсерваторији ради од 1992. године. У овој служби данас раде Бора Јовановић (на Опсерваторији од 1982.) и Ђуро Божичковић (на Опсерваторији од 1977.).

Од краја 1957. године до краја 1959., изграђени су павиљони у које су постављена, после 34 године, три велика фундаментална астрометријска инструмента, што је учинило Опсерваторију једном од најопремљенијих у свету за истраживања у области фунадаменталне астрометрије. Поред овога, изграђени су још неколико помоћних објеката, стамбена зграда и пут, а круг Опсерваторије је проширен на садашњих око 10 ха. Укупна улагања чине око трећине вредности грађевинских радова из 1929/30. год. То доводи до оснивања три нове научне групе: Групе за релативне координате (Велики меридијански круг, љ. Дачић), Групе за апсолутне ректасцензије (Велики пасажни инструмент, Љ. Митић) и Групе за апсолутне деклинације (Велики вертикални круг, Ђ. Телеки). Од тог времена, научни рад у области астрометрије, достигао је, под руководством Љ. Митића, Ђ. Телекија, Б. Шеварлића и С. Саџаков, светски ниво. На Меридијанском кругу, за последњих тридесет година је урађено седам посматрачких каталога положаја звезда, под руководством Софије Саџаков, а сви су били део међународних посматрачких програма. За оваква достигнућа године 1990. С. Саџаков и М.Дачић постају добитници Октобарске награде града Београда. Софија Саџаков која је на Опсерваторију дошла 1962. године, од 1972. је шеф групе за релативне координате. У ову групу 1962. године долази и Иван Паквор који касније прелази у групу за апсолутне координате. Године 1970. долази Миодраг Дачић а 1984. Зорица Станчић, удата Цветковић. Године 1989. под руководством С. Саџаков и Астрономске опсерваторије започињу координирана мултидисциплинарна истраживања промена средњих географских координата Београда на Астрономској опсерваторији и у више института из области геомагнетизма, геофизике и сеизмологије.

Групом за апсолутне деклинације небеских тела руководио је Ђ. Телеки од њеног оснивања 1960. до своје смрти 1987 године, са изузетком 1984.

године, када је на овој дужности била С. Сацаков. У групи су сарађивали и М. Мијатов, Б. Кубичела, Ђура Божичковић, Веселка Трајковска (на Опсерваторији од 1977.) и О. Атанацковић - Вукмановић.

Године 1970. по замисли Љ. Митића и залагањем И. Паквора, Велики пасажни инструмент је добио систем вакуумских мира, јединствен у свету, који је знатно повисио тачност апсолутних мерења на овом инструменту, на коме је урађен први апсолутни каталог ректасцензија Београдске опсерваторије, који је садржао 308 звезда. Каталог апсолутних деклинација ових 308 звезда урађен је на Вертикалном кругу.

После М. Протића на челу установе је Василије Оскањан, прво од 1960. као вршилац дужности а од 1964. до 1965. као директор. После њега од 9.VII.1965. до 1970. директор је Перо Ђурковић, када на овај положај, у периоду од 1971. до 1975. опет долази М. Протић. Од 1975. прво као вршилац дужности а од 13.VII.1977. до септембра 1981. на челу установе је Милан Мијатов (Београд, 3.VII.1933 - Београд, 19.XI.1996). На положају директора је од 1982. до 1989. Миодраг Митровић, од 1990. до 1993. Иштван Винце, а од 21. XI. 1994. Милан Димитријевић.

Године 1987. прослављена је стогодишњица оснивања Опсерваторије. Поводом овог јубилеја у Београду су одржане три међународне и једна југословенска научна конференција, и то Колоквијум 100 Међународне астрономске уније "Фундаментална астрометрија" (8-11.IX - Председник научног комитета Х. Еичорн из Гаинсвилле-а УСА), Међународни скуп о астрономској рефракцији посвећен успомени на Ђ. Телекија, председника радне групе за астрономску рефракцију Међународне астрономске уније (3-4.IX - Председник научног комитета В. Миловановић), Други међународни скуп о катастрофалним сударима малих тела Сунчевог система (8-11.IX - Председник научног комитета, В. Заппала, Италија) и Други семинар "Астрофизика у Југославији" (8-10.IX - Председник научног комитета М. Димитријевић). Поводом прославе стогодишњице, у старој згради Опсерваторије у Карађорђевом парку, отворен је мали музеј у коме је једна соба посвећена развоју Астрономске опсерваторије.

Године 1994. долази до реорганизације унутрашње структуре Опсерваторије, тако да се формирају одсек за астрофизику, одсек за динамичку астрономију и одсек за астрометрију. У одсеку за астрометрију данас раде и Предраг Јовановић (на Опсерваторији од 1996.) и Наташа Поповић (на Опсерваторији од 1997.)

Године 1995. Опсерваторија учествује у организацији Међународне Руско - Југословенске конференције "Њукомб и фундаментална астрометрија" у Ст. Петерсбургу, I Мађарско - Југословенске конференције у Бају, I Румунско - Југословенског округлог стола о сарадњи у астрономији у

Темишвару и организује I Југословенску конференцију о облицима спектралних линија у Кривају.

Године 1996. Опсерваторија организује II Југословенско - Румунски округли сто о сарадњи у астрономији у Београду и астрофизичку секцију на XVIII Међународном симпозијуму о физици јонизованих гасова у Котору. Опсерваторија учествује у организовању I Белоруско - Југословенске конференције о физици и дијагностици лабораторијске и астрофизичке плазме у Минску. Сарадници излажу своје резултате на 13 међународних конференција и 6 националних, објављују 129 библиографских јединица, од којих су 16 у најреномиранијим међународним часописима, држе шест уводних предавања на међународним конференцијама и четири на националним. Објављена су два посматрачка каталога, један у *Astronomy and Astrophysics Supplement Series* и други у *Bulletin Astronomique de Belgrade*. Такође је одбрањена и једна магистарска теза. Сарадници Астрономске опсерваторије били су присутни на 13 међународних конференција у иностранству (16 путовања, 8 људи) и 6 конференција у Југославији (49 путовања, 22 човека). Астрономска опсерваторија је у 1996. години штампала четири публикације монографског типа и два броја часописа *Bull. Astron. Belgrade*.

Године 1997. Опсерваторија у оквиру прославе 110 годишњице организује научну конференцију "Развој астрономије код Срба". Опсерваторија учествује у организовању III Румунско - Југословенског округлог стола о сарадњи у астрономији у Клужу, као и II Југословенске конференције о облицима спектралних линија у Белој Цркви. Сарадници излажу своје резултате на 13 међународних конференција (30 путовања, 10 људи) и четири националне (21 путовање, 16 људи) и објављују 152 библиографске јединице, од којих су 11 у најреномиранијим међународним часописима. Поред тога одржано је осам уводних предавања на националним конференцијама а објављен је и један посматрачки каталог у *Bulletin Astronomique de Belgrade*. Осим тога одбрањене су и две магистарске тезе. Астрономска опсерваторија публикује у 1997. години, као и 1996. године, четири публикације монографског типа и два броја часописа *Bull. Astron. Belgrade*.

Године 1998., Астрономска опсерваторија организује IV Југословенско - румунски астрономски скуп (Београд 5-8 мај 1998) и II Југословенско - Белоруски симпозијум о физици и дијагностици лабораторијске и астрофизичке плазме (Златибор 5-6 септембар 1998). Поред тога, Астрономска опсерваторија учествује у организацији I Бугарско - Српског астрономског семинара (Белоградик 6-8 август 1998) и секције Астрофизичка плазма на XIX Летњој школи и међународном симпозијуму о Физици јонизованих гасова (Златибор 31. август - 4. септембар 1998).

Од 1997, *Bulletin Astronomique de Belgrade*, односно данас *Serbian Astronomical Journal* је постављен на интернет преко Система за Астрофизичке податке

(АДС). Адреса билтена на интернету је:
http://adswww.harvard.edu/BOBeo.

На Астрономској опсерваторији на дан 1. октобра 1998. године било је 39 запослених од којих је 31 астроном. Ова установа са столетном традицијом и богатом историјом од великог је значаја за историју не само астрономије већ и метеорологије, сеизмологије и геомагнетских истраживања. Низ славних личности из историје наше науке, везаних за ову установу, допринели су да достигнућа српских астронома стекну углед у међународној научној јавности, а млади перспективу да се у нашој земљи могу бавити овом лепом и изазовном науком у окружењу које им омогућава да постигну резултате који се могу публиковати и у најпознатијим светским научним часописима.

3. Универзитетска настава астрономије у Србији после Другог светског рата

Осим Астрономске опсерваторије, у Београду се налази и Катедра за Астрономију Математичког факултета. Када се 1947. године од Филозофског факултета издвојио Природно - математички факултет, формирана је Катедра за Небеску механику и астрономију, али је убрзо променила име у Катедру за Механику и астрономију. Раздвајање ове Катедре на Катедру за Механику и Катедру за Астрономију почело је 1960. а завршило се 1962. године. Реорганизацијом Природно - математичког факултета 1971. године, Катедра за Астрономију постаје Институт за Астрономију. Године 1995. долази до поделе Природно - математичког факултета на више факултета. На Математичком факултету остала је Катедра за Астрономију, која је у новој организацији вратила старо име.

Године 1961. на Катедри су формиране две студијске групе - за астрономију и за астрофизику. Данас на Катедри за Астрономију раде десет астронома са пуним радним временом и два до једне трећине радног времена и предају шеснаест предмета. Имена сарадника Катедре са предметима које предају и и њиховим електронским адресама, дати су у Додатку 2.

Јуна 1936. године Слободанка Димитријевић је постала први дипломирани астроном који је студије завршио на Београдском Универзитету. Пре Другог светског рата дипломирао је још само Лео Рандић, октобра 1938. године. У чланку Милоградов - Турин (1997) дат је списак од 155 студената који су дипломирали астрономију. Прву докторску теза на Катедри за Астрономију, са насловом "Анализа систематских грешака пасажног инструмента и других систематских утицаја на одређивање времена", одбранио је 26. септембра 1958. године Захарије Бркић, а прву магистарску тезу

а главни и одговорни уредници су били Ђорђе Николић (1935), Др Војислав Ј. Грујић (1936 - 1939) и Ненад Ђ. Јанковић (1940). За време окупације, рад Друштва је био забрањен.

После рата 9. XII 1951. одржана је оснивачка скупштина Београдског асстрономског клуба "Руђер Бошковић" (у саставу Удружења студената Природно - математичког факултета (ПМФ)) и за председника је изабран Др Радован Данић. С обзиром да је у Клубу већ 1952. године било 64 члана од којих су већина били ван ПМФ, Управни одбор Клуба, на седници од 23. III 1952. доноси одлуку да се Клуб пререгиструје у Астрономско друштво "Руђер Бошковић". Потписници документа упућеног Министарству унутрашњих послова НР Србије, који су истовремено и оснивачи обновљеног Друштва су: Др Радован Данић (хирург, пуковник ЈНА), Перо Ђурковић (научни сарадник Астрономске опсерваторије), Александар Кубичела (студент), Др Ђорђе Николић (начелник Астрономског одсека Географског института ЈНА), Миленко Николић (студент), Божидар Поповић (научни сарадник Астрономске опсерваторије), Јован Симовљевић (студент), Јосип Славенски (композитор), Ђорђе Телеки (студент) и Милорад Топалов (студент). Оснивачка скупштина Друштва одржана је 18. V 1952. а за председника је изабран Др Радован Данић (1952 - 1966). После њега председници Друштва су Бранислав Шеварлић (1966 - 1970), Перо Ђурковић (1970 - 1972), Ненад Јанковић (1972 - 1974), Божидар Поповић (1974 - 1979), Зоран Кнежевић (1979 - 1982) и Милан Димитријевић (1982 -).

Године 1953. Друштво заједно са Ваздухопловним савезом Југославије, почиње са издавањем часописа за астрономију и астронаутику (данас часопис за астрономију) *Васиона*. Главни и одговорни уредници овог часописа су Ненад Ђ. Јанковић (1953 - 1972), Перо Ђурковић (1973 - 1974), Јелена Милоградов - Турин (1975 - 1982), Бранислав Шеварлић (1983 - 1984) и Милан С. Димитријевић (1985 -).

Залагањем Пере Ђурковића и Радована Данића, Друштво добија просторије у Деспотовој кули на Калимегдану, где је 20.XII 1964. свечано отворена Народна опсерваторија, која са редовним радом почиње јуна 1965. Управници Народне опсерваторије су Перо Ђурковић (1. VI 1965 - 1.XII 1965), Радован Данић (1.XII 1965 - 6.III 1977), Александар Томић (6.III 1977 - 31.I 1991), Лука Ч. Поповић (1.IV 1991 - 31.V 1995), Јелена Милоградов - Турин (1.VI 1995 -). Друштво успева да набави планетаријум Цајсове производње, који је смештен у старом купатилу - Амаму у Доњем Граду. Планетаријум је почео да ради 1969. а отворен је званично 27.II 1970.

Друштво је имало подружнице у Новом Саду (касније прерасла у Астрономско друштво "Нови Сад"), Крагујевцу, Сомбору, Сремској Митро-

"Понашање секундарних либела у пољу хоризонталних градијената температуре", 12. октобра 1968. године Софија Сајаков. У чланку Милоградов - Турин (1997) дат је списак од 22 одбрањене докторске тезе и 34 магистарске.

Осим у Београду, астрономија се предаје и на Универзитетима у Новом Саду, Нишу и Крагујевцу. На Природно - математичком факултету Универзитета у Новом Саду од 1986. године постоји у VIII семестру предмет "Астрофизика и Астрономија" са два часа предавања и два часа вежби недељно. Предмет је обавезан за студенте који хоће да предају физику у средњој школи а опциони за студенте Примењене физике.

На Филозофском факултету Универзитета у Нишу, на студијској групи Физика, на смеру Општа физика, од школске 1990/91 до 1993/94, предаван је у VII и VIII семестру предмет "Основи астрофизике" са два часа недељно. После тога предмет две године није био у наставном плану да би од 1996/97 поново почео да се предаје само у VII семестру са два часа недељно. Осим тога, на студијској групи за хемију постоји катедра за гео и космохемију, која се бави и проучавањем метеора и метеорита.

На Природно - математичком факултету Универзитета у Крагујевцу, школске 1998/99 године уведен је предмет "Астрофизика са Астрономијом" у VI семестру Наставног смера групе за Физику, са два часа предавања и два часа вежби недељно.

4. Аматерска астрономска друштва

Осим професионалне астрономије у Србији је развијена и аматерска астрономија. Највећа и најстарија организација астронома аматера је Астрономско друштво "Руђер Бошковић" из Београда (Калемегдан, Горњи град 16, 11000 Београд), које је током 65 година постојања ширило астрономска знања у нашој земљи.

На иницијативу Ђорђа М. Николића, Павла Емануела и Франа Симовића, године 1934. основано је Универзитетско астрономско друштво, прво таквог карактера на Балкану. Потписници Правила друштва, која је одобрио Универзитетски сенат 22.XII 1933. су осим поменутих и Винка Бањић, Олга Бранкован, Радмила Комарчевић, Слободанка Димитријевић, и Вера Грбовић. Оснивачка скупштина одржана је 22.IV 1934. од. Први председник друштва био је Ђорђе Николић (1934-1936), а други Војин Ђуричић (1936 - 1941), управник Државне хипотекарне банке.

У предратном периоду, највећи подухват Друштва био је покретање часописа *Сатурн* 1935. године. До краја 1940. часопис излази 12 пута годишње

вици, Ваљеву, Старој Пазови, Белој Цркви, Нишу, Суботици, Зрењанину, Бечеју, Новом Бечеју... које су се временом угасиле.

Најуспешнија подружница Астрономског друштва "Руђер Бошковић" била је у Новом Саду. Она је основана 1954. године при Вишој педагошкој школи, под руководством Живојина Ћулума. Укидањем Више педагошке школе 1962. године и подружница престаје са радом. Оснивачка скупштина Астрономског друштва "Нови Сад" - АДНОС (Јарослав Францисти, Астрономска опсерваторија, Петроварадинска тврђава, 21000 Нови Сад) одржана је 4. марта 1974. године. Године 1976. купљени су телескопи 20T Observatory 108/1600mm; 10K 80/1200mm и 14T 60/900mm, америчке фирме Tasco, а 1991. набављени су и телескопи рефлекторског типа Meade 200/1500mm и 102/1000mm. Године 1989. завршена је адаптација Астрономске опсерваторије на Петроварадинској тврђави, а 1996. године добијен је и простор за планетаријум, чија је адаптација у току. Председник Друштва у периду 1974 - 1980. године био је Живојин Ћулум, у периоду 1980 - 1984. Божидар Јовановић, а од 1984. године до данас, председник је Ђура Паунић.

У Петници код Ваљева, организација Младих истраживача Србије гради Дом младих истраживача. Ова установа, у почетку рекреативног карактера, постаје Истраживачка станица Петница (Петница, 14000 Ваљево). Први програми се изводе 1982. године, а први семинар из астрономије 1983, као припрема за одлазак на Ргајску планину где су вршена астроклиматска снимања. Године 1988. Петница добија Целестронов телескоп Шмит - Касегреновог типа, пречника објектива 20 цм. Касније, набављени су и Целестронов рефрактор од 102 мм и рефлектор од 33 цм, који је изградио Аљоша Јовановић. Руководиоци семинара астрономије били су Дарко Јевремовић и Силвана Николић, а данас је на тој дужности Самир Салим. У Ваљеву, у оквиру Друштва истраживача "Владимир Мандић - Манда" основаног 16. фебруара 1969. године, делује и Астрономска група основана 1972. године (Никола Божић, Бирчанинова 68, П. фах 118, 14000 Ваљево).

У Крагујевцу, на крову Института за Физику Природно - математичког факултета, налази се Белерофонт опсерваторија (Вукота Бабовић, Институт за Физику ПМФ, Сестре Јањић 4, Крагујевац), отворена 20. фебруара 1986. године. Има телескоп Meniskus Cassegrain Spigel 150/2250mm.

У Нишу је крајем шездесетих и почетком седамдесетих година деловала подружница Астрономског друштва "Руђер Бошковић, а на Филозофском факултету је у периоду 1976 - 1980. године постојало "Астро-геофизичко друштво". Године 1996. основано је Астрономско друштво "Алфа" (Драган Ж. Гајић, Филозофски факултет, Студијска група за Физику, П. Фах 91, 18001 Ниш). Први претседник Друштва је Зоран Секулић а од марта 1997. године председник је Драган Ж. Гајић.

Године 1996. и Зрењанин је добио организацију астронома аматера, Астрономско друштво "Милутин Миланковић (Крсте Наумовски, Миша Брадић, Зрењанинска гимназија, Гимназијска 2, 23000 Зрењанин). Аматерска астрономска друштва дала су велики допринос ширењу астрономских знања и нових научних достигнућа у астрономији, у нашој средини и стварању повољније климе у друштву за развој астрономије у Србији.

Референце

***: 1989, Sto godina Astronomske opservatorije u Beogradu, *Publ. Obs. Astron. Belgrade*, **36**.

Babović Vukota: 1997, Multidisciplinarnost u razvoju Belerofonta, u Razvoj astronomije kod Srba, eds. M. S. Dimitrijević, J. Milogradov-Turin, L.Č. Popović, *Publ. Astron. Obs. Belgrade*, **56**, 95.

Dimitrijević Milan S.: 1996, Beogradska Astronomska opservatorija u 1995, Belgrade Astronomical observatory in 1995, *Publ. Obs. Astron. Belgrade*, **52**.

Dimitrijević Milan S.: 1997, 110 godina Astronomske opservatorije, u: Razvoj astronomije kod Srba, eds. M. S. Dimitrijević, J. Milogradov-Turin, L.Č. Popović, *Publ. Astron. Obs. Belgrade*, **56**, 9.

Dimitrijević Milan S.: 1997, Beogradska Astronomska opservatorija u 1996, Belgrade Astronomical observatory in 1996, *Publ. Astron. Obs. Belgrade*, **55**.

Dimitrijević Milan S.: 1998, Beogradska Astronomska opservatorija u 1997, Belgrade Astronomical observatory in 1997, *Publ. Astron. Obs. Belgrade*, **59**.

Djokić Milorad: 1989, Arhivska gradja o Opservatoriji Velike škole i Univerziteta u Beogradu u vremenu od 1887. do 1924. godine, u: Sto godina Astronomske opservatorije u Beogradu, *Publ. Obs. Astron. Belgrade*, **36**, 177.

Djurković Pero: 1968, Sedamdeset pet godina rada Astronomske opservatorije u Beogradu, *Publ. Obs. Astron. Belgrade*, **12**, 15.

Djurković P.: 1969, Rapport sur l'activité de l'Observatoire Astronomique de Belgrade de 1966 á 1969, *Bull. Obs. Astron. Belgrade* **XXII**, No 2, 143.

Djurković P.: 1970, Rapport sur l'activité de l'Observatoire Astronomique de Belgrade en 1970, *Bull. Obs. Astron. Belgrade* **124**, 195.

Francisti Jaroslav: 1997, Astronomsko društvo "Novi sad" - ADNOS, u Razvoj astronomije kod Srba, eds. M. S. Dimitrijević, J. Milogradov-Turin, L.Č. Popović, *Publ. Astron. Obs. Belgrade*, **56**, 91.

Gajić Dragan Ž.: 1997, Astronomija i astrofizika na Univerzitetu u Nišu, u: Razvoj astronomije kod Srba, eds. M. S. Dimitrijević, J. Milogradov-Turin, L.Č. Popović, *Publ. Astron. Obs. Belgrade*, **56**, 109.

Janković, Nenad Dj.: 1984, Zapisi i sećanja na Astronomsko društvo, *Publ. Astron. Društva "Rudjer Bošković"*, No. 3.

Janković Dj. Nenad: 1986, Pregled istorije astronomije u Jugoslovenskim zemljama, u: Istorija astronomske nauke od Njutnovog doba do naših dana (B.M. Ševarlić), Univerzitet u Beogradu, Beograd, 143.

Janković Dj. Nenad: 1989, Milan Nedeljković, profesor Velike škole i osnivač njene Opservatorije, u: Sto godina Astronomske opservatorije u Beogradu, *Publ. Obs. Astron. Belgrade*, **36**, 107.

Jeličić, Milan: 1984, Pedest godina Astronomskog društva "Rudjer Bošković", Vasiona, XXXII, No 1, 1.

Jeličić Milan: 1987, Provizorna Astronomska i meteorološka opservatorija u Beogradu, Vasiona, **XXXV**, No 3-4, 78.

Michkovitch V.V.: 1930, Rapport annuel sur l'état et les travaux de l'Observatoire Astronomique de Belgrade pour l'année 1929, Annuaire pour l'an 1930, 125.

Michkovitch V.V.: 1931, Rapport annuel sur l'état et les travaux de l'Observatoire Astronomique de Belgrade pour l'année 1930, Annuaire pour l'an 1931, 133.

Michkovitch V.V.: 1932, Rapport annuel pour l'année 1931 sur l'état et les travaux de l'Observatoire Astronomique de l'Université de Belgrade, Mémoires I, 38.

Michkovitch V.V.: 1941, Services et travaux d'observations en 1939 á l'Observatoire Astronomique de l'Université de Belgrade, *Bull. Obs. Astron. Belgrade* **V**, No 1-2, 1.

Michkovitch V.V.: 1950, Services et travaux d'observations en 1940 á l'Observatoire Astronomique de l'Université de Belgrade, *Bull. Obs. Astron. Belgrade* **VI**, No 1-2, 1.

Michkovitch V.V.: 1952, Rapport annuel présenté à l'Academie des sciences Serbe, sur l'état et l'activité de l'Observatoire en 1951, *Bull. Obs. Astron. Belgrade* **XVI**, No 1-4, 1.

Milogradov - Turin J.: 1996, Astronomy education in FR Yugoslavia 1993 - 1996, *Publ. Astron. Obs. Belgrade*, **54**, 165.

Milogradov - Turin J.: 1997, Jedan prilog istoriji Katedre za astronomiju Univerziteta u Beogradu, u Razvoj astronomije kod Srba, eds. M. S. Dimitrijević, J. Milogradov-Turin, L.Č. Popović, *Publ. Astron. Obs. Belgrade*, **56**, 65.

Milogradov - Turin J.: 1998, Chair of Astronomy of the University of Belgrade, *Publ. Astron. Obs. Belgrade*, **60**, 193.

Naumovski Krste, Bradić Miša: 1997, Astronomsko društvo u Zrenjaninu, u: Razvoj astronomije kod Srba, eds. M. S. Dimitrijević, J. Milogradov-Turin, L.Č. Popović, *Publ. Astron. Obs. Belgrade*, **56**, 115.

Nedeljković Milan: 1904, Izveštaj Opservatorije Velike škole i njenih meteoroloških stacija, 1899-1903, Državna štamparija, Beograd.

Nedeljković Milan: 1905, Izveštaj Opservatorije i Meteoroloških stacija, 1904, Državna štamparija, Beograd.

Nedeljković Milan: 1907, Izveštaj Opservatorije i Meteoroloških stacija, 1905-1906, Štamparija Davidović, Beograd.

Nedeljković Milan: 1908, Izveštaj Opservatorije i Meteoroloških stacija, 1907, Državna štamparija, Beograd.

Nedeljković Milan: 1909, Izveštaj Opservatorije i Meteoroloških stacija, 1908-1909, Državna štamparija, Beograd.

Nedeljković Milan: 1910, Izveštaj Opservatorije i Meteoroloških stacija, 1910, Državna štamparija, Beograd.

Nedeljković Milan: 1914, Izveštaj Opservatorije i Meteoroloških stacija, 1911-1912, Merkur, Beograd.

Nedeljković Milan: 1923, Izveštaj Opservatorije, za 1919-1920, 1922 i 1923, Beogradska opservatorija, Beograd.

Nedeljković Milan: 1925, Izveštaj Opservatorije, za 1924, Beogradska opservatorija, Beograd.

Popović B.: 1950, Services et travaux d'observations en 1949 á l'Observatoire astronomique de l'Université de Belgrade, *Bull. Obs. Astron. Belgrade* **XIV- 1949**, VII.

Popović B.: 1951, Rapport annuel sur l'état et l'activité de l'Observatoire astronomique de Belgrade en 1950, *Bull. Obs. Astron. Belgrade* **XV - 1950**, VII.

Popović, L. Č.: 1997, Razvoj i aktivnosti Astronomskog društva "Rudjer Bošković", u Razvoj astronomije kod Srba, eds. M. S. Dimitrijević, J. Milogradov-Turin, L.Č. Popović, *Publ. Astron. Obs. Belgrade*, **56**, 77.

Protić, M.: 1975, Izveštaj o radu Astronomske opservatorije u Beogradu tokom 1973. godine, *Publ. Obs. Astron. Belgrade*, **20**, 231.

Protić-Benišek Vojislava: 1987, Jedan vek Astronomske opservatorije u Beogradu, Vasiona **XXXV**, No 3-4, 64.

Protitch M.: 1950, Services et travaux d'observations en 1941 á l'Observatoire astronomique de l'Université de Belgrade, *Bull. Obs. Astron. Belgrade* **VII - 1942**, 1.

Protitch M.: 1956, Rapport annuel sur l'état et les travaux de l'Observatoire en 1955, *Bull. Obs. Astron. Belgrade* **XX**, No 3-4, 16.

Protitch M.: 1960, Rapport annuel sur l'état et les travaux de l'Observatoire en 1959, *Bull. Obs. Astron. Belgrade* **XXIV**, No 3-4, 42.

Salim Samir: 1997, Astronomija u Istraživačkoj stanici Petnica, u: Razvoj astronomije kod Srba, eds. M. S. Dimitrijević, J. Milogradov-Turin, L.Č. Popović, *Publ. Astron. Obs. Belgrade*, **56**, 101.

Sekulić Miodrag: 1997, Astronomsko društvo "Alfa" - Niš, u: Razvoj astronomije kod Srba, eds. M. S. Dimitrijević, J. Milogradov-Turin, L.Č. Popović, *Publ. Astron. Obs. Belgrade*, **56**, 111.

Simovljević Jovan: 1987, Astronomija, Četrdeset godina Prirodno - Matematičkog fakulteta u Beogradu, Beograd, 166.

Stanojević M. Djordje: 1905b, Beogradska opservatorija i njen izveštaj za 1899 - 1903. god., str. 32, Beograd.

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САРАДНИЦИ КАТЕДРЕ ЗА АСТРОНОМИЈУ МАТЕМАТИЧКОГ ФАКУЛТЕТА У БЕОГРАДУ

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ON THE STARK BROADENING OF Kr VIII LINES

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Abstract. Using a semiclassical approach, we have calculated electron-, proton-, and He III-impact line widths and shifts for 6 Kr VIII multiplets.

1. INTRODUCTION

Spectral line parameters even for trace elements become of increasing interest for astrophysics, due to the development of observations from the space. By using the Goddard High Resolution Spectrograph on Hubble Space Telescope, Cardelli *et al.* (1991) have, for the first time, begun detecting elements such as krypton. Stark broadening data for higher ionization stages, may be of interest for the investigation of subphotospheric layers (Seaton, 1987), as well as for the investigation of regularities and systematic trends along isoelectronic sequences. Griem and Moreno (1990) and Fill and Schöning (1994) pointed out the importance of such results for the development of soft x-ray lasers, where Stark broadening data are needed to calculate gain values, model radiation trapping and to consider photoresonant pumping schemes.

In order to provide Stark broadening data needed for the investigation and modeling of astrophysical and laboratory plasmas, we have calculated within the semiclassical-perturbation formalism (Sahal–Bréchot 1969ab, Dimitrijević and Sahal - Bréchot, 1984, Dimitrijević *et al.* 1991, Dimitrijević and Sahal - Bréchot, 1995) electron-, proton-, and He III-impact line widths and shifts for 6 Kr VIII multiplets.

2. RESULTS AND DISCUSSION

As the continuation of our project to provide to astrophysicists and plasma physicists the needed Stark-broadening parameters (see Dimitrijević 1996, Dimitrijević and Sahal-Bréchot 1995 and references therein), electron-, proton-, and He III- impact line widths and shifts have been calculated for Kr VIII. Energy levels for Kr VIII are taken from Sugar and Musgrove (1991). Our results for 6 Kr VIII multiplets, for perturber densities 10^{17} - 10^{22} cm^{-3} and temperatures T = 200,000 -3,000,000K will be published in Dimitrijević and Sahal-Bréchot (1999a,b).

Table 1

This Table shows electron- and proton-impact broadening full half-widths (FWHM) and shifts for Kr VIII for a perturber density of 10^{17} cm^{-3} and temperatures from 200,000 up to 3,000,000 K. By deviding C with the full line width, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used.

PERTURBER DENSITY = 1.E+17cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Kr VIII4S 4P	200000.	0.991E-03	-0.143E-04	0.240E-04	-0.105E-04
665.7 A	500000.	0.656E-03	-0.169E-04	0.516E-04	-0.219E-04
C=0.67E+20	1000000.	0.499E-03	-0.155E-04	0.731E-04	-0.315E-04
	1500000.	0.432E-03	-0.157E-04	0.808E-04	-0.376E-04
	2000000.	0.393E-03	-0.152E-04	0.866E-04	-0.405E-04
	3000000.	0.347E-03	-0.145E-04	0.939E-04	-0.451E-04
Kr VIII4S 5P	200000.	0.175E-03	0.751E-06	0.134E-04	0.320E-06
182.1 A	500000.	0.121E-03	0.113E-05	0.201E-04	0.731E-06
C=0.20E+19	1000000.	0.956E-04	0.973E-06	0.228E-04	0.115E-05
	1500000.	0.848E-04	0.100E-05	0.243E-04	0.139E-05
	2000000.	0.785E-04	0.890E-06	0.254E-04	0.158E-05
	3000000.	0.709E-04	0.105E-05	0.265E-04	0.177E-05
Kr VIII5S 5P	200000.	0.185E-01	-0.514E-03	0.121E-02	-0.584E-03
1692.0 A	500000.	0.131E-01	-0.623E-03	0.187E-02	-0.929E-03
C=0.17E+21	1000000.	0.105E-01	-0.578E-03	0.218E-02	-0.114E-02
	1500000.	0.941E-02	-0.546E-03	0.237E-02	-0.126E-02
	2000000.	0.873E-02	-0.550E-03	0.251E-02	-0.136E-02
	3000000.	0.789E-02	-0.474E-03	0.269E-02	-0.150E-02
Kr VIII4P 5S	200000.	0.302E-03	0.204E-04	0.112E-04	0.198E-04
294.2 A	500000.	0.211E-03	0.252E-04	0.260E-04	0.309E-04
C=0.51E+19	1000000.	0.167E-03	0.231E-04	0.380E-04	0.378E-04
	1500000.	0.148E-03	0.222E-04	0.437E-04	0.419E-04
	2000000.	0.136E-03	0.219E-04	0.477E-04	0.449E-04
	3000000.	0.122E-03	0.199E-04	0.553E-04	0.497E-04
Kr VIII4P 6S	200000.	0.227E-03	0.327E-04	0.196E-04	0.295E-04
184.4 A	500000.	0.166E-03	0.320E-04	0.373E-04	0.401E-04
C=0.10E+19	1000000.	0.136E-03	0.298E-04	0.479E-04	0.478E-04
	1500000.	0.121E-03	0.286E-04	0.550E-04	0.526E-04
	2000000.	0.112E-03	0.263E-04	0.612E-04	0.560E-04
	3000000.	0.101E-03	0.231E-04	0.666E-04	0.597E-04

Table 1 continued

PERTURBER DENSITY = 1.E+17cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Kr VIII5P 6S	200000.	0.467E-02	0.439E-03	0.359E-03	0.416E-03
697.9 A	500000.	0.341E-02	0.421E-03	0.602E-03	0.565E-03
C=0.14E+20	1000000.	0.279E-02	0.395E-03	0.746E-03	0.671E-03
	1500000.	0.250E-02	0.377E-03	0.851E-03	0.739E-03
	2000000.	0.233E-02	0.347E-03	0.932E-03	0.788E-03
	3000000.	0.210E-02	0.299E-03	0.101E-02	0.839E-03

As a part of our results, the Stark broadening widths (FWHM) and shifts due to electron and proton impacts, for a perturber density of 10^{17} cm^{-3}, are shown in Table 1. Parameter C (Dimitrijević and Sahal-Bréchot 1984), given also in Table 1, provides an estimate for the maximum perturber density for which the line may be treated as isolated when divided by the corresponding electron-impact full width at half maximum. For each value given in Table 1, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid (Sahal–Bréchot, 1969ab). Values for NV $>$ 0.5 are not given and values for 0.1 $<$ NV $\leq$ 0.5 are denoted by an asterisk.

The complete results will be published in Dimitrijević and Sahal–Bréchot (1999ab).

References

Cardelli, J.A., Savage, B.D., Ebbets, D.C.: 1991, *Astrophys. J.*, **383**, L23.
Dimitrijević, M.S.: 1996, *Zh. Prikl. Spektrosk.* **63**, 810.
Dimitrijević, M.S., and Sahal-Bréchot, S.: 1984, *JQSRT* **31**, 301.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1995, *Astron. Astrophys. Suppl. Series* **109**, 551.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1999a, *Physica Scripta* submitted.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1999b, *Serb. Astron. J.* **159**, in press.
Dimitrijević, M.S., Sahal-Bréchot, S. and Bommier, V.: 1991, *Astron. Astrophys. Suppl. Series* **89**, 581.
Fill, E.E., Schöning, T.: 1994, *J. Appl. Phys.* **76**, 1423.
Griem, H.R., Moreno, J.C.: 1990, in: *X-Ray Lasers*, ed. G. Tallents, Institute of Physics, Bristol, 301.
Sahal-Bréchot, S.: 1969a, *Astron.Astrophys.* **1**, 91.
Sahal-Bréchot, S.: 1969b, *Astron.Astrophys.* **2**, 322.
Seaton, M.J.: 1987, *J. Phys. B*, **20**, 6363.
Sugar, J., Musgrove, A.: 1991, *J. Phys. Chem. Ref. Data*, **20**, 875.

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SERBIAN ASTRONOMERS IN SCIENCE CITATION INDEX IN 1946 – 1998 PERIOD

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Abstract. The presence of Serbian astronomers in Science Citation Index within 1946-1998 period has been analyzed and the most cited astronomers and articles have been identified.

1. INTRODUCTION

The description of the Science Citation Index method and its possibilities for scientometric applications, and for the analysis and planing of scientific work have been analysed *e. g.* in Hajtun (1983), Abt (1990) and Dimitrijević (1996, 1997). According to the analysis of Abt (1990), at the beginning of the 20th century, the number of authors per article, was 1.1 on the average and now it is 3.2. Within the same period the contribution of articles with a single author to the total number of articles have decreased from 90 per cent to 10 per cent. It is interesting also that only 5 per cent of the articles published in astronomy have been theoretical ones at the begining of the 20th century, while according to Abt (1990) 45 per cent of astronomical articles are theoretical now wittnessing on the development of this science.

In Dimitrijević (1996) the presence of Serbian astronomers in Science Citation Index within 1961-1995 period has been analyzed, and the most cited astronomers and articles within the considered period have been identified. In this contribution the previous analysis has been enlarged from 1961-1995 period to 1946-1998 period.

2. RESULTS AND DISCUSSION

In order to identify the presence of Serbian astronomers in the Science Citation Index (SCI), a list of all astronomers working on the project "Physics and Dynamics of Celestial Bodies" has been taken as well as the bibliography of the project. Moreover, all who are working or worked as astronomers and have at least one reference in Serbian scientific astronomical publications, as well as all professors of the Department of Astronomy of the Belgrade University and Directors of Belgrade Astronomical Observatory, have been added to the list.

Table 1. Serbian astronomers with at least ten citations registered in the Science Citation Index, within the period 1946-1998.

No.	Name	Year of the first cit.	No. cit.	No cit. as the first author	No. without auto cit.
1.	Milan Dimitrijević	1975	1274	943	576
2.	Milutin Milanković	1945	570	570	570
3.	Zoran Knežević	1982	346	117	269
4.	Dragutin Djurović	1972	113	113	61
5.	Vasilije Oskanjan	1955	87	79	87
6.	Slobodan Ninković	1983	84	38	50
7.	Ištvan Vince	1977	59	17	55
8.	Gojko Djurašević	1981	59	37	27
9.	Aleksandar Kubičela	1966	50	34	40
10.	Slobodan Jankov	1986	47	29	34
11.	Jelisaveta Arsenijević	1981	38	21	30
12.	Djordje Teleki	1972	34	27	29
13.	Vladimir Kršljanin	1986	34	7	28
14.	Sofija Sadžakov	1987	31	28	9
15.	Jelena Milogradov-Turin	1970	29	29	24
16.	Danilo Zulević	1969	26	23	26
17.	Georgije Popović	1969	26	20	22
18.	Luka Popović	1991	25	15	13
19.	Mirjana Vukićević-Karabin	1978	24	3	22
20.	Miodrag Dačić	1988	22	1	7
21.	Milorad Protić	1956	18	18	18
22.	Jovan Lazović	1986	16	16	16
23.	Vera Erceg	1976	16	9	16
24.	Desanka Šulić	1974	16	4	13
25.	Mike Kuzmanoski	1987	13	8	5
26.	Ivan Atanasijević	1953	12	8	12
27.	Dušan Šaletić	1988	12	2	12
28.	Nada Pejović	1985	12	12	10
29.	Ilija Lukačević	1971	11	11	1
30.	Dragomir Olević	1980	11	7	11
31.	Branislav Ševarlić	1951	11	6	11

Table 2. Articles of Serbian astronomers with at least 20 citations registered in the Science Citation Index, within the period 1946-1998.

1. Milanković, M.: 1941, Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem, *Königlisch Serbische Akademie, Editions Speciales, Sciences mathématiques et naturelles*, Belgrade, **CXXXIII**, 33. [279 citations].
2. Milanković, M.: 1930, Mathematische Klimalehre und Astronomische Theorie der Klimaschwankungen, *Handbuch der Klimatologie*, Bd. I, T.A. Hrsg Von Köppen und R.Geiger, Berlin, Gebrüder Borntraeger [148 citations].
3. Dimitrijević, M.S., Konjević, N.: 1980, Stark widths of doubly- and triply-ionized atom lines, *J. Quant. Spectrosc. Radiative Transfer* **24**, 451 [99 citations].
4. Dimitrijević, M.S., Sahal-Bréchot, S.: 1984, Stark broadening of neutral helium lines, *J. Quant. Spectrosc. Radiative Transfer* **31**, 301 [81 citations].
5. Zappala, V., Farinella, P., Knežević, Z., Paolicchi, P.: 1984, Collisional origin of the asteroid families: Mass and velocity distributions, *Icarus* **59**, 261 [54 citations]
6. Konjević, N., Dimitrijević, M.S., Wiese, W.L.: 1984, Experimental Stark widths and shifts for spectral lines of positive ions (a critical review of selected data for the period 1976 to 1982, *J. Phys. Chem. Reference Data* **13**, 649 [53 citations].
7. Milanković, M.: 1920, Théorie mathématique des phénomènes thérmiques produits par la radiation solaire, Paris, Zagreb, Gauthier - Villars et Cie, Ed. Académie Yougoslave des Sciences et des Arts [52 citations].
8. Dimitrijević, M.S., Konjević, N.: 1981, Modified semiempirical formula for the electron-impact widths of ionized atom lines, in Spectral Line Shapes, Vol. 1, ed. B.Wende, Walter de Gruyter, Berlin, New York, p.211 [48 citations].
9. Konjević, N., Dimitrijević, M.S., Wiese, W.L.: 1984, Experimental Stark widths and shifts for spectral lines of neutral atoms (a critical review of selected data for the period 1976 to 1982, *J. Phys. Chem. Reference Data* **13**, 619 [47 citations].
10. Dimitrijević, M.S., Sahal-Bréchot, S., Bommier, V.: 1991, Stark broadening of spectral lines of multiply charged ions of astrophysical interest. I. C IV lines, *Astron. Astrophys. Suppl. Series* **89**, 581 [44 citations].
11. Knežević, Z., Milani, A., Farinella, P., Froeschle, C.: 1991, Secular resonances from 2 to 50 AU, *Icarus* **93**, 316 [43 citations]
12. Lanz, T., Dimitrijević, M.S., Artru, M.C.: 1988, Stark broadening of visible Si II lines in stellar atmospheres, *Astron. Astrophys.* **192**, 249 [43 citations]
13. Oskanjan, V.S., Evans, D.S., Lacy, S., McMillan, R.S.: 1977, An Analysis of the slow light variability of BY Draconis, *Astrophys. J.* **214**, 430 [40 citations].
14. Dimitrijević, M.S., Konjević, N.: 1986, Simple estimates for Stark broadening of ion lines in stellar plasmas, *Astron. Astrophys.* **172**, 345 [40 citations]
15. Milanković, M.: 1938, Astronomische Mittel zur Erforschung der Erdgeschichtlichen Klimate, *Handbuch der Geophysik*, Bd IX, Lieferung 3, Abschniht VII, Hrsg von Beno Gutenberg, Berlin, Gebrüder Borntraeger [37 citations]
16. Zappala, V., Knežević, Z.: 1984, Rotation axes of asteroids: Results for 14 objects, *Icarus* **59**, 436 [36 citations]
17. Milani, A., Knežević, Z.: 1990, Secular perturbation theory and computation of asteroid proper elements, *Celestial Mechanics and Dynamical Astronomy* **49**, 347 [33 citations]

18. Dimitrijević, M.S., Konjević, N.: 1986, Simple formulae for estimating Stark widths and shifts of neutral atom lines, *Astron. Astrophys.* **163**, 297 [30 citations]
19. Milani, A., Knežević, Z.: 1992, Asteroid proper elements and secular resonances, *Icarus* **98**, 211 [27 citations]
20. Platiša, M., Popović, M., Dimitrijević, M., Konjević, N.: 1975, Stark Broadening of A III and A IV Lines, *Zeitschrift für Naturforschung* **30a**, 212 [24 citations]
21. Dimitrijević, M. S.: 1988, Electron-impact widths of doubly and triply charged ion lines of astrophysical importance, *Astron. Astrophys. Suppl. Series* **76**, 53 [23 citations]
22. Brosche, P., Tucholke, H.J., Klemola, A.R., Ninković, S., Geffert, M., Doerenkamp, P.: 1991, Space Motions of Globular Clusters NGC 362 and NGC 6218 (M12), *Astronomical Journal* **102**, 2022.

In Table 1, astronomers with at least ten citations registered in the Science Citation Index, within the period 1946-1998 are presented with the year of the first citation in the Science Citation Index, number of citations, number of citations as the first author and the number of citations without autocitations. In Table 2, articles with at least twenty citations in the considered period, are presented.

References

Abt, H.A.: 1990, The Use of Publication Studies to Affect Policies and Attitudes in Astronomy II, Current Contents, No 40, 1 Oct., 7.
Dimitrijević, M.S.: 1996, *Publ. Astron. Obs. Belgrade*, **54**, 217.
Dimitrijević, M.S.: 1997, In: Vrednovanje naučnog rada, ed. M.R. Sarić, Srpska Akademija Nauka i Umetnosti, 61.
Hajtun, S.D.: 1983, Naukometriya, sostoyanie i perspektivy, Nauka, Moskva.

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ACTIVITY AND BIBLIOGRAPHY OF MILAN NEDELJKOVIĆ

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Abstract. The activity of Milan Nedeljković, the founder of Observatory and his published works are discussed. His bibliography of his works is enclosed.

1. ACTIVITY OF MILAN NEDELJKOVIĆ

One of the personalities having mostly contributes to the professional pursuit of astronomy and meteorology in Serbia in the second half of the 19th and the beginning of the 20th century is certainly Milan Nedeljković. (born Belgrade, Sept. 27, 1857, died Belgrade, Dec. 21, 1950). He was a professor of astronomy and meteorology at the Grand School, later University of Belgrade. Thanks to his enthusiasm, love of astronomy and meteorology and to his outstanding abilities, by a decree of the Ministry of Education and Church Affairs on March 26, 1887 (old style) the first Observatory in Serbia was founded. Initially it was provisory, meant for both astronomical and meteorological observations and researches. By the same decree it was ordained "the Observatory to be under direction and management of Mr. Milan Nedeljković, professor of the Grand School". Besides his performing the duties of the Observatory's director, he wrote paper dealing with astronomical and meteorological subjects. Shortly after the Observatory was founded he started publishing monthly reports on meteorological observations made at the Observatory in "Prosvetni glasnik" (Enlightenment Messenger), (the official periodical of the Royal-Serbian Ministry of Education and Church Affairs, edition and press of the Royal-Serbian State Printing Firm). His printed papers were published in the period 1888-1925. In his bibliography one notes that the bulk of his papers was published before 1910 (the maximum in 1902-1903). During the First World War the Austrian military were quartered in the Observatory. Thereafter Milan Nedeljković, still Observatory's director, directed his activity and efforts toward acquisition of astronomical instruments, which resulted in the Observatory obtaining them, on account of reparations, from Germany. At this time he published, besides reports on the Observatory and the meteorological stations, a little book "About Calendar".

Milan Nedeljković continued, even after having been sent into retirement on Jan. 30, 1924, by the Minister Of Education Miša Trifunović, with his selfless endeavourings to support the Observatory (he wrote to the Minister suggesting the Observatory to be organized as an "independent and practical institution of the Kingdom"), requesting all the decisions concerning the instruments to remain in force.

Nedeljković's bibliography is not large (it contains 34 entries) but it is important from the aspect of it being concerned with the beginnings of professional cultivation of astronomy and meteorology in Serbia.

Intense work and a great deal of time Nedeljković dedicated to the founding of the Observatory and to the organisation of a net of its meteorological stations throughout Serbia, which is evident also from his bibliography. Most of the items in this bibliography are dedicated to the directions for work at the stations and for the meteorological observations on them (2,3,5,8–18) as well as to annual reports on the activity of the Observatory (19–21,24,25,28,30,32–34). His annual reports present precious material on its history, on the pioneer observational activity in Serbia, containing his reflexions on various events, having also memoiristic elements. The entries 6,26 and 27 are equally devoted to the Observatory and its activities.

In his papers 22 and 23 "Meteorology and Agriculture" and "Observatory and Agriculture" he points to the significance for the vital branche of the Serbian economy - agriculture - of the meteorology, i.e. of the Observatory and its net of stations. In the Works 7 and 31 Nedeljković deals with the calendar and its reforming. In the works 1 and 4 are his meditations on astronomy, meteorology, science and school.

Some of his works have not been printed as he himself sais "in consequence of many unfavorable circumstances".

2. BIBLIOGRAPHY OF PUBLISHED WORKS OF MILAN NEDELJKOVIĆ

1. Reč o astronomiji i meteorologiji od Milana Nedeljkovića. (Preštampano iz "Prosv. Glasnika za 1888 g.) – U Beogradu. Štampano u Kralj.-srp. drž. štampariji. 1888. Str. 40. M. 8°.

2. Meteorološka uputstva za srpske stacije. Sastavio Milan Nedelković. – Beograd. Ministarstvo prosvete i crkvenih poslova. Štampano u Srpsko-kraljevskoj državnoj štampariji. 1888. Str. [1] + II + VI + IV + 261 + [1] + 5 pril. sa crt.i tabelom. V. 8°.

3. Upustvo za telegrafisanje meteoroloških podataka, Milan Nedeljković.

4. Misli o školi i nauci. Govor prof. Milana Nedeljkovića, držan u dvorani Velike škole o Sv. Savi 1892 g. (Na po se štampano iz "Nastavnika". – U Beogradu. Kraljevsko-srpska državna štamparija. 1893. Str. 29. V. 8°.

5. Meteorološka uputstva za stacije III reda i niže stacije. Od Milana Nedeljkovića. – U Beogradu. Štampano u Državnoj štampariji Kraljevine Srbije. 1895. Str. XII + 237 sa 7 crt. i tab. +[1]. V. 8°.

6. Opservatorija Velike škole i njene meteorološke stacije. Od Milana Nedeljkovića. – Beograd. Štamparija Petra K. Tanaskovića. 1898. Str. 37. 8°.

7. Projet de réforme du calendrier. Présenté par Milan Nedeljkovitch. – Belgrade. Imprimerie Royale de Serbie. 1900. Str. [1] + 38. 4°.

Tableau des années bissextiles (15 – 37 str.).

8. Opservatorija. Uputstvo za posmatranje grada. Od Milana Nedeljkovića. Napose odštampano iz Privrednog glasnika. – Beograd. Službeno izdanje Ministarstva Narodne privrede. Štampano u Državnoj štampariji Kraljevine Srbije. 1901. Str. 17. 8°.

9. Uputstvo za posmatranje nepogodskih pojava. Beograd. Državna štamparija Kraljevine Srbije. 1901. Str. 37.

10. Kišomerske stacije. Uputstva i propisi. Od Milana Nedeljkovića. – Beograd. Opservatorija. Štampano u Državnoj štamariji Kraljevine Srbije. 1902. Str. *XI* + 256 sa sl. i tabel. +1 pril. mesečnih tablica obične kišomerske stacije. V. 8°.

11. Kratko uputstvo za kišomerske stacije. Od Milana Nedeljkovića. – Beograd. Opservatorija. <Izdanje kr. srp. drž. štamparije>. Štampano y Državnoj štampariji Kraljevine Srbije. 1902. <1903>. Str. [1] + 26. V. 8°.

12. Opredeljenje časa pomoću sunčanika. Od Milana Nedeljkovića. – Beograd. Štampa i izdanje Kraljevske državne štamparije. 1902. <1903>. Str. *VII*+]1] + 130 sa tabelama. V. 8°.

Opservatorija.

13. Opredéljenje strana sveta. Uputstva za stacije III i IV reda. Od Milana Nedeljkovića. – Beograd. Opservatorija. <Izdanje kr. srp. drž. štamparije>. Štampano u Državnoj štampariji Kraljevine Srbije. 1902. <1903>. Str. [1] + 12 sa 5 crt. V. 8°.

14. Posmatranje poslednjih slana s proleća i prvih s jeseni. Od Milana Nedeljkovića. – Beograd. Opservatorija. <Izdanje kr. srp. drž. štamparije>. Štampano u Državnoj štampariji Kraljevine Srbije. 1902. <1903>. Str. [1] + 5 sa 1 l. V. 8°.

15. Posmatranje snežnog pokrivača zemljinog. Uputstvo i propisi. Od Milana Nedeljkovića. – Beograd. Opservatorija. <Izdanje Kr. srp. Državne štamparije>. Štampano u Državnoj štamariji Kraljevine Srbije. 1902. <1903>. Str. [1] + *II* + 61 sa 10 crt. V. 8°.

16. Posmatranje temperature vazduha. Uputstva i propisi za stacije IV reda. Od Milana Nedeljkovića. – Beograd. Opservatorija. <Izdanje Kr. srp. drž. stamparije>. Štampano u Državnoj štamariji Kraljevine Srbije. 1902. <1903>. Str. [3] + 24 sa 7 crt. V. 8°.

17. Kišomerska Uputstva. Od Milana Nedeljkovića. – Beograd. Opservatorija. Izdanje Kr. Srp. drž. štamparije. Štampano u Državnoj štamariji Kraljevine Srbije. 1903. Str. *IX* + 128 sa 11 crt. i šemama +1 pril. sa tab. V. 8°.

18. Dnevnik posmatranja i mesečna tablica stacija II i III reda. Od Milana Nedeljkovića. – Beograd. Državna štamarija Kraljevine Srbije. 1903. Str. 48.

19. Izveštaj Opservatorije Velike škole i njenih meteoroloških stacija 1899 – 1903. Od Milana Nedeljkovića. – Beograd. [Izdanje Opservatorije]. Štampano u Državnoj štampariji Kraljevine Srbije. 1904. Str. *XVI* + 223. V. 8°.

Jedinstven dodatak: Dj.[ordje] M. Stanojević: Pismo uredništvu (219 – 223 str.).

20. Izveštaj Opservatorije Velike škole i meteoroloških stacija 1904. Od Milana Nedeljkovića. – Beograd. [Opservatorija]. Štampano u Državnoj Štampariji Kraljevine Srbije. 1905. Str. [3] + 46. V. 8°.

21. Izveštaj Opservatorije Velike škcle i meteoroloških stacija 1905. – 1906. Od Milana Nedeljkovića. – Beograd. [Izdanje Opservatorije] . Štampano u Novoj štampariji Davidović. 1907. Str. 45. + [1]. V. 8°.

22. Meteorologija i poljoprivreda. Od Milana Nedeljkovića. (Na po se odštampano iz Poljoprivrednog Glasnika). – Beograd. "Dositije Obradović". Štamparija Ace M.

Stanojevića. 1907. Str. 98 sa tabelom +[2]. V. 8°.

23. Opservatorija i poljoprivreda. I. Izveštaji Opservatorije 1905. – 1907. II. Meteorologija i poljoprivreda od prof. Milana Nedeljkovića. – Beograd. Štampano u Državnoj štampariji Kraljevine Srbije. 1907–1908. Str. [3]+45+[1]+40+[1]+98+[2]. V. 8°.

U ovu jednu knjigu združene su tri posebne izdate knjige.

24. Izveštaj Opservatorije i meteoroloških stacija 1907. Od Milana Nedeljkovića. – U Beogradu. [Izdanje Opservatorije]. Štampano u Državnoj štampariji Kraljevine Srbije. 1908. Str. 40 + [1]. V. 8°.

25. Izveštaj Opservatorije i meteoroloških stacija 1908. – 1909. Od Milana Nedeljkovića. – U Beogradu. [Izdanje Opservatorije] . Štampano u Državnoj štampariji Kraljevine Srbije. 1909. Str. [3] + 52. V. 8°.

26. Sprovodno pismo uz Izveštaj Opservatorije 1908. – 1909. Od Milana Nedeljkovića. – Beograd. Opservatorija. Nova štamparija "Davidović". 1909. Str. 14. 8°.

27. Exposé sur l'observatoire central de Belgrade par Milan Nedeljkovitch. – Belgrade. Observation. Imrimerie Royale. 1909. Str. 15. 4°.

28. Izveštaj Opservatorije i meteoroloških stacija 1910. Od Milana Nedeljkovića. – Beograd. [Izdanje Opservatorije]. Štamparija "Merkur". 1910. Str. 16 V. 8°.

29. Svet i Halejeva Kometa. Od Milana Nedeljkovića. – Beograd. (Izdanje autora). Štamparija Savića i Komp. 1910. Str. 31. V. 8°. (Podaci sa korica)

30. Izveštaj Opservatorije i meteoroloških stacija 1911. – 1912. Od Milana Nedeljkovića. – Beograd. [Izdanje Opservatorije]. Štamparija "Merkur". 1914. Str. 46 V. 8°.

31. O kalendaru. Milan Nedeljković. –Beograd. "Narodna samouprava" a.d. 1923. Str. 20. V. 8°.

Odštampano iz "Novog života".

32. Izveštaj Opservatorije za godine 1919. – 1920. – 1921. – 1922. i 1923. Od Milana Nedeljkovića. – [Beograd. Izdanje Opservatorije]. <Štampano u Beogradskoj Opservatoriji>. [1924]. Str. [59]. 4°.

Numerisani tabaci od 1 – 15.

33. <Prof. Milan Nedeljković>. Izveštaj Opservatorije za 1924. Moj izveštaj Opservatorije za 1919. – 1920. – 1921. – 1922. – 1923. dopunjujem ovim Izveštajem za 1924. – [Beograd. 1925]. Str. [24]. 8°.

Naslov iznad teksta.

34. Dodatak Izveštaja Opservatorije za 1924. od prof. Milana Nedeljkovića. – [Beograd. 1925]. Str. 21. V.8°.

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BELDATA – THE ASTRONOMICAL DATABASE OF ASTRONOMICAL OBSERVATORY: PRESENT STATUS AND FUTURE

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The astronomical database are very important for collection and distribution of astronomical data. A large number of astronomical databases exist in the world. Astronomical Database System has as a goal to provide the fast and easy data exchange between Internet users and database.

We have created the BELDATA – the astronomical database of Astronomical observatory in Belgrade that will include:

1) Stark broadening data set,
2) spectra of AGNs,
3) observation made at Belgrad's Astronomical Observatory,
4) abstracts of papers printed in Serbian Astronomical Journal and Publication of Astronomical Observatory.

Access to the BELDATA is possible through Internet with 24 hour online support on address `http://www.aob.bg.ac.yu/BELDATA`.

The BELDATA system is based on following components:

1. Database (four mentioned segments)
2. HTTPD (Hyper Text Transfer Protocol Daemon) or www server that has role to provide mutual HTML document communication between Internet and local server.
3. MI (Manager Interface) will transform HTML format document from HTTPD in appropriate form for DataBase Manager System.
4. DBMS (DataBase Manager System) is capable for manipulating with the database.

After data processing, DBMS will retrieve the data. The data will be taken by MI, transformed to HTML format document and proceeded by HTTPD over Internet to user.

Query form, which will be fulfilled by an Internet user, have two return option: data needed for laboratory plasma modeling and data needed for stellar plasma modeling. In future, BELDATA will be extended with spectra of active galactic nuclei and solar spectra. New Stark broadening parameter data will be added to the database when calculated. Whole system needs constant maintenance effort. Moreover, we have planned to expand capabilities of DBMS. Presently, it is one executable program which may take the needed data from the database but in the future it will be a complex system with numerous functions. These functions will include various database multiple search options fully configurable within one HTML form controlled by user.

PUBLIKACIJE ASTRONOMSKE OPSERVATORIJE U BEOGRADU
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SOME REGULARITIES OF STARK WIDTHS OF ALKALI - METAL AND SINGLY IONIZED EARTH ALKALI - METAL RESONANT SPECTRAL LINES

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SUMMARY: Stark widths of Li I, Na I, K I and Rb I resonant lines have been experimentally determined in an electromagnetic T - tube plasma, with T_e = 15-26000 K and N_e = 1.5-5×10^{17} cm $^{-3}$, and presented together with our semiclassical calculations for Be II, Mg II, Sr II and Ba II resonant lines, in order to show certain regularities within this two groups of homologous atoms. A weak linear dependence of the Stark widths on the nuclear charge number, and a constant ratio of the Stark widths of corresponding izoelectronic atomic species from this two groups of elements, have been found.

INTRODUCTION

Recently, with the increase of the data on the Stark broadening, started the work on systematization of experimental results. Stark width and shift dependence on plasma parameters, especially on the plasma electron density, is known very well, but investigation of the effects of the emitter atomic structure similarities are still in the beginning. In this contribution, our recent experimental work on the alkali-atom resonant spectral lines is reported. Stark widths of resonant spectral lines of singly ionized earth alkali atoms were calculated and compared with Fleurier's et al. (1977) experimental results. An attempt has been made to systematize data for both groups of periodic system and to investigate their dependence on atomic number.

EXPERIMENT

The experimental method is described elsewhere (Konjević et al. 1970a, Purić et al. 1974) and here only few details will be given. As the plasma source, an electromagnetic T tube was used. During the experiment a continuous flow of argon was sustained at a pressure of 0.5 torr. Except sodium, which was released from the expansion tube during the initial stage of discharge, other alkali-metals have been introduced as impurities in order to avoid self - absorption. By changing the condensor bank energy, a wide range of electron temperature was obtained.

The electron temperature was measured by two different methods: from the Boltzman slope of seven Ar II spectral lines and from the relative intensity ratio of silicon spectral lines of two succesive ionization

stages (see e.g. Wilner 1966, Konjević et al. 1970b). Obtained temperatures were in the range 15000- 26000 K.

The electron density of $1.5 - 5\times10^{17}$ cm^{-3} $\pm$ 7% was determined using single - wavelength interferrometry (see e.g. Konjević et al. 1970b).

RESULTS

Experimentally obtained Stark half - half widths of Li I (Purić et al. 1977), Na I and K I (Purić et al. 1976) and Rb I, W_{exp}, together with theoretical values W_{th} obtained by Jones et al. 1971, are presented in Table 1. As can be seen, the agreement between experimental and theoretical data is within the experimental error of $\pm$ 15%.

THEORY

We calculated Stark widths of the resonant lines of singly ionized earth alkali atoms using the semiclassical procedure described by Jones et al. 1971. All energy levels needed for calculations were taken from the Moore's (1959) book. Oscillator strengths were taken from Wiese et al. 1966 except those for Sr II and Ba II, which were taken from Gallager's (1967) paper. All calculations were made on IBM 360/44 computer at the Institute of Mathematics, Belgrade, using the computer code developped by Jones and kindly supplied by professor Griem.

Obtained results were compared with Fleurier's et al. (1977) experimental data and with the semiclassical calculations by Jones et al. (1971) (which can be also found in Griem's (1974) book) when available.

REGULARITIES

Our experimental Stark half-half widths [●] for resonant lines of neutral alkali-metals are presented in Fig. 1 versus nuclear charge number, together with our theoretical [X] and Fleurier's et al. [▣] experimental data for resonant lines of earth-alkali atoms. Theoretical results by Jones et al. [●] are also presented, when available. As can be seen, a weak linear dependence of Stark widths on nuclear charge number exists within two examined homologous groups of atoms.
Besides, the ratio of experimental Stark widths of corresponding neutral and ionized emitter resonant lines is constant within ±21%, as can be seen from Fig. 2.

Table 1.

Stark half - half widths of spectral lines of alkali - atoms

Element	Mult.	λ(Å)	Temperature (K) 15000 W_{exp} (Å)	W_J (Å)	17500 W_{exp} (Å)	W_J (Å)	20800 W_{exp} (Å)	W_J (Å)	26000 W_{exp} (Å)	W_J (Å)
Li I	1	6707,70 6707,90	-	-	0.19	0.18	-	-	0.23	0.22
Na I	1	5899,95	0.180	0.184	0.210	0.198	0.211	0.215	0.230	0.231
		5895.92	0.185		0.190		0.200		0.216	
K I	1	7664,91	-	0.480	-	-	0.590	0.575	0.650	0.635
		7698,98	0.525		-		0.620		0.680	
Rb I	1	7800,23 7947,60	0.830 0.91	0.800*	0.850 0.960	-	0.88 1.00	0.91*	0.96 1.10	0.94*

* Calculated using Griem's semiempirical formula (Griem 1974, equation (459), p. 255).

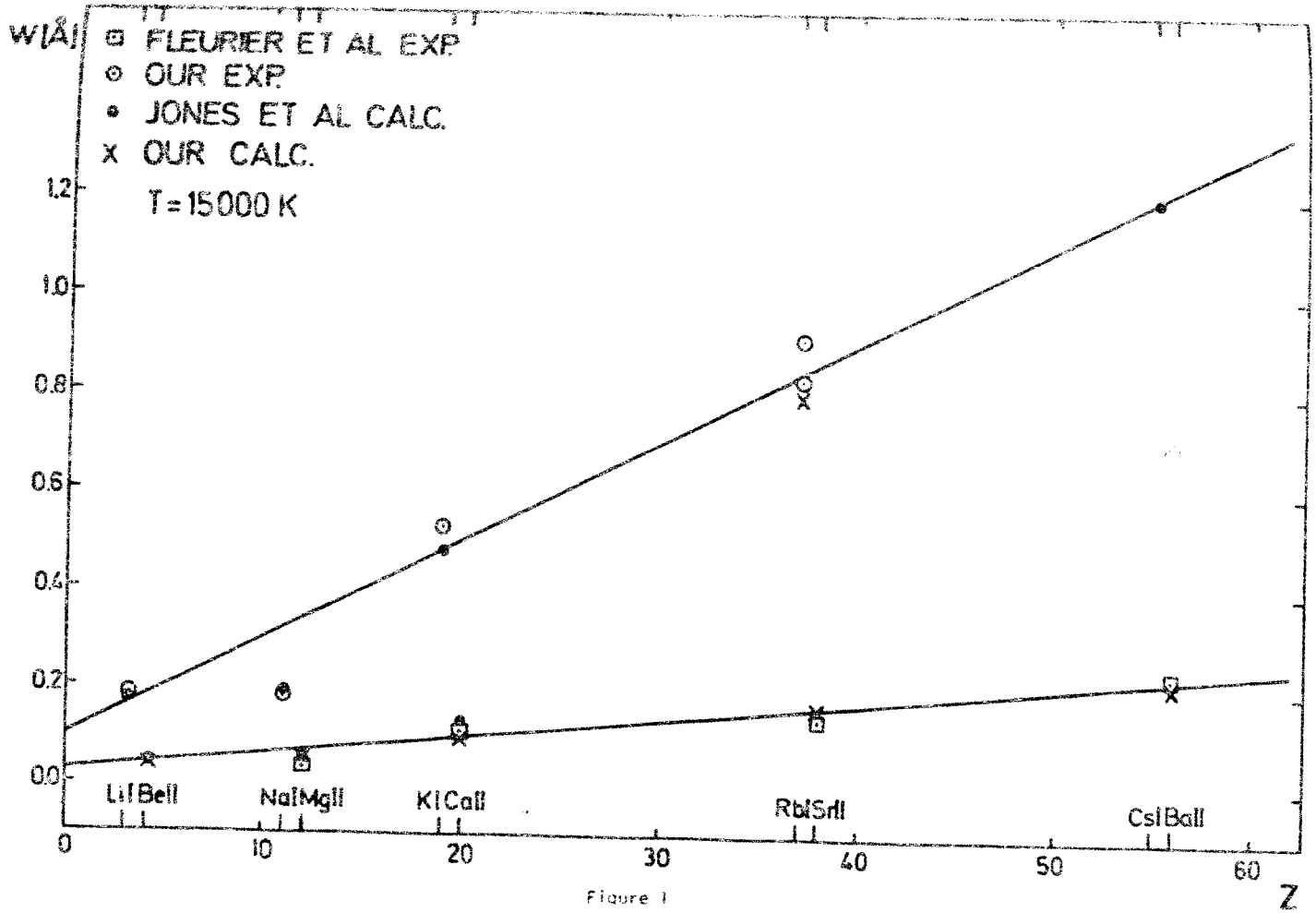

Figure 1

Experimental and theoretical Stark half - half widths of spectral lines of neutral alkali and singly ionized earth alkali - metals versus nuclear charge number

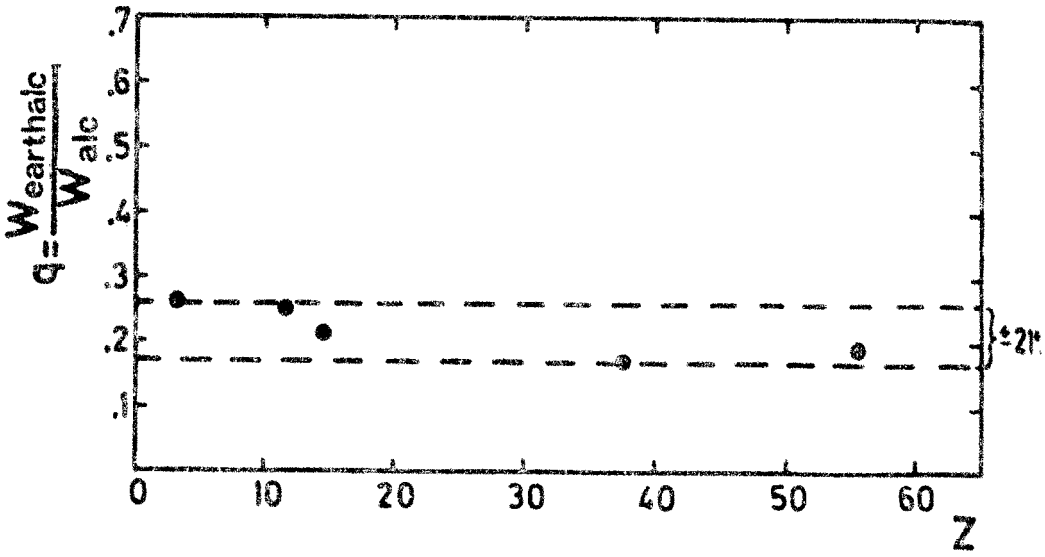

Figure 2

Ratio of experimental Stark widths for corresponding neutral and ionized emitter versus nuclear charge number.

CONCLUSION

Singly ionized earth alkali-metal atoms are izoelectronic with corresponding neutral alkali-metal atoms. Since they have the same optical electron configuration, they suffer similar Stark broadening effects. The only difference lies in charge of the core, which gives rise to the difference by almost factor of four in the Stark width of corresponding spectral resonant lines; for these two groups of homologous atoms the ratio is, however, constant.

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REFERENCES:

Fleurier C., Sahal - Brechot S., Chapelle J., 1977, JQSRT, 17, 595

Gallagher A., 1967, Phys. Rev., 157, 24

Griem H.R., 1974, Spectral Line Broadening by Plasmas, Academic Press, New York and London

Jones W.W., Benett S.M. and Griem H.R., 1971, Techn.Rep. No 71-128, Univ. of Maryland, College Park, Maryland

Konjević N., Labat J., Ćirković Lj. and Purić J., 1970a, Z.Phys., 235, 35

Konjević N., Ćirković Lj. and Labat J., 1970b, Fizika, 2, 121

Moore C.E., 1959, A Multiplet Table of Astrophysical interest, NBS - Technical Note 36, Washington

Moore C.E., 1972, Atomic Energy Levels, vol. I, NSRDS - NBS - 40, Washington

Purić J., Djeniže S., Labat J. and Ćirković Lj., 1974, Z.Phys. 267, 71

Purić J., Labat J., Djeniže S., Ćirković Lj. and Lakićević I., 1976, Phys. Lett., 56A, 83

Purić J., Labat J., Ćirković Lj. and Djeniže S., 1977., J.Phys. B, 10, 2375

Wiese W.L., Smith M.W. and Glennon B.M., 1966, Atomic Transition Probabilities, Vol. I, U.S. Govt. Printing Office, Washington D.C.

Wilner B., 1966, Acta Politechnica Scandinavica, Physics Including Nucleonics, Series No 41, Stokholm

NEKE REGULARNOSTI ŠTARKOVIH ŠIRINA REZONANTNIH SPEKTRALNIH LINIJA ALKALNIH I JEDNOM JONIZOVANIH ZEMNOALKALNIH ELEMENATA

Predstavljen je rad na odredjivanju Štarkovih širina rezonantnih linija alkalnih elemenata Li I, Na I, K I i Rb I. Eksperimenti su izvodjeni pomoću T-cevi u kojoj je stvarana plazma čija je $T_e \sim 15 - 26000$ K i $N_e \sim 1.5 - 5 \times 10^{17}$ cm^{-3}. Izvršena su i semiklasična izračunavanja Štarkovih poluširina rezonantnih linija Be II, Mg II, Sr II i Ba II i upoređena sa poznatim eksperimentalnim i teorijskim podacima, kao i sa prethodnim eksperimentima, da bi se ustanovile eventualne regularnosti unutar ove dve grupe homolognih atoma. Nadjena je slaba linearna zavisnost Štarkovih širina odgovarajućih izoelektronskih atoma iz ove dve grupe elemenata.

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MILUTIN MILANKOVIĆ I ASTRONOMIJA

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1. RAD MILUTINA MILANKOVIĆA U ASTRONOMIJI

Milutin Milanković (Dalj, 28.V.1879 - Beograd, 12.XII.1958) je u istoriju nauke ušao kao čovek koji je objasnio pojavu ledenih doba, sporim promenama u osunčavanju Zemlje usled različitih uticaja usled kojih se menja nagib Zemljine ose i karakteristike njenog kretanja oko Sunca. Milanković je rastumačio i istoriju klime na Zemlji i drugim planetama i tvorac je matematičke teorije klime i teorije o pomeranju Zemljinih polova. Unapredio je nebesku mehaniku u koju je uveo vektorski račun a dao je i nekoliko originalnih doprinosa rešavanju problema tri tela, što je detaljno analizirano u radovima Popovića (1979ab). Bavio se i pitanjem reforme kalendara, predloživši njegovo poboljšanje. Milanković od 1909. godine predaje astronomske sadržaje na Beogradskom Univerzitetu (vidi na primer Dimitrijević, 1997b). Napisao je udžbenike za fakultet *Nebeska mehanika* (Milanković, 1935), *Istorija astronomske nauke od njenih početaka do 1727.* (Milanković, 1948a) i *Astronomska teorija klimatskih promena i njena primena u geofizici* (Milanković, 1948b), pri čemu je zadnji namenjen postdiplomcima i doktorantima. Milanković je dao značajan doprinos i popularizaciji astronomije i njegova knjiga *Kroz vasionu i vekove* doživela je više izdanja (Milanković, 1926a, 1927, 1928ab, 1936, 1939a, 1943, 1944, 1952, 1979c, 1997c).

Milanković je dao veliki doprinos organizaciji astronomije u našoj zemlji. Godine 1925., on je u grupi profesora Filozofskog fakulteta u Beogradu predvodjenoj Miškovićem, koja je 30. aprila (Indjić, 1997) povela akciju za izgradnju nove Astronomske opservatorije u Beogradu. Od 1933. do 1940. godine, Milanković je član ispitne komisije za polaganje državnog ispita za osoblje Astronomske opservatorije u Beogradu za predmet - Nebeska mehanika. Od 1936. do 1939. godine on je predsednik prvog Nacionalnog komiteta za astronomiju, uz pomoć koga je Jugoslavija postala član Medjunarodne astronomske unije. Na godišnjoj skupštini Jugoslovenskog astronomskog društva (Danas Astronomsko društvo "Rudjer Bošković"), održanoj 21. januara 1940. izabran je za počasnog člana na predlog Stjepana Mohorovičića i Vojislava Grujića. Za počasnog člana Astronomskog društva "Rudjer Bošković, ponovo je izabran 22. februara 1953. Na Kongresu Medjunarodne astronomske unije 1948. u Cirihu, izabran je za člana Komisije 7 za Nebesku mehaniku, koja je tada obnovljena posle ukidanja 1932. godine. Kada je maja 1948. godine prihvaćena ostavka Vojislava Miškovića na položaj direktora, za direktora Opservatorije biva imenovan akademik

Milutin Milanković. On je honorarni direktor Opservatorije do 27. januara 1951. kada postaje direktor sa punim radnim vremenom i na ovom položaju ostaje do 26. juna 1951. Predsednik Naučnog saveta Opservatorije ostaje do marta 1954. godine. Rad Milutina Milankovića kao direktora Astronomske opservatorije, detaljno je analiziran u radu Popovića i Dimitrijevića (1999). Godine 1949., 26. oktobra izabran je za člana naučnog saveta Astronomsko - Numeričkog instituta Srpske akademije nauka.

2. KANON OSUNČAVANJA ZEMLJE

Astronomskim uzrocima klimatskih promena i matematičkom teorijom klime Milanković počinje da se bavi u Beogradu pa 1912. objavljuje *Prilog teoriji matematičke klime* (Milanković, 1912b), 1913. *O primeni matematičke teorije sprovodjenja toplote na probleme kosmičke fizike* (Milanković, 1913), a 1916. *Ispitivanja o klimi planete Mars* (Milanković, 1916). U *Théorie mathématique des phénomènes thérmiques produits par la radiation solaire* (Matematička teorija toplotnih pojava izazvanih Sunčevim zračenjem) (Milanković, 1920), Milanković razvija teoriju zasnovanu na principima Nebeske mehanike i Teorijske fizike, koja objašnjava raspodelu Sunčevog zračenja u medjuplanetarnom prostoru i na površinama planeta. On takodje pokazuje vezu izmedju osunčavanja i temperature planetarnih slojeva i pokazuje dnevnu, godišnju i vekovnu promenu osunčavanja.

Godine 1926. objavljuje naučni rad *Ispitivanje o termičkoj konstituciji planetskih atmosfera* (Milanković, 1926). U ovim radovima on je posebnu pažnju posvetio klimi planete Mars i utvrdio da je na ovoj planeti srednja godišnja temperatura minus 17 Celzijusovih stepeni. Njegova istraživanja klime Marsa kao i predvidjanja da na ovoj planeti nema visokorazvijenog života, potvrdila su moderna kosmička istraživanja. U vezi sa istraživanjem Marsa, naučni radovi Milankovića su korišćeni u naučnim istraživanjima i raspravama o tečnoj vodi na Marsu (Hoffert *et al.*, 1981), o kori i atmosferi Marsa (Miyamoto, 1966), o površinskoj temperaturi i klimi na Marsu (Gifford, 1956), kao i o astronomskoj teoriji o klimatskim promenama na Marsu (Toon *et al.*, 1980).

U Kanonu Milanković je objedinio rezultate svojih dugogodišnjih istraživanja u kojima je pokazao da su dugoperiodične ciklične promene klime na Zemlji i pojava ledenih doba, posledica sledeća tri uzroka:

(a) Promene nagiba Zemljine ose izmedju 22° i 24.5^o sa periodom od 41,000 godinu, usled čega se menjaju uslovi osunčavanja na nekoj izabranoj tački na Zemlji.

(b) Promena ekscentričnosti Zemljine putanje oko Sunca sa periodom od 100,000 godina usled čega se menja udaljenost Zemlje od Sunca što ima uticaj i na trajanje godišnjih doba.

(c) Precesija usled koje se tačka zimskog solsticija pomera duž prividne godišnje Sunčeve putanje, što utiče na dužinu trajanja godišnjih doba sa periodom od 22,000 godina.

Da bi razrešio problem pojave ledenih doba u kvartaru, Milanković 1932. godine dolazi do svoje čuvene diferencijalne jednačine kretanja Zemljinih polova. On nalazi da se pre oko 300 miliona godina Severni pol nalazio u Tihom okeanu na geografskoj širini od 20° i dužini od 168°. I danas Severni pol se kreće prema svom ravnotežnom

krajnjem položaju u Sibiru, blizu mesta gde reka Pečora utiče u Severni ledeni okean (Milanković, 1933a-d; 1934ab).

Najznačajnije delo Milutina Milankovića je *Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem* (Kanon osunčavanja Zemlje i njegovog uticaja na problem ledenih doba) (Milanković, 1941). To je njegovo kapitalno naučno delo, monografija koja uključuje rezultate istraživanja, koji su prethodno bili publikovani u 28 naučnih radova. U ovoj monografiji ti rezultati su sakupljeni u celinu, zajedno sa novim analizama i dodacima i sa brojnim primerima i primenama njegove teorije. U ovom kapitalnom delu Milanković daje matematičku teoriju klime Zemlje (koja se može primeniti i na druge planete), objašnjava poreklo ledenih doba i daje svoju teoriju pomeranja Zemljinih polova. Kanon je Milanković počeo da piše 30. marta 1939. a završio ga je u prvoj polovini februara 1941. (Indjić, 1997).

Dimitrijević (1997a) daje rezultat istraživanja prisustva Milankovićevog Kanona u Indeksu citata u periodu 1946. - 1996. U ovom periodu nadjeno je 253 referenci koje citiraju Kanon. Analizom raspodele citiranja Kanona po godinama, izveden je zaključak da je ovo jedinstveno delo, čija citiranost ne opada sa godinama nego raste ili ostaje konstantna. Tako se u periodu od 1945. do 1960. Kanon citira 5 puta. U periodu od 1961. do 1975. godine jedan do dva puta godišnje s tim što 1964. i 1971. nije zabeležen u Indeksu citata, 1961. se citira tri puta, a 1966. šest puta. Prvi skok u citiranosti je verovatno povezan sa završetkom Američkog CLIMAP (Climate Long Range Investigation, Mapping and Prediction) projekta 1976. godine (Hays, Imbrie i Shackleton, 1976). Povećanju citiranosti u to vreme svakako je doprinela i pojava engleskog izdanja Kanona (Milanković, 1969). Posle blagog porasta (1976. pet puta, 1977. tri puta), 1978. nastaje skok na osam citata i u periodu od 1978. do 1990. Kanon se citira od šest do 12 puta godišnje. Godine 1991., dolazi opet do skoka, Kanon je citiran 19 puta; 1992., 17 puta; 1993., 19 puta; 1994., 13 puta; 1995., 14 puta i 1996., 14 puta. Ovaj drugi skok u citiranosti verovatno je povezan sa radjanjem nove naučne discipline - ciklostratigrafije, koja je zasnovana na Milankovićevoj krivoj osunčavanja. Prvi medjunarodni kongres posvećen novoj naučnoj oblasti bio je u Perudji 1988. godine.

U Indeksu naučnih citata objavljenom u periodu 1946 - 1996, Dimitrijević (1997a) je pronašao 522 citata Milutina Milankovića. Oni se odnose na 17 članaka i knjiga a u tri slučaja citiranje je indirektno. Osim kanona za koji je nadjeno 253 citata, naučni radovi Milanković (1920), Milanković (1930ab) i Milanković (1938ab; 1939d) imaju 46, 135 i 37 citata. Ovi članci su blisko povezani sa matematičkom teorijom klime i njihovi rezultati su uključeni u Kanon, kao i rezultati drugih radova (Milanković, 1923; Milanković, 1931; Milanković, 1933d) citiranih (prema SCI) u neposrednoj vezi sa astronomskim problemima. Astronomski problemi u vezi sa kojima se koristi ova grupa radova su na primer: promene klime u kosmičkoj perspektivi (Opik, 1965, 1966; van den Heuve, 1966), masena spektrometrija u kosmohemiji (Delaeter, 1990), sekularne promene u zvezdanoj strukturi i ledena doba (Opik, 1950), Sunčevi neutrini i promene sjaja Sunca (Ulrich, 1975), fundamentalni astronomski sistem (Fleckenstein, 1953), stabilnost Sunčevog sistema (Kopal, 1980)...

Napominjem da se pojavom Indeksa citata (Science Citation Index - SCI), koji danas naročito u prirodnim naukama obuhvata najznačajniju literaturu koja izlazi

u svetu, razvio Metod indeksa citata za istraživanje naučnog stvaralaštva i njegovog značaja. U mnogobrojnim analizama, pokazano je (Hajtun, 1993), da je broj citata indikator *kvaliteta* naučnog rada, njegove *vrednosti, značaja, koristi* i *važnosti*. Metod Indeksa citata interesantan je i za istoričare nauke, da bi identifikovali najznačajnije autore, dela, kao i različite formalne i neformalne grupe. On je takodje indikator *individualnog doprinosa nauci* pojedinog naučnika i njegovog *prestiža*. Osim toga, podaci o citiranosti ukazuju na radove, koje smatraju važnim oni naučnici koji su upravo aktivni u datoj naučnoj oblasti (Garfield, Welljams-Dorof, 1992).

Broj od 253 citata u razmatranom periodu (1946 - 1996), identifikuje Kanon kao najcitiranije (u bazi podataka Indeksa citata) pojedinačno delo iz astronomije, kod Srba (Dimitrijević, 1996). Osim toga utvrdjeno da su su značajna dela starijih naučnika manje citirana od savremenih dela iste takve važnosti, s obzirom da se broj citata jednog dela u proseku smanjuje sa godinama a nauka se tako razvija da sa vremenom broj naučnika pa samim tim i verovatnoća citiranja raste. Ako uzmemo u obzir činjenicu da je Kanon napisan i objavljen pre drugog svetskog rata, možemo zaključiti i da je to najcitiranije u medjunarodnoj naučnoj javnosti pojedinačno delo (prema Indeksu citata), koje je do početka perioda obuhvaćenog Indeksom citata (1946.) objavljeno kod Srba i od strane Srba u nauci u celini. Godine 1997, Kanon je objavljen na srpskom jeziku (Milanković, 1997a).

3. NEBESKA MEHANIKA

Ministar prosvete i crkvenih poslova Ljub. Stojanović potpisuje 9 septembra 1909. godine ukaz o postavljenju Milutina Milankovića, koji je radio kao viši inženjer u preduzeću Betonbau - Unternehmung Pittel und Brausewetter u Beču, za vanrednog profesora primenjene matematike, koju su činile racionalna mehanika, nebeska mehanika i teorijska fizika. Tako Milanković dolazi u Srbiju u Beograd i započinje univerzitetsku karijeru. Predavanja drži u ciklusima od šest semestara pri čemu je nebeskoj mehanici pripadao nepun semestar. On se bavi i naučnim istraživanjem u oblasti nebeske mehanike a dobijene rezultate objavljuje u radovima *Osobine kretanja u jednom specijaliziranom problemu triju tela* (Milanković, 1910), *O opštim integralima problema n tela* (Milanković, 1911), *O kinematičkoj simetriji i njenoj primeni na kvalitativna rešenja problema dinamike* (Milanković, 1912a). Za redovnog profesora primenjene matematike izabran je 29 septembra 1919. godine a od školske 1920/21. godine predaje samo teorijsku fiziku i nebesku mehaniku, a racionalnu mehaniku prepušta Antonu Bilimoviću, bivšem profesoru Univerziteta u Odesi. Zahvaljujući uvodjenju vektorskih metoda, ova predavanja bila su modernija nego na nekim zapadnim univerzitetima. Posle okupacije naše zemlje, ostaje na Univerzitetu do poslednje sednice fakultetskog odbora 19. oktobra 1941., posle koje zajedno sa celokupnim osobljem Univerziteta biva stavljen na raspolaganje. Od 6 marta 1942. postavljen je za redovnog profesora Filosofskog fakulteta Univerziteta u Beogradu na katedri za teorijsku i primenjenu matematiku za predmete astronomija i nebeska mehanika. Posle drugog svetskog rata nastavlja da predaje nebesku mehaniku na Beogradskom fakultetu kao poseban predmet sa fondom časova 2 + 0. Osim toga, jedan semestar kursa nebeske mehanike koristio je za obradu istorije astronomije, tako da su studenti ove dve naučne discipline polagali kao jedan predmet (Andjelić, 1977).

Nebesku mehaniku, koja je predstavljala udžbenik za ovaj predmet (Milanković, 1935), je započeo prema pedantnim beleškama koje je vodio, 20 jula 1934. godine a završio je 14 januara 1935 (Indjić, 1993). Zahvaljujući tome što je medju prvima u svetu za izlaganje nebeske mehanike koristio metode vektorskog računa on je "u najmanju ruku tri puta sažeo , skratio, uprostio i učinio očiglednijom, za šta je dobio i inostrana priznanja" (Ševarlić, 1979; B. Š. (Ševarlić), 1980; Popović, 1979ab). Umesto šest brojčanih elemenata koji su do tada služili za odredjivanje eliptičkih putanja nebeskih tela u Sunčevom sistemu, on uvodi dva vektora "čime je znatno uprostio i učinio elegantnijim sva rešenja u ovoj oblasti" (Ševarlić, 1979).

Predratno izdanje Nebeske mehanike Milanković je sažeo i pod naslovom *Osnovi nebeske mehanike* objavio 1947. godine kao udžbenik za taj predmet (Milanković, 1947). U ovom skraćenom izdanju iznet je deo nebeske mehanike koji se bavi kretanjem planeta i njegovim sekularnim poremećajima. Osim toga, koristeći rezultate svoga rada *O upotrebi vektorskih elemenata u računu planetskih poremećaja* (Milanković, 1939bc) i Kanona (Milanković, 1941) dolazi do "glavnih stavova izložene teorije kraćim i preglednijim putem nego što je to drugde učinjeno" (Milanković, 1947, predgovor). Ovaj njegov rad našao je široku primenu u astronomiji i citiran je više puta (Musen, 1947, 1948, 1961, 1966; Fleckenstein, 1952; Allan i Ward, 1963; Deprit, 1975; Hestenes, 1983; Bartnik *et al.* 1988) u vezi sa problemom tri tela u slučaju planeta i zvezda, ispitivanjem planetarnih putanja i istraživanjem kretanja veštačkih satelita. Drugo izdanje objavljeno je 1955. godine (Milanković, 1955a), treće 1980. godine (Milanković, 1980), povodom stogodišnjice njegovog rodjenja, 1978. godine a četvrto 1988. (Milanković, 1988). Pored toga godine 1977. objavljeno je kompletno predratno izdanje (Milanković, 1997b).

4. ISTORIJA I POPULARIZACIJA ASTRONOMIJE

Interes za istoriju nauke pojavio se kod Milankovića još za vreme njegovog boravka u Beču. U svojim *Uspomenama, doživljajima i saznanjima* (Milanković, 1979b) on ističe "da se svaka nauka može samo onda u potpunosti shvatiti kada se upozna njen postanak i postepeni razvitak" i opisuje kako se u njemu "začela misao da je istorija nauka najveličanstveniji deo cele istorije čovečanstva" (Mužijević, 1979), kao i ljubav prema takvoj istoriji. Milanković je čitao, proučavao i sakupljao dela iz istorije nauke i tehnike i to sistematski sa strašću kolekcionara. Kao profesor univerziteta pobrinuo se da biblioteka seminara za matematiku a i biblioteka Astronomske opservatorije "pruži jasan pregled istorijskog razvitka tih nauka" (Milanković, 1979b). U svojoj knjizi Tehnika u toku davnih vekova (Milanković, 1955b) on sa žaljenjem konstatuje da "dok bi dela svetske istorije napunila veliku biblioteku, najvažnija dela istorije matematike, astronomije i fizike mogu se smestiti u ma kojoj ličnoj biblioteci". Za razliku od svetske istorije, prema Milankoviću u istoriji nauke umesto naslednih vladara, glavnu ulogu igraju oni koji su svoje mesto u istoriji osvojili snagom svoga duha i napominje da se "vredelo upoznati izbliže sa njima! Zato se moja lična biblioteka iz godine u godinu obogaćivala delima iz istorije egzaktnih nauka i njihovih primena" (Milanković, 1953 uvod).

Istorija astronomije objavljena je 1948. godine (Milanković, 1948a) njeno drugo izdanje 1954. (Milanković, 1954) a treće 1979., takodje povodom stogodišnjice rodjenja

1978. godine (Milanković, 1979a). Osim toga, ova knjiga je prevedena i na slovenački jezik i objavljena u Ljubljani 1951. godine. (Milanković, 1951), a objavlena je i 1997. godine (Milanković, 1997b).

Knjigu Istorija astronomske nauke od njenih početaka do 1727., koja je bila udžbenik za istoriju astronomije, počinje da piše krajem novembra 1946., rukopis je pripremljen za štampu 19 septembra 1947. godine a knjiga je štampana 1948. godine. U ovoj zanimljivoj i veoma lepo dokumentovanoj knjizi, obuhvatio je period od prvih početaka astronomske nauke pa do Njutnove smrti 1727. godine. Pri tome, on u ovome delu daje i svoj originalni naučni doprinos, "kao što je na primer raščišćavanje uloge Aristarha u razvoju heliocentrične misli ili dokaz da je Apolonije stvorio svoju znamenitu teoriju epicikala polazeći od heliocentrizma, a ne od geocentrizma, kao što se pre njega smatralo" (Ševarlić, 1979). U svome prikazu B. Ševarlić (1980a) kaže: "Knjiga po svojim kvalitetima, predstavlja malo remek-delo, pravi spomenik Milankovićevog nastavnog i naučnog rada koje studenti sa velikim interesovanjem proradjuju. No knjiga daleko prevazilazi udžbeničke okvire i predstavlja pravu poslasticu za sve ljubitelje astronomije." Njegova želja izražena u predgovoru "da jednim kasnijim delom, obuhvati u širem obimu celokupnu istoriju astronomije", ostala je na žalost neostvarena.

Svoje remek delo u oblasti popularizacije astronomske nauke, knjigu *Kroz vasionu i vekove* (Milanković, 1928b), Milanković je počeo da piše u leto 1925. godine u Austriji. U periodu od 1926. do 1928. godine objavljivao ga je u nastavcima u Letopisu Matice srpske (Milanković, 1926a, 1927, 1928a) a kao knjigu je objavio 1928. (Milanković, 1928b). Godine 1936. knjigu je preveo na nemački pri čemu je preradio i znatno proširio tekst (Milanković, 1936), a drugo nemačko izdanje izašlo je u Lajpcigu 1939. (Milanković, 1939a). Znatno prošireno srpsko izdanje izlazi 1943. (Milanković, 1943), a ova knjiga je ponovo izdavana još četiri puta (Milanković, 1944, 1952, 1979c, 1997c). Pojedina pisma iz knjige *Kroz vasionu i vekove* Milanković je objavljivao u Politici (19. XII 1928), Deutsche Algemeine Zeitung (2. XII 1936), Aachener Anzeiger u. Politisches Tageblatt (20. X 1936), Wolfenbütteler Zeitung (9. X 1936), Das Weltall (1936, Vol. 37, No 4), Berwardsblatt (1937, No 22), Kasseler Post (1. VI 1937), Mitteldeutsche National Zeitung (23. V 1937), Osteroder Zeitung (25. V 1937), Saarbrücker Landes Zeitung (21. V 1937) Sqwerter Zeitung (7. VI 1937), Sonntagsbeilage der Nordhäuser Zeitung (5. VI 1937), Der Westen (13. VI 1937), Altonaer Nachrichten (17. III 1937), kao i u časopisima Saturn (1938, Vol. IV, Nos. 1, 2 i 3), Proteus (Ljubljana, 1940, VII, Nos. 2/3, 4/5, 1941, VIII, No 9) i u almanahu naučne fantastike Andromeda (1978, No 3). Ova zanimljivo pisana knjiga u obliku pisama sa obiljem podataka o istoriji astronomije i problemima ove nauke, verovatno je naša najviše objavljivana knjiga iz oblasti popularizacije nauke.

5. KALENDAR

Jedan od najvažnijih zadataka astronomije u prošlosti bio je praćenje perioda izmene godišnjih doba, zbog njegove izuzetne važnosti za čovekovu delatnost. Ciklus izmene godišnjih doba definisan jednim obrtajem Zemlje oko Sunca (precizno rečeno period izmedju dva prolaska prividnog lika Sunca kroz prolećnu ili gama tačku za vreme

uzastopnih prolećnih ravnodnevica) naziva se tropska godina i iznosi 365,2422 dana. Kalendar je sistem po kome se tropska godina deli na dane, nedelje i mesece. Glavna teškoća je u tome što kalendar mora imati ceo broj dana, a tropska godina ih nema. Zato se nastoji da pravila za kalendar dovedu do toga da u dužem nizu godina kalendarska godina bude u proseku što bliža tropskoj.

Još stari Egipćani su zapazili da je godina od 365 dana, koja je primenjivana u Mesopotamiji suviše kratka. Svake četiri godine razlika poraste za gotovo jedan dan. Ova neusaglašenost ispravljena je Kanopskim ediktom 238. godine pre n.e. tako što je svaka četvrta godina odredjena kao prestupna pa ima jedan dan više t.j. 366 dana. Prema savetu astronoma Sozigena ovaj kalendar je u Rimu uveo Julije Cezar 46. godine pre n.e., pa se po njemu takav kalendar naziva Julijanski. Prestupne godine su definisane jednostavnim matematičkim pravilom, to su one koje su deljive sa 4. Po julijanskom kalendaru, godina u četvorogodišnjem proseku traje 365,25 dana t.j. nešto je duža od tropske, pa kasni za promenom godišnjih doba. Ona se od tropske razlikuje za 0.0078 dana. Razlika od 1 dan nakupi se za 128 godina. Zato se početak kalendarske godine morao s vremena na vreme podešavati, kao što je to uradjeno na koncilu u Nikeji 325. godine.

Papa Grgur XIII uveo je 1582. godine kalendar prilagodjeniji tropskoj godini na savet astronoma Lilioa. Ovaj kalendar dobio je ime gregorijanski. Lilio je predložio da se u roku od 400. godina tri prestupne godine pretvore u obične. Tako je postavio pravilo da nisu prestupne godine kojima se završavaju stoleća a koje imaju dve nule na kraju, osim ako su deljive sa 400. To znači da na primer u prvih 400 godina jednog milenijuma nisu prestupne godine koje se završavaju na 100, 200 i 300. Sada kalendarska godina traje 365,2425 dana pa je od tropske duža za 0.0003 dana. Ta će razlika narasti na jedan dan tek nakon 3000 godina.

Na saboru pravoslavne crkve u Carigradu, 1923. godine, dat je predlog koji je srpski astronom Milutin Milanković (Milanković, 1997d) razradio zajedno sa profesorom Trpkovićem, još tačniji nego šo je to gregorijanski kalendar. Umesto 3 dana u 4 stoleća, treba oduzeti 7 dana u 9 stoleća ili 0.0077 dana po godini. To znači da bi samo 2 od 9 godina kojima se završavaju stoleća bile prestupne. Pravilo je da su prestupne godine koje se završavaju sa dve nule samo ako broj vekova koji sadrže podeljen sa 9 daje ostatak 2 ili 6. Na primer 2000. godina kojom se završava XX vek je prestupna pošto je 20:9=18 i ostatak je 2. Milankovićev predlog se u srednjem razlikuje od prave tropske godine za 0.000002 dana. Dalja usavršavanja što se tiče približavanja trajanju tropske godine nisu potrebna, jer se i ona u dužim periodima menja. Eventualna dalja usavršavanja ako ih bude, pre će težiti pogodnijoj raspodeli dana unutar meseci zbog različitih prednosti koje bi iz toga mogle da proizadju.

Milutin Milanković je najznamenitiji srpski astronom. Treba takodje istaći da je za razliku od Nikole Tesle i Mihajla Pupina koji su do svojih otkrića došli u inostranstvu, Milanković svetsku slavu stekao radeći u Beogradu, u svojoj skromnoj sobi u Kapetan Mišinom zdanju. U čast njegovih naučnih dostignuća na polju astronomije, na XIV Kongresu Medjunarodne astronomske unije u Brajtonu, jedan krater na nevidljivoj strani Meseca (sa koordinatama $+170^o$ $+77^o$) dobio je njegovo ime. Na XV Kongresu Medjunarodne astronomske unije u Sidneju, njegovo ime je dobio i jedan krater na Marsu (sa koordinatama $+147^o$, $+55^o$), a 1982. je mala planeta sa privremenom oz-

nakom 1936 GA, koju su 1936. otkrili Milorad Protić i Pero Djurković, dobila ime 1605 Milanković.

Literatura

Allan, R.R., Ward, G.N.: 1963, Planetary equations in terms of vectorial elements, *Proceedings of the Cambridge Philosophical Society*, **59**, 669.

Andjelić, Tatomir: 1977, Mehanika. u Trideset godina Prirodno - Matematičkog fakulteta u Beogradu, PMF, Beograd, 151.

Bartnik, E.A., Haberzettl, H., Sandhas, W.: 1988, Equations of Motion Using the Dynamical Evolution of the Runge-Lenz Vector, *Astrophysical Journal*, **334**, 517.

Delaeter, J. R.: 1990, Mass-Spectrometry in Cosmochemistry, *Mass Spectrometry Reviews*, **9**, 453.

Deprit, A.: 1975, Ideal elements for perturbed Keplerian motions, *Journal of Research of the National Bureau of Standards, section B, Mathematics and Mathematical Physics*, **79**, 1.

Dimitrijević, M. S.: 1996, Serbian astronomers in Science Citation Index in 1961 - 1995, period, *Publ. Obs. Astron. Belgrade*, **54**, 217.

Dimitrijević, M. S.: 1997a, Milutin Milanković in Science citation index 1946 - 1996, *Bull. Astron. Belgrade*, **156**, 205.

Dimitrijević, M. S.: 1997b, Predgovor, U: Milanković, Milutin, Nebeska mehanika / Istorija astronomske nauke, urednik: M. S. Dimitrijević, Izabrana dela Milutina Milankovića 3, Zavod za udžbenike i nastavna sredstva, Beograd.

Fleckenstein, J.O.: 1952, Les theoremes de Laplace sur les perturbations seculaires dans les elements vectoriels des orbites planetaires, *Experientia*, **8**, 136.

Fleckenstein, J.O.: 1953, Erdkreisel der Geophysik und Fundamentalsystem der Astronomie, *Experientia*, **9**, 437.

Garfield, E., Welljams-Dorof, A.: 1992, Science and Public Policy, **19** (5), 321.

Gifford, F.: 1956, The Surface - temperature climate of Mars, *Astrophysical Journal*, **123**, 154.

Hajtun, S.D.: 1983, Naukometriya, sostoyanie i perspektivy, Nauka, Moskva.

Hays, J. D., Imbrie, J., Shackleton, N. J.: 1976, Variations in Earths orbit peacemaker of ice ages, *Science*, **194**, 1121.

Hestenes, D.: 1983, Celestial Mechanics with Geometric Algebra, *Celestial Mechanics*, **30**, 151.

van den Heuvel, E. P. J.: 1966, On climatic change in cosmic perspective, *Icarus*, **5**, 214.

Hoffert, M.I., Callegari, A.J., Hsieh, C.T., Ziegler, W.: 1981, Liquid Water on Mars - An Energy-Balance Climate Model for $CO_2 - H_2O$ Atmospheres, *Icarus*, **47**, 112.

Indjić, Milica: 1993, Bibliografija Milutina Milankovića, SANU, Bibliografije, Knj. II, Odeljenje jezika i književnosti, knj. 2, urednik Miroslav Pantić, Beograd, 1993.

Indjić, M.: 1997, Life, scientific and professional activity of Milutin Milanković, *Bulletin Astronomique de Belgrade*, **155**, 169.

Kopal, Z.: 1980, Stability of the Solar-System, *Moon and the Planets*, **22**, 5.

Milanković, Milutin: 1910, Osobine kretanja u jednom specijaliziranom problemu triju tela, *Glas SKA*, **LXXIX**, 218.

Milanković, Milutin: 1911, O opštim integralima problema n tela, *Glas SKA*, **LXXXIII**, 156.

Milanković, Milutin: 1912a, O kinematičkoj simetriji i njenoj primeni na kvalitativna rešenja problema dinamike, *Glas SKA*, **LXXXV**, 109.

Milanković, Milutin: 1912b, Prilog teoriji matematičke klime, *Glas SKA*, **LXXXVII**, 136.

Milanković, Milutin: 1913, O primeni matematičke teorije sprovodjenja toplote na probleme kosmičke fizike, *Rad JAZU*, **200**, 109.

Milanković, Milutin: 1916, Ispitivanja o klimi planete Mars, *Rad JAZU*, **213**, 64.

Milanković, Milutin: 1920, Théorie mathématique des phénomenes thérmiques produits par la radiation solaire, Paris, Zagreb, Gauthier-Villars et Cie, Ed. Académie Yougoslave des Sciences et des Arts.

Milanković, Milutin: 1923, Kaloričnа godišnja doba i njihova primena u paleoklimatskom problemu, *Glas SKA*, **CIX**.

Milanković, Milutin: 1926a, Kroz vasionu i vekove. Pisma jednog astronoma, I-VII, *Letopis Matice srpske*, **307**, 16-19, 221-224; **308**, 52-55; **309**, 61-65, 314-316; **310**, 119-122, 309-312.

Milanković, Milutin: 1926b, Ispitivanja o termičkoj konstituciji planetskih atmosfera, *Glas SKA*, **CXX**, 19.

Milanković, Milutin: 1927, Kroz vasionu i vekove. Pisma jednog astronoma, VIII-XV, *Letopis Matice srpske*, **311**, 69-79, 341-348; **312**, 73-80, 263-269; **313**, 180-185; **314**, 36-50, 193-210, 355-364.

Milanković, Milutin: 1928a, Kroz vasionu i vekove. Pisma jednog astronoma, XVI-XXIV, *Letopis Matice srpske*, **315**, 55-64, 203-211, 364-369; **316**, 79-82, 221-225, 382-386; **317**, 64-69, 180-186; **318**, 73-82.

Milanković, Milutin: 1928b, Kroz vasionu i vekove. Pisma jednog astronoma, I-XXXVI, Matica Srpska, Novi Sad.

Milanković, Milutin: 1930a, Mathematische Klimalehre und Astronomische Theorie der Klimaschwankungen, Handbuch der Klimatologie, Bd I, T.A. Hrsg. von W.Köppen und R. Geiger, Berlin, Gebrüder Borntraeger.

Milanković, Milutin: 1930b, Mathematische Klimalehre und Astronomische Theorie derKlimaschwankungen, Berlin, Gebrüder Borntraeger.

Milanković, Milutin: 1931, Astronomska teorija sekularnih varijacija klime, *Glas SKA*, **CXLIII**, 27.

Milanković, Milutin: 1933a, Drehbewegungen der Erde, Handbuch der Geophysik, Bd 1, Lieferung 2, Abschnitt VI. Hrsg von Beno Gutenberg, Berlin, Gebrüder Borntraeger, 371.

Milanković, Milutin: 1933b, Säkulare Pollverlagerungen, Handbuch der Geophysik, Bd 1,Lieferung 2, Abschnitt VII. Hrsg von Beno Gutenberg, Berlin, Gebrüder Borntraeger, 438.

Milanković, Milutin: 1933c, Numeričko izračunavanje sekularne putanje Zemljinih polova, *Glas Srpske Kraljevske Akademije*, **CLIV**, Prvi razred, **77**, 3.

Milanković, Milutin: 1933d, Das Problem der Verlagerungen der Drehpole der Erde in den exakten und in den beschreibenden Naturwissenschaften. Erinnerungen an Alfred Wegener, *Publications mathématiques de l'Université de Belgrade*, **II**, 166.

Milanković, Milutin: 1934a, Der Mechanismus der Polverlagerungen und die daraus sichergebenden Polbahnkurven, *Gerlands Beiträge zur Geophysik*, **42**, 70.

Milanković, Milutin: 1934b, Zur Berechnung der Polfluchtkraft. Antwort auf die Bemerkungen von Herrn Grabowski, *Gerlands Beiträge zur Geophysik*, **43**, 325.

Milanković, Milutin: 1935, Nebeska mehanika, Zadužbina Luke Ćelovića - Trebinjca, Beograd.

Milanković, Milutin: 1936, Durch ferne Welten und Zeiten. Briefe eines Weltallbummlers, Koehler und Amelang, Leipzig.

Milanković, Milutin: 1938a, Astronomische Mittel zur Erforschung der Erdgeschichtlichen Klimate, Handbuch der Geophysik, Bd IX, Lieferung 3, Abschnitt VII. Hrsg von Beno Gutenberg, Berlin, Gebrüder Borntraeger, 593.

Milanković, Milutin: 1938b, Neue Ergebnisse der Astronomischen Theorie der Klimaschwankungen, *Bulletin de l'Academie Royal Serbe*, 1938, Academie des Sciences Mathématiques et Naturelles A, Sciences Mathématiques et Physiques, 4, 1-41 + 14 Tab.

Milanković, Milutin: 1939a, Durch ferne Welten und Zeiten. Briefe eines Weltallbummlers, 2 Aufl., Koehler und Amelang, Leipzig.

Milanković, Milutin: 1939b, Ueber die Verwendung vektorieller Bahnelemente in der Störungsrechnung, *Bulletin de l'Academie Royal Serbe*, 1939, Academiedes Sciences Mathématiques et Naturelles A, Sciences Mathématiques et Physiques, 6, 1-70.

Milanković, Milutin: 1939c, O upotrebi vektorskih elemenata u računu planetskih poremećaja, *Glas Srpske kraljevske akademije*, **CLXXXI**, 1.

Milanković, Milutin: 1939d, Matematicheskaya klimatologiya i astronomicheskaya teoriya kolebaniya klimata. Perevod s nemeckogo A. Kh. Khrgian. Pod redakciej prof. S. L. Bastamova. S dobavleniem A. Kh. Khrgiana "Klimaty geologicheskikh epokh i peremeshcheniye materikov". Moskva, Leningrad. Gosudarstvennoe ob'edinennoe nauchno-tekhnicheskoe izdatel'stvo.

Milanković, Milutin: 1941, Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem, Posebna izdanja Srpske kraljevske akademije, **CXXIII**, Beograd.

Milanković, Milutin: 1943, Kroz vasionu i vekove. Jedna astronomija za svakog, Jugoistok, Beograd.

Milanković, Milutin: 1944, Kroz vasionu i vekove. Jedna astronomija za svakog, 2 izdanje, Jugoistok, Beograd.

Milanković, Milutin: 1947, Osnovi Nebeske mehanike, štamparija Rožanovski, Zagreb, Prosveta, Beograd.

Milanković, Milutin: 1948a, Istorija astronomske nauke od njenih početaka do 1727, Naučna knjiga, Beograd.

Milanković, Milutin: 1948b, Astronomska teorija klimatskih promena i njena primena u geofizici, Beograd, Naučna knjiga.

Milanković, Milutin: 1951, Zgodovina astronomije od njenih prvih začetkov do leta 1727, Prev. Črtomir Zupančič, Poljudno znanstvena knjižnica 27, Slovenski knjižni zavod, Ljubljana.

Milanković, Milutin: 1952, Kroz vasionu i vekove, Tehnička knjiga, Beograd.

Milanković, Milutin: 1953, Dvadeset i dva veka hemije, Svetlost (Biblioteka Svetlost, kolo I, 1), Kragujevac.

Milanković, Milutin: 1954, Istorija astronomske nauke od njenih početaka do 1727 (2. izdanje), Naučna knjiga, Beograd.

Milanković, Milutin: 1955a, Osnovi Nebeske mehanike, 2. izdanje, Naučna knjiga, Beograd.

Milanković, Milutin: 1955b, Tehnika u toku davnih vekova, Nolit, Beograd.

Milanković, Milutin: 1969, Canon of Insolation and the Ice - age Problem. Transl. from German. - (Belgrad, Königlich Serbische Akademie, 1941; Special Publications **132**). Jerusalem, Israel Program for Scientific Translations.

Milanković, Milutin: 1979a, Istorija astronomske nauke od njenih početaka do 1727 (Reprint drugog izdanja iz 1954.), Naučna knjiga, Beograd.

Milanković, Milutin: 1979b, Uspomene, doživljaji i saznanja, SANU, Beograd.

Milanković, Milutin: 1979c, Kroz vasionu i vekove, Nolit, Beograd.

Milanković, Milutin: 1980, Osnovi Nebeske mehanike, 3. izdanje, Naučna knjiga, Beograd.

Milanković, Milutin: 1988, Osnovi Nebeske mehanike, 4 izdanje, Naučna knjiga, Beograd.

Milanković, Milutin: 1997a, Kanon osunčavanja Zemlje i njegova primena na problem ledenih doba, urednici: V. Vujičić, M. S. Dimitrijević, Izabrana dela Milutina Milankovića 1-2, Zavod za udžbenike i nastavna sredstva, Beograd.

Milanković, Milutin: 1997b, Nebeska mehanika / Istorija astronomske nauke, urednik: M. S. Dimitrijević, Izabrana dela Milutina Milankovića 3, Zavod za udžbenike i nastavna sredstva, Beograd.

Milanković, Milutin: 1997c, Kroz vasionu i vekove / Kroz carstvo nauka, urednici: N. Pantić, A. Petrović, Izabrana dela Milutina Milankovića 4, Zavod za udžbenike i nastavna sredstva, Beograd.

Milanković, Milutin: 1997d, Reforma Julijanskog kalendara, U: Spisi iz istorije nauke, urednici: N. Pantić, A. Petrović, Izabrana dela Milutina Milankovića 5, Zavod za udžbenike i nastavna sredstva, Beograd, 31.

Miyamoto, S.: 1966, Martian atmosphere and crust, *Icarus*, **5**, 360.

Musen, P.: 1947, Uber die Vektoriel-Skalaren Gleichungen der Astronomisches Storungs Theorie, *Zeitschrift für Naturforschung A*, **2**, 365.

Musen, P.: 1948, Zur Reduktion des Dreikorperproblems, *Zeitschrift für Naturforschung A*, **3**, 360.

Musen, P.: 1961, On long-period lunar and solar effects on motion of an artificial satellite 2., *Journal of Geophysical Research*, **66**, 2797.

Musen, P.: 1966, Application of Krylov - Bogolubov method to solution of stellar 3 body problem, *Journal of Astronautical Sciences*, **13**, 177.

Mužijević, Milica: 1979, Milanković kao istoričar i popularizator nauke, Vasiona XXVII, No 4, 126.

Opik, E.J.: 1950, Secular changes of the stellar structure and the ice ages, *Monthly Notices of the Royal Astronomical Society*, **110**, 49.

Opik, E. J.: 1965, Climatic change in cosmic perspective, *Icarus*, **4**, 289.

Opik, E. J.: 1966, More on climatic change, *Icarus*, **5**, 215.

Popović, Božidar: 1979a, Milankovićevi radovi u nebeskoj mehanici, u Život i delo Milutina Milankovića 1879 - 1979, Galerija SANU 36, 133.

Popović, Božidar: 1979b, Nebeska mehanika i njena primena u delima M. Milankovića, *Vasiona*, **XXVII**, 111.

Popović, Luka Č., Dimitrijević, Milan S., Milovanović, Nenad: 1999, *Simpozijum "Milanković – juče, danas, sutra"*, Beograd, 25. i 26. novembar 1999., Rudarsko-geološki fakultet, Beograd, 43-51.

Ševarlić, Branislav: 1979, Milankovićeva astronomska otkrića, *Vasiona* **XXVII**, No 4, 101.

B. Š (Branislav Ševarlić), 1980a, Milutin Milanković, "Istorija astronomske nauke od njenih prvih početaka do 1727", Naučna knjiga, Beograd 1979. g., *Vasiona*, **XXVIII**, No. 4, 85.

Toon, O.B., Bilski, K., Burns, J.A., Pollack, J.B., Ward, W.: 1980, The Astronomical Theory of Climatic-Change on Mars, *Icarus*, **44**, 552.

Ulrich, R.K.: 1975, Solar neutrinos and variations in solar luminosity, *Science*, **190**, 619.

Wen, L.S.: 1962, A unified treatment of variation of parameters and differential expressions methods in trajectory prediction and error analysis, *Journal of Aerospace Science*, **29**, 61.

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USE OF THE VAN DER WAALS BROADENING OF ATOMIC ARGON LINES TO MEASURE THE GAS TEMPERATURE IN AN ATMOSPHERIC PRESSURE Ar-He SURFACE WAVE DISCHARGE

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Abstract. The use of the van der Waals broadening to measure the gas temperature in an atmospheric pressure Ar-He surface-wave discharge is studied comparing the obtained results with those given by the OH radical and extended to He proportions up to 50%. Influence of the electron density through Stark broadening of the calculation of this parameter is found to be negligible. A good agreement is found between both techniques. Spectral line 603.2 nm is found to be the best choice for this purpose. An increase in the temperature from 1200 K to 2000 K is found when He is added to the discharge.

1. INTRODUCTION

A common characteristic of most of the technological applications of plasmas is that they are carried out with gas mixtures. When more than one kind of gas is present in the discharge, the complexity of experimental determination of plasma parameters by spectroscopic techniques increases as a consequence of the existence of different types of species in the discharge. Studying such influences is important for the application of diagnosis techniques in plasmas generated with gas mixtures. Usually, the gas temperature (T_g) is measured from the analysis of the rotational spectra of molecular species existing in the discharge, such as the OH species, N_2^+, CN or C_2. But sometimes, as is the case of the Ar-He microwave plasma studied herein, these species can not be properly detected. In such cases, T_g can be determined from the Doppler or the van der Waals broadenings of emitted atomic spectral lines, which are related to this parameter.

While theoretically any spectral line could be used for the determination of T_g from its van der Waals broadening (w_W), studies carried out by several authors (see J. Muñoz et al. (to be published) and references therein) have stated that only a few lines can be used for this purpose. On the other hand, the theory does not describe equally well the van der Waals broadening for each spectral line and for each kind of perturbers, and so investigations devoted to find out most convenient lines for this purpose are of interest.

A method to measure the gas temperature T_g from atomic lines whose Stark broadening is comparable with the van der Waals one was proposed by Yubero et al. (2007). Gas temperature was obtained from the origin ordinate corresponding to the Lorentzian width for zero electron density which could be considered approximately equal to van der Waals line width. The best argon atomic lines for the gas temperature T_g calculation in an argon microwave plasma at atmospheric pressure were found to be 603.2 nm, 549.6 nm and 522.1 nm. On the other hand, in the study of Christova et al. (2004) the Stark broadening of the 425.9 nm line was examined. By extrapolating the results of this work to their experimental conditions, Yubero et al. obtained that the van der Waals width value of the above mentioned line as about 90% of the total Lorentzian width and the gas temperature from the van der Waals broadening of this line was equal to 1380 K. Consequently, the use of $425.9, 603.2, 549.6$ and 522.1 nm lines to measure T_g in an Ar-He SWD has been considered in the present study.

In this work, the use of the van der Waals broadening of the atomic lines to determine the gas temperature in Ar-He plasmas, taking into account both argon and helium atoms as perturbers has been analyzed in an atmospheric pressure surface wave discharge with a setup similar to that described in the work of J. Muñoz et al. (2008). The values of the gas temperature inferred from this broadening have been compared with the ones obtained from the spectra emitted by the OH molecular species in the discharges.

2. GAS TEMPERATURE DETERMINATION

The Lorentzian width can be considered as the sum of the Stark and the van der Waals broadenings under our experimental conditions. The Stark broadening of these lines was estimated using the expression given by Griem (1964) for the electron density, calculated for different Ar-He mixtures from the H_β line using the data from Gigosos et al.(1996).

Table 1: Van der Waals and Lorentzian broadenings of the 603.2 atomic argon line for the different He concentration in the discharge

[He](%)	w_S (x 10^{-2} nm)	w_L (x 10^{-2} nm)
0	0.154	2.915
5	0.134	2.632
10	0.110	2.363
15	0.108	2.091
20	0.099	1.999
25	0.096	1.964
30	0.094	1.949

In Table 1, the values of the 603.2 nm Lorentzian width and the Stark broadening for the studied Ar-He mixtures are shown. One observes that w_S is one order lower than w_L. So, the assumption that w_L is mainly due to the van der Waals effect does not induce a significant error in the calculation of T_g. A similar result was obtained for

the 425.9 nm line. Following from Yubero et al. (2007), the van der Waals broadening of these two lines in the case of an Ar-He mixed gas discharge as can be written as:

$$w_W(425.9\,\mathrm{nm}) = \chi_{Ar}\frac{1.479}{T_g^{0.7}} + \chi_{He}\frac{1.059}{T_g^{0.7}} \tag{1}$$

$$w_W(603.2\,\mathrm{nm}) = \chi_{Ar}\frac{4.217}{T_g^{0.7}} + \chi_{He}\frac{3.019}{T_g^{0.7}} \tag{2}$$

Values of T_g obtained using the expressions above can be seen in Figure 1. There, T_g values have been compared with those ones obtained considering $\chi_{He} = 0$ and with the ones obtained from the OH molecular specie.

From these figures, it can be seen that the T_g values obtained from OH radical only experience a little variation when He is added in a 5% in the mixture and, from this percentage on, the temperature keeps almost constant at 1500 K. This can be due to a lack of sensitivity of the OH radical for temperatures above $1600 - 1800$ K.

A larger dispersion in T_g values obtained from the 425.9 nm line can be observed compared to those obtained from the 603.2 nm line. This is a consequence of its smaller Lorentzian width, which results in a higher error in the deconvolution process. Consequently, the 603.2 nm line should be considered more appropriate for the purpose of obtaining the gas temperature from its van der Waals broadening.

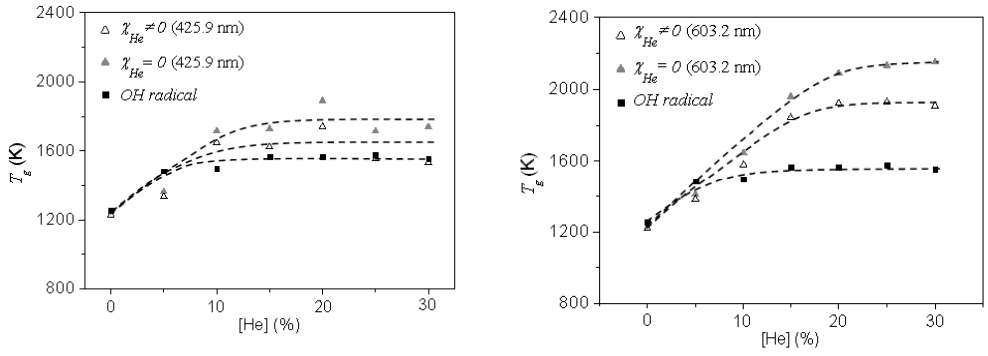

Figure 1: Gas temperature calculated using the $(0-0)$ 309 nm rovibrational band of the OH radical and 425.9 nm (left) and 603.2 nm (right) atomic argon lines taking into account (hollow triangle) and neglecting (full triangle) the contribution of He to the van der Waals broadening.

It is important to remark that, even while the larger difference in T_g temperatures obtained taking into account the influence of Helium in the van der Waals broadening in equations (1) and (2) is only about 300 K, the new term added to the equations in the case of gas mixtures shall not be rejected, specially for higher He proportions.

The measurement of T_g in a discharge generated with Ar-He mixtures for He percentages over 30% was carried out using the van der Waals broadening of the 603.2 nm atomic line, following the procedure proposed previously.

In order to verify the non-influence of the coolant used, the gas temperature were also calculated for the interval between 0% and 30% of He in the mixture. In Figure

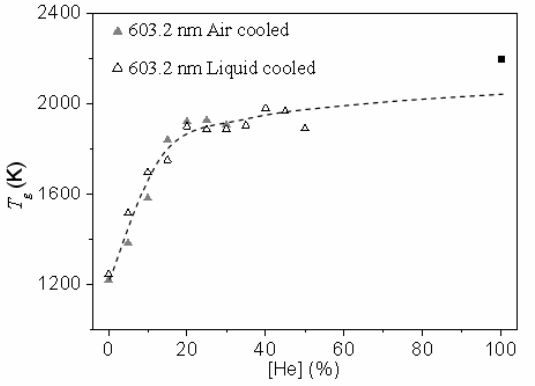

Figure 2: Gas temperature calculated using the van der Waals broadening of the 603.2 nm argon atomic line.

2, the T_g values obtained in this way are shown. It can be seen that the same values for this parameter are obtained in both cases, using air or dielectric liquid as coolant of the discharge tube. An extrapolation to 100% of He is shown too, the T_g value for a pure He discharge obtained in this way being approximately equal to 2200 K, which is in a good agreement with that obtained in Kabouzi et al. (2002).

Acknowledgements

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References

Christova, M., Castaños–Martínez, E., Calzada, M. D., Kabouzi, Y., Luque, J. M. and Moisan, M.: 2004, *Appl. Spectrosc.*, **58**, 1032.

Gigosos, M. A., Cardeñoso, V.: 1996 *J. Phys. B: At. Mol. Opt. Phys.*, **29**, 4795.

Griem, H. R.: 1974, Spectral Line Broadening by Plasmas, Academic Press (London).

Kabouzi, Y., Calzada, M. D., Moisan, M., Tran, K. C. and Trassy, C.: 2002, *J. Appl. Phys.*, **91**, 1008.

Muñoz, J., Calzada, M. D. : 2008, *Journal of Physics D*, (accepted).

Muñoz, J., Dimitrijević, M. S., Yubero, C., Calzada, M. D.: to be published.

Yubero, C., Dimitrijević, M. S., García, M. C., Calzada, M. D.: 2007, *Spectrochim. Acta B*, **62**, 169.

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KINEMATICAL PARAMETERS IN THE CORONAL AND POST-CORONAL REGIONS OF THE Oe STARS

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Abstract. In this progress report we present the main results of our research. Using a new model we studied the kinematical parameters such as the random velocities of the ions, which create the spectral lines of the C IV, N IV and N V in the spectra of 20 O_e stars, as well as the rotational and radial velocities of the regions, where the above ions are created. We calculated the values of the above parameters and we present the relations between them as well as the variation of them as a function of the spectral subtype. We present the random velocities of the ions for each one of the C IV, N IV and N V regions as a function of the photospheric rotational velocities. Finally, we propose an explanation for the large widths that we observe in the studied spectral lines, as these widths can not be explained as large rotational or random velocities.

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A STUDY OF AX Mon (HD 45910) KINEMATICAL PARAMETERS OF THE Fe II DENSITY REGIONS

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Abstract. The UV spectrum of AX Mon (HD 45910) presents a series of complex structure spectral lines, that present SACs or DACs. In this paper, using the GR model, we study the complex profile of Fe II spectral lines and we calculate the relation of some physical parameters with the excitation potential.

1. INTRODUCTION

Fleming (1898) was the first that noted that AX Mon (HD 45910=BD+5°, 1267=SAO 13974, a=6^h 27^m 52^s, δ=+5°, 54′,1 (1950), V=6,59-6,88 mag) had bright hydrogen lines. Merrill (1923) and Plaskett (1923) noted a variability of the spectrum. The most pronounced changes discovered in photographic studies were the occasional appearance of a shell spectrum of ionized metals and variable hydrogen lines with one or more components.

Merrill (1952) discovered the binary nature of AX Mon. He derived an orbit for the late-type star with a period of 232 days. Cowley (1964) concluded that the system consists of a rapidly rotating B3nn star and a somewhat fainter K0 giant and that the rotational velocity of the early-type star is 345 km/s.

Danezis et al. (1991) studied a series of Fe II lines with classical method and indicated the existence of three satellite components with radial velocities of -75, -260 and +10 km/s. These values did not present any variation with the excitation potential.

In this paper we study a series of Fe II lines with GR model (Danezis et al. 2007), in order to verify the results found by Danezis et al. (1991), as well as the accuracy of GR model. Additionally, we present the radial, rotational and random velocities, the FWHM and the absorbed energy of a group of Fe II lines, as a function of their excitation potential between 0.08 and 4.75 eV.

Table 1: The λ_{lab} of the Fe II spectral lines and the respective excitation potential

λ_{lab} (Å)	Excitation Potential (eV)
1558.542	0.35
1646.187	1.07
1673.462	1.96
1679.388	2.02
1720.042	1.72
1731.038	2.27
1880.976	2.57
2237.577	4.75
2445.559	2.69
2607.086	0.08
2767.500	3.23
2858.340	3.75

2. OBSERVATIONAL DATA

In Table 1 we present the studied Fe II spectral lines, taken with IUE, and the respective excitation potential.

3. RESULTS AND DISCUSSION

In Figure 1, we give as an example the fit of the λ 2607.086 Å Fe II spectral line. We can see that the observed complex structure can be explained with SACs phenomenon.

In Figure 2 we present the variation of the radial velocities of the studied group of Fe II lines as a function of the excitation potential (left). As we can see the radial velocities stay nearly constant as a function of I.P. We detected three levels of radial velocities. The first level has values about -260 km/s (circle), the second one has values about -125 km/s (open square) and the third one has values about -18 km/s (triangle). We compare our results with the results found by Danezis et al. (1991) (right). As we can see the results are almost the same. This fact verifies the previous results, as well as the accuracy of GR model. Specifically, we verify the number of satellite components, their radial velocities, and the relation between the radial velocities of the Fe II lines with their excitation potential.

In Figure 3 we present the variation of the rotational and the random velocities of the studied group of Fe II lines as a function of the excitation potential. As the radial velocities, the random velocities stay also nearly constant as a function of I.P. The values of the rotational velocities (left) for all SACs are between 20 and 60 km/s. We detected three levels of the random velocities of the ions (right). The first level has values about 115 km/s (open circle), the second one about 70 km/s (square) and the third one about 35 km/s (triangle).

In Figure 4 we present the variation of the Full Width at Half Maximum (FWHM in Å) of the studied group of Fe II lines as a function of the excitation potential. We also detected three levels of values of the FWHM. The first level has values about 2 Å, the second one about 1.3 Å and the third one about 0.6 Å.

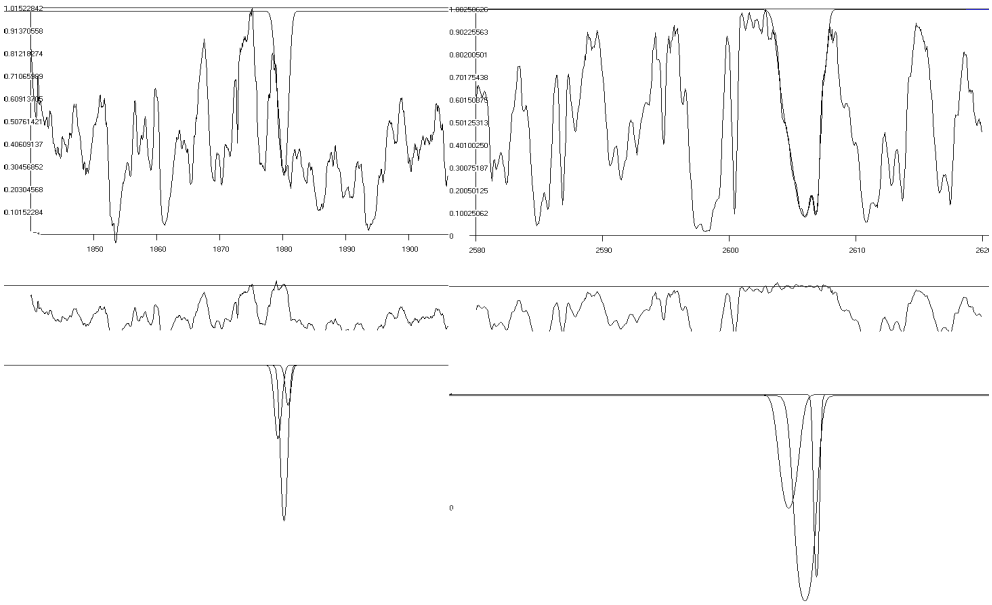

Figure 1: Best fit of the λ 1880.976 Å (left) and λ 2607.086 Å Fe II (right) spectral line. We can explain the complex structure of these lines as a DACs or SACs phenomenon. Below the fit one can see the analysis (GR model) of the observed profile to its SACs.

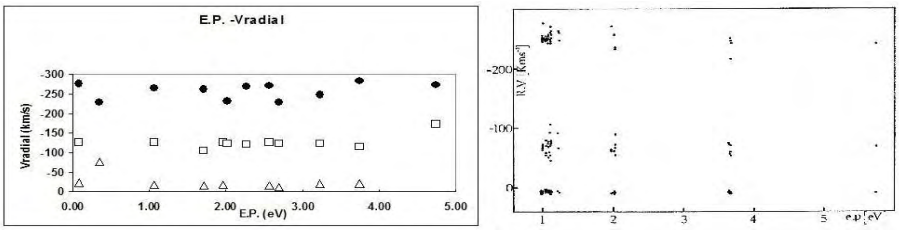

Figure 2: Radial velocities of the studied group of Fe II spectral line as a function of the excitation potential (E.P.) that result from this study (left), compared with the results deriving from the study of Danezis et al. (1991) (right).

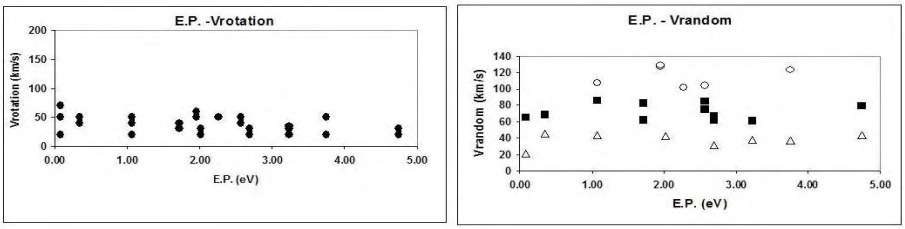

Figure 3: Rotational (left) and random (right) velocities of the studied group of Fe II spectral line as a function of the excitation potential (E.P.).

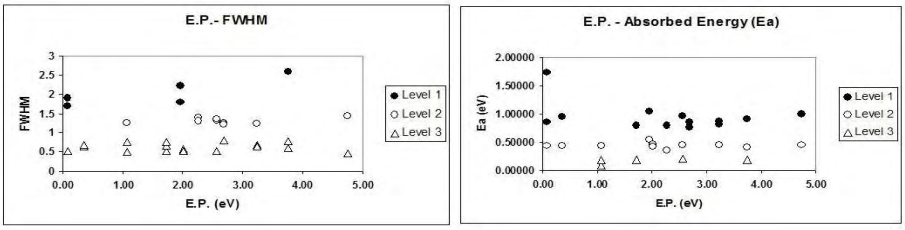

Figure 4: Full Width at Half Maximum (FWHM) and Absorbed Energy (Ea in eV) of the studied group of Fe II spectral line as a function of the excitation potential (E.P.).

Finally, in Figure 5 we present the variation of the absorbed energy (Ea in eV) of the studied group of Fe II lines as a function of the excitation potential. Also here we found three levels of absorbed energy. The first level has values about 1 eV, the second one about 0.4 eV and the third one about 0.14 eV.

Acknowledgments

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References

Cowley, A. P.: 1964, *Astrophys. J.*, **139**, 817.
Danezis, E., Theodossiou, E., Laskarides, P.: 1991, *Astrophys. Sp. Sc.*, **179**, 111.
Danezis, E., Nikolaidis, D., Lyratzi, E., Popović, L. Č., Dimitrijević, M. S., Antoniou, A., Theodossiou, E.: 2007, *PASJ*, **59**, 827.
Fleming, W. P.: 1898, *Harvard College Obs.*, No **32**.
Merrill, P. W.: 1923, *PASP*, **35**, 303.
Merrill, P. W.: 1952, *Astrophys. J.*, **115**, 145.
Plaskett, J. S.: 1923, *PASP*, **35**, 145.

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THE VERY BROAD LINES IN THE UV SPECTRA OF HOT EMISSION STARS - A POSSIBLE EXPLANATION

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Abstract. In some cases, the UV spectral lines of hot emission stars and quasars have very large widths that can not be explained as the consequence of rotational or random velocities. In this paper we present a new idea to explain this phenomenon.

1. INTRODUCTION

In the UV spectra of some hot emission stars and quasars (Andrillat & Fehrenbach 1982, Andrillat 1983, Marlborough 1969, Poeckert & Marlborough 1979, Doazan 1970, Antoniou et al. 2008) we can detect very broad absorption or emission lines that we can not explain as rotational or random velocities of the density layers that construct these lines.

In the case of emission lines, Marlborough (1969) and Poeckert & Marlborough (1979) tried to justify the large width of the Hα line wings, with their model, according to which the envelope is rotating and expanding. They showed that the photon scattering due to electrons is able to produce significant wing broadening, meaning that a large number of photons may be scattered from the center of the emission line towards the wings. Also, Doazan (1970) suggested that the rotation of the regions that create the Hα line is not able to explain the whole observed width and there should be an additional way of acceleration. This means that the observed width is due to the combination of these two movements. She concluded that since these movements affect the width of Hβ and Hγ, we should accept that such regions exist also in the surface of the star. This means that a similar phenomenon could happen in the C IV regions.

Moreover, Doazan (1970) observed that in many Be stellar spectra the rotational velocity which corresponds to the width of the Hα emission line, is larger than the velocity which is due to the stellar rotation ($V\sin\, i$), when $V\sin\, i$ is smaller than 350 km/s. She suggested that if we accept that the only reason of the emission line

broadening is the rotation, then we should also accept that the emission layers rotate more quickly than the central star and that in many cases their rotational velocity is larger than the critical velocity. Finally, she proposed that the large width of the Hα, Hβ and Hγ emission lines is due to the movement of matter that lies in regions away from the central star. She concludes that since these movements affect the width of Hβ and Hγ, we should accept that such regions exist also in the surface of the star. However, the rotation of these regions is not able to explain the whole observed width and there should be an additional way of acceleration. This means that the observed width is due to the combination of these two movements.

In this paper we propose a new idea in order to explain the large absorption broadening, based on the theory of SACs phenomenon (see also Antoniou 2008).

2. DISCUSSION

In Figure 1 we present the analysis of SACs that construct the Hα line in the spectrum of HD 57815 (Lyratzi et al. 2005). We can detect very large absorption components with widths that can not be explained as random velocities (V_{rand}) of the ions or rotational velocity (V_{rot}) of the region that produces the spectral line. This means that if we consider V_{rot} or V_{rand} as main reasons of the line broadening, we calculate too large values for them, that are not physically accepted.

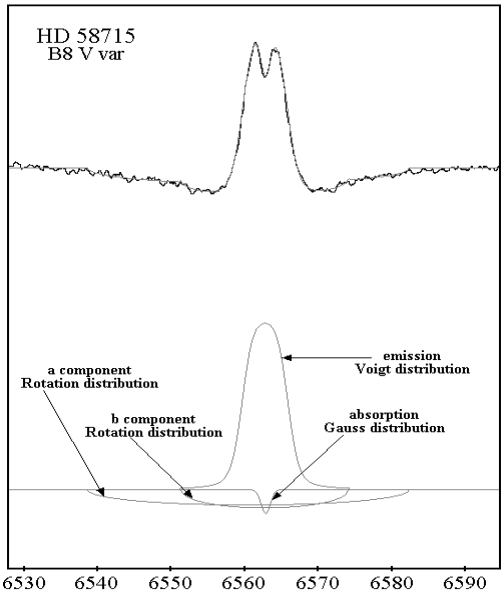

Figure 1: Very broad absorption lines of Hα in the spectrum of HD 57815. Below the fit one can see the analysis (GR model) of the observed profile to its SACs. Some of the SACs present widths which can not be interpreted as rotational or random velocities.

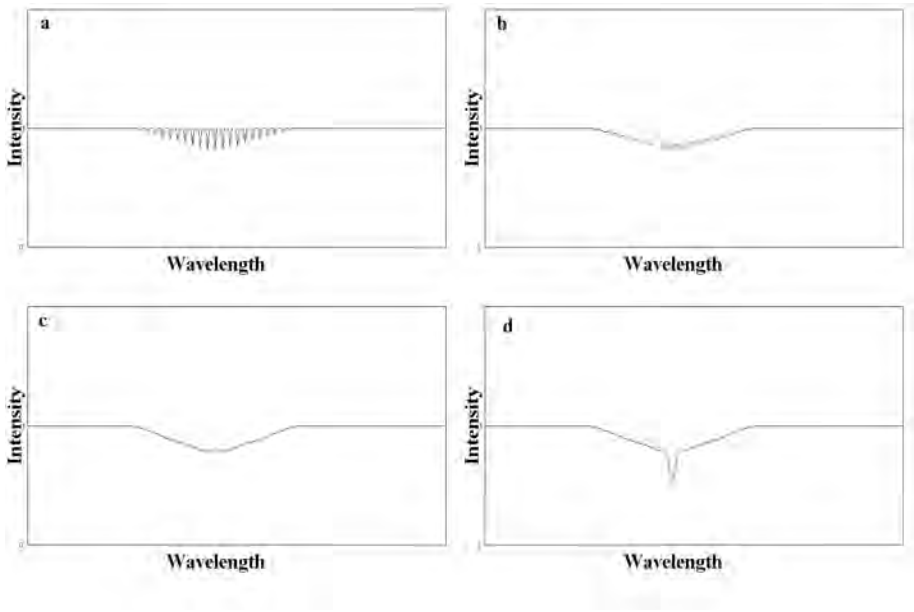

Figure 2: In (a) to (c) one can see how a sequence of lines could produce an apparent very broad absorption spectral line as an effect of SACs phenomenon. This means that when the width of each of the narrow lines is increasing (from a to c), the final observed feature looks like a single very broad absorption spectral line. In (d) one can see a combination of the apparent very broad absorption spectral line with a classical absorption line.

In Figure 2 we explain how a sequence of lines could produce an apparent very broad spectral line as an effect of SACs phenomenon.

In order to explain this very large width we propose that around a central density region that produces the main absorption lines (that may have the form of spiral streams and which have accepted values of rotational and random velocities), we can detect micro-turbulent movements, which produce narrow absorption components with different shifts. These narrow lines create a sequence of lines, on the left and on the right of the main components. The density of these lines and their widths, which are added, give us the sense of line broadening (SACs phenomenon, see Lyratzi & Danezis 2004, Danezis et al. 2007). As a result, what we measure as very broad absorption line, is the composition of the narrow absorption lines that are created by micro-turbulent effects. If this hypothesis is correct, the calculated width gives only the maximum value of the radial velocities of these very narrow components. Their appearance depends on the inclination of the rotational axis of the stellar disk.

Acknowledgments

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Account for Research Grants, which we thank very much. This work also was supported by Ministry of Science of Serbia, through the projects "Influence of collisional processes on astrophysical plasma line shapes" and "Astrophysical spectroscopy of extragalactic objects".

References

Andrillat, Y. & Fehrenbach, Ch.: 1982, *Astron. Astrophys. Suppl.*, **48**, 93.
Andrillat, Y.: 1983, *Astron. Astrophys. Suppl.*, **53**, 319.
Antoniou, A., Danezis, E., Lyratzi, E., Popović, L. Č., Dimitrijević, M. S.: 2008 *PASJ*, submited.
Danezis, E., Nikolaidis, D., Lyratzi, E., Popović, L. Č., Dimitrijević, M. S., Antoniou, A., Theodossiou, E.: 2007, *PASJ*, **59**, 827.
Doazan, V.: 1970, *Astron. Astrophys.*, **8**, 148.
Marlborough, J. M.: 1969, *Astrophys. J.*, **156**, 135.
Lyratzi, E. & Danezis E.: 2004, *AIP Conference Proceedings*, **740**, 458.
Lyratzi, E., Danezis, E., Nikolaidis, D., Popović, L. Č., Dimitrijević, M. S., Theodossiou E., Antoniou, A.: 2005, *MSAIS*, **7**, 114.
Poeckert, R., Marlborough, J. M.: 1979, *Astrophys. J.*, **233**, 259.

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RELATIONS AMONG EMISSION LINES AND CONTINUUM LUMINOSITY IN ACTIVE GALACTIC NUCLEI

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Abstract. We have investigated the line-continuum relations by using an AGN SDSS sample. For the first time we have considered $H\alpha$ and [N II] emission lines in the line-continuum analysis. Also, in order to find more details, we decomposed complex profiles of Balmer lines ($H\alpha$ and $H\beta$) on three components (NLR, ILR and BLR) which are coming from different line emission regions and we examine line components-continuum relations. Numerous Fe II lines ($\lambda\lambda$ 4450-5350 Å) are separated in the three groups (^4F, ^6S and ^4G), according to atomic properties of their transitions, and each Fe II line group is compared separately with continuum luminosity. Indications of Baldwin effect are found for the [O III], [N II] and NLR component of $H\beta$, but trends of inverse Baldwin effect are observed for the Fe II ^6S line group, $H\beta$ BLR, $H\alpha$ ILR and specially for the $H\alpha$ BLR component. Different trends in line-continuum relations required further investigations, to explain their physical background.

1. INTRODUCTION

Investigation of emission lines and continuum luminosity relations may help in understanding AGN structure and physics. In 1977. Baldwin discovered an anticorrelation between equivalent width (EW) of C IV λ1549 Å line and the continuum luminosity L_λ1450 Å (Baldwin 1977). Later, it is detected that majority of emission lines in the UV and V spectral range, and also some lines from the X range are showing the Baldwin effect, i.e. their equivalent width decreases with increase of continuum luminosity. Dietrich et al. (2002) have found Baldwin Effect in almost all lines from O VI λ1034 Å to [O III] λ5007 Å. Only a few lines from considered range, show no correlation or they are showing weak inverse Baldwin Effect (N V λ1240 Å, $H\beta$, $H\gamma$ and Fe II optical lines). Baldwin Effect could be described by function: $EW_{line} \sim L_\lambda^\alpha$, $\alpha < 0$, where EW_{line} is the line equivalent width, L_λ is continuum luminosity for given λ and α is index of the slope. It is noticed that different lines are showing different slopes in the EW versus L diagram. Higher ionization lines usually have steeper slopes than low ionization lines.

The physical explanation of Baldwin effect is still an open question. It is proposed that the continuum shape is luminosity-dependent, i.e. that the UV and X spectra are softer in more luminous AGNs. This results in weaker ionization and heating of emission gas around central engine which cause decreasing of line equivalent widths (Netzer et al. 1992, Korista et al. 1998).

It is also proposed that Baldwin Effect may be driven by an increase of metallicities in more luminous AGNs (Korista et al. 1998). Very interesting question is whether the Baldwin Effect is caused by some stronger, more fundamental relation among equivalent widths and another AGN property, which correlates with AGN luminosity, such as: redshift, the Eddington ratio (L/L_{Edd}) or black hole mass M_{BH}. Baskin & Laor (2004) have found that EW (C IV) better correlate with L/L_{Edd}, then with continuum luminosity, which is also confirmed from other authors using different lines (Warner et al. 2004).

It is observed that Baldwin Effect is connected with group of correlations "Eigenvector 1" (E1), identified by Boroson & Green (1992) in optical AGN spectra. The proposed physical causes which lie under E1 correlations are the same as those proposed for Baldwin Effect (L/L_{Edd}, M_{BH} or inclination angle), which make connection between this two phenomena.

The importance of Baldwin Effect is that it could be used as cosmological standard candle and it could help in studying metal abundances (Korista et al. 1998) as evolution and physics of AGNs.

2. THE SAMPLE AND ANALYSIS

We selected 79 AGN spectra from the Date Release Four (DR4) of the SDSS Database. Our sample is chosen by criteria of high signal to noise ($S/N > 30$), and $z < 0.7$. Spectra are corrected for Galactic reddening and continuum emission is substracted by DIPSO software.

We considered two spectral ranges: $\lambda\lambda$ 4400-5500 Å (Fe II lines, [O III] $\lambda\lambda$4959, 5007 Å, $H\beta$, He II λ4686 Å) and $\lambda\lambda$ 6400-6800 Å ($H\alpha$ and [N II] $\lambda\lambda$6548, 6583 Å) (Fig. 1). We assume that emission lines arise in two or more emission regions, so we fit their profiles with sum of Gaussian functions. Shifts, widths and intensities of Gaussian functions are reflecting physical conditions of emission regions where those components arise. $H\alpha$ and $H\beta$ are decomposed with three Gaussians, which represent emission from BLR (Broad Line Region), ILR (Intermediate Line Region) and NLR (Narrow Line Region).

Parameters of shift and width of the [O III], [N II] and NLR components of $H\beta$ and $H\alpha$, have the same value for a particular AGNs spectrum, because all those lines originate from the same Narrow Line Region. Optical Fe II lines were fited with template calculated by using of the 29 strongest Fe II lines within the $\lambda\lambda$ 4450-5350 Å, and they are separated into three line groups according to the lower level of transition: $3d^6$ ($^3F2$) $4s$ $^{\mathbf{4}}\mathbf{F}$, $3d^54s^2$ $^{\mathbf{6}}\mathbf{S}$ and $3d^6$ (^3G) $4s$ $^{\mathbf{4}}\mathbf{G}$ (in further text ^4F, ^6S and ^4G groups of lines). Detailed description of fitting procedure and Fe II calculated template is given in Kovačević et al. (2008).

3. PRELIMINARY RESULTS

We analyzed the relations of equivalent widths (EW) of considered lines and continuum luminosity (λ5100 Å). For the first time we considered $H\alpha$ and [N II] emission lines in the line-continuum analysis. In order to find more details, we analyzed the relations of the line components (NLR, ILR and BLR of $H\alpha$ and $H\beta$) and continuum. EW Fe II lines-continuum relation is examined by comparing continuum luminosity with three Fe II line groups (^4F, ^6S and ^4G). In this way, we connected Fe II atomic

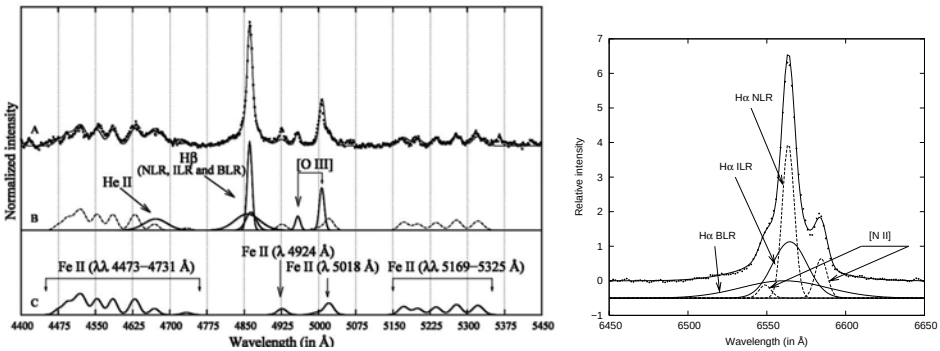

Figure 1: Example of fit of Mrk 493 in the $\lambda\lambda$ 4400-5500 Å range (Fe II lines, [OIII], $H\beta$, He II) (left) and in $\lambda\lambda$ 6400-6800 Å range ($H\alpha$ and [N II]) (right). Lines are decomposed on Gaussians and Fe II lines were fited with calculated template.

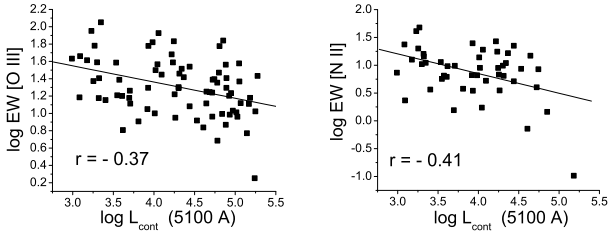

Figure 2: Correlation among continuum luminosity (λ5100 Å) and EW [O III] lines (left) and EW N II (right). Significant negative trend is present (Baldwin effect).

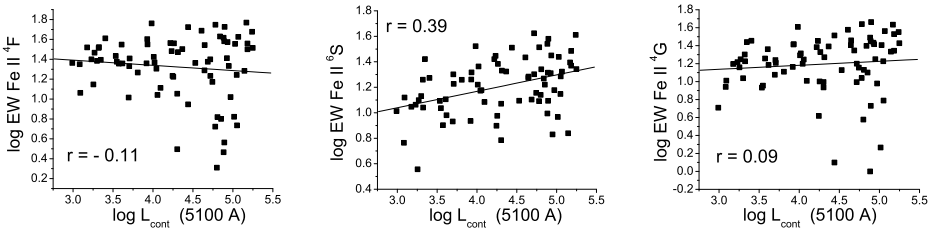

Figure 3: Relation among continuum luminosity (λ5100 Å) and EW $^{4}\mathbf{F}$, $^{6}\mathbf{S}$ and $^{4}\mathbf{G}$ line groups (up) and total EW Fe II (down). The correlation is not observed, but weak positive trend is present only in the case of $^{6}\mathbf{S}$ group.

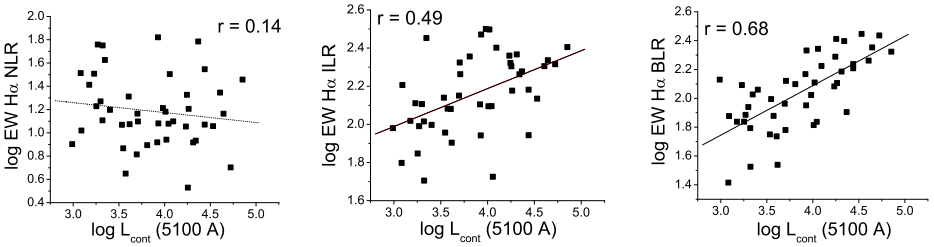

Figure 4: Correlation among continuum luminosity (λ5100 Å) and EW $H\alpha$ NLR (left), ILR (middle) and BLR (right) components. Significant positive trend is observed in the case of EW $H\alpha$ ILR and strong correlation in the case of EW $H\alpha$ BLR.

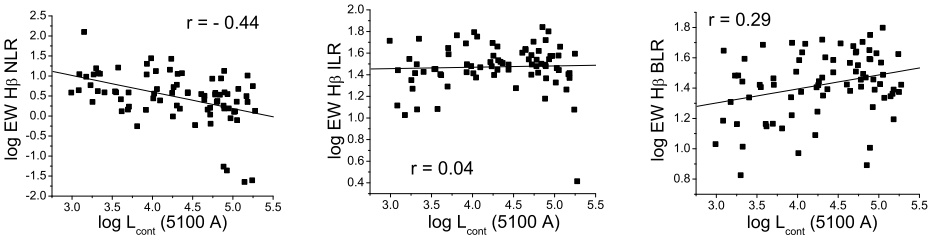

Figure 5: Correlation among continuum luminosity (λ5100 Å) and EW $H\beta$ NLR (left), ILR (middle) and BLR (right) components. Significant negative trend is observed in the case of EW $H\beta$ NLR and weak positive trend in case of EW $H\beta$ BLR.

structure with physical properties of AGN, which brings more information about the Fe II emission region.

Baldwin effect is noticed for the [O III] (the coefficient of correlation r=-0.37) and [N II] (r=-0.41) lines (Fig. 2), as significant negative trends. There is no correlation among log EW Fe II $^{4}\mathbf{F}$, $^{6}\mathbf{S}$, $^{4}\mathbf{G}$ and log L_{cont} (Fig. 3), only weak positive trend is noticed in the case of log EW FeII $^{6}\mathbf{S}$ (0.29). This difference may originate in diverse multiplicity of Fe II line groups (M=6 for $^{6}\mathbf{S}$ and M=4 for $^{4}\mathbf{F}$ and $^{4}\mathbf{G}$). Trends of Balmer lines vs. continuum luminosity are shown in Fig. 4 and Fig. 5. BLR and ILR components of $H\alpha$ and BLR $H\beta$ are showing indications of inverse Baldwin Effect, which is specially strong in the case of the BLR $H\alpha$ (0.68). Contrary, the NLR $H\beta$ is showing Baldwin Effect (-0.44). No trends are noticed in case of the NLR $H\alpha$ and ILR $H\beta$.

For explanation of those different trends and correlations and finding their physical cause, more detailed analysis is required, and it will be presented in future work.

Acknowledgment

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References

Baldwin, J.A.: 1977, *ApJ*, **214**, 679.
Baskin, A. & Laor, A.: 2004, *MNRAS*, **350**, L31.
Boroson, T. A. & Green, R. F.: 1992, *Astrophys. J. Suppl. Series*, **80**, 109.
Dietrich, M., Hamann, F., Shields, J. C., Constantin, A.,Vestergaard, M., Chaffee, F., Foltz, C. B., Junkkarinen, V. T.: 2002, *ApJ*, **581**, 912.
Korista, K., Baldwin, J. & Ferland, G.: 1998, *ApJ*, **507**, 24.
Kovačević, J., Popović, L. Č., Dimitrijević, M. S.: 2008, to be submitted to *MNRAS*.
Netzer, H., Laor, A. & Gondhalekar, P. M.: 1992, *MNRAS*, **254**, 15.
Warner, C., Hamann, F. & Dietrich, M.: 2004, *ApJ*, **608**, 136.

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DACs AND SACs PHENOMENA IN THE C IV EMITTING REGIONS OF QSOs

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Abstract. In this paper we study the C IV resonance lines in the UV spectra of 5 Broad Absorption Line Quasars (BAL QSOs). We found that the Broad Absorption Lines (BALs) that we analyzed in the spectra of some BAL QSOs, are created by a number of Satellite Absorption Components (SACs). We calculated the kinematical parameters such as the apparent rotational (V_{rot}) and radial (V_{rad}) velocities of the regions where the studied lines are created and the random velocities (V_{rand}) of the C IV ions. We also calculated the Full Width at Half Maximum (FWHM) and the column density (CD).

1. INTRODUCTION

In the spectra of Broad Absorption Line Quasars (BAL QSOs) we observe complex profiles of Broad Absorption Lines (BALs), mainly in the case of high ionization ions (e.g. C IV, Si IV, N V). Danezis et al. (2006, 2008) indicated that these complex profiles result from the fact that the BALs are composed of a number of Satellite Absorption Components (SACs). In this paper we test the idea of SACs in quasars' spectra, proposed by Danezis et al. (2006, 2008), using the GR model (Danezis et al. 2007).

Here we investigate the physical properties of Broad Absorption Line Regions (BALRs), where the C IV resonance lines ($\lambda\lambda$ 1548.187, 1550.772 Å) are created, in the case of five quasars. With this model one can accurately fit the observed complex profiles of both emission and absorption spectral lines. Generally, with this model we can calculate the apparent rotational and radial velocities, the random velocities of the ions, as well as the Full Width at Half Maximum (FWHM), the column density of the independent density regions of matter which produce the main and the satellite components of the studied spectral lines and the respective absorbed or emitted energy. We are able to explain the observed peculiar profiles of the BALs using the DACs/SACs theory, i.e. the complex profiles of the BALs are composed

by a number of DACs or SACs which are created in different regions (Danezis et al. 2006, 2008).

2. OBSERVATIONAL DATA AND METHOD OF ANALYSIS

The observational data are taken with HST and are shown in Table 1. The studied spectra have resolution between 1.2 and 3.2 Å.

In order to study the C IV regions of the above BAL QSOs, we used the model proposed by Danezis et al. (2007).

3. RESULTS AND DISCUSSION

In Figure 1 one can see the best fit of the C IV resonance lines in the spectra of PG 0946+301 (left) and PG 1700+518 (right). In the case of PG 1700+518 the complex profile of the observed C IV Broad Absorption Line (BAL) is composed by a number of Satellite Absorption Components (SACs). However, in the case of PG 0946+301 the complex profile of the C IV BAL is composed by two discrete groups of SACs. This means that we also observe the DACs phenomenon.

We point out that the C IV doublet of PG 0946+301 is one of the very few lines that present clearly the DACs phenomenon, in the case of quasars.

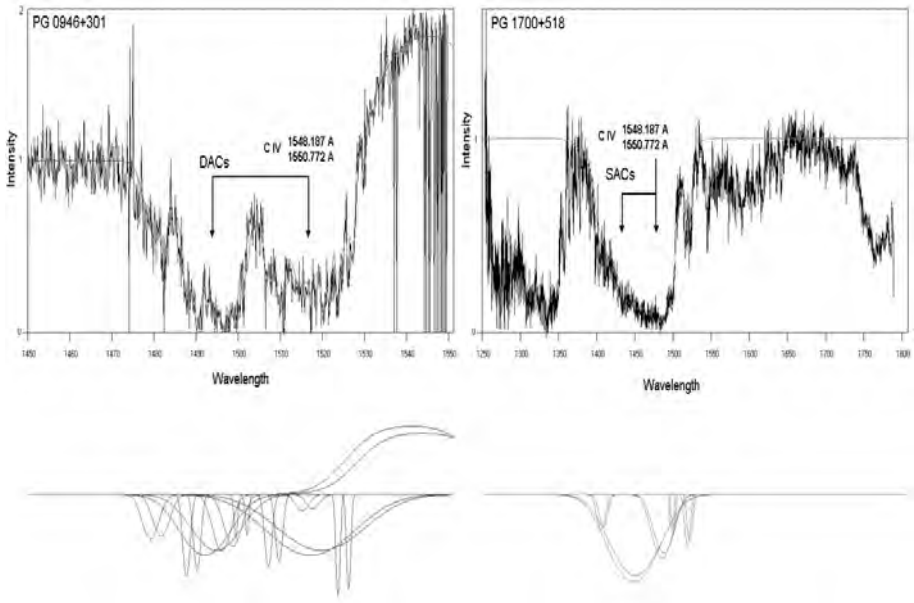

Figure 1: Best fit of the C IV resonance lines in the spectra of PG 0946+301 (left) and PG 1700+518 (right). We can explain the complex structure of these lines as a DACs or SACs phenomenon, respectively. Below the fit one can see the analysis of the observed profile to its DACs/SACs.

Table 1: Observational Data

Name	Z	Obs. Date	Ins./grat.
PG 0946+301	1.216	Feb 16, 1992	FOS/G400,G570
PG 1700+518	0.292	Sep 12, 2000	STIS/G430L,G750L
3C 351	0.371940	Oct 22,1991	FOS/G190H
H 1413+1143	2.551	Jun 23, 1993, Dec 23,1994	FOS/G400H,G570H
PG1254+047	1.024	Feb 17,1993	FOS/G160L,G270H

Table 2: Random (V_{rand}), Rotational (V_{rot}), Radial (V_{rad}) velocities (in km/s) of all the C IV SACs (a to e) of the studied quasars spectra.

Object	SAC	V_{rand} (km/s)	V_{rad} (km/s)	V_{rot} (km/s)
PG0946+301	a	615	-5998	3000
	b	615	-10835	1800
	c	228	-10061	600
PG1700+518	a	5699	-19348	6500
	b	2280	-12092	3000
	c	1140	-27474	1000
	d	456	-5611	1000
	e	114	-9674	800
3C351	a	39	-1722	270
H1413+1143	a	2280	-5224	3600
PG1254+047	a	1596	-5804	1000

Table 3: Full Width at Half Maximum (FWHM) (in km/s) and Column Density (CD) (in cm^{-2}) of all the C IV SACs (a to e) of the studied quasars spectra.

Object	SAC	FWHM	CD (cm^{-2})	
		(km/s)	λ 1548.187 Å	λ 1550.772 Å
PG0946+301	a	5058	$5.84 \cdot 10^{10}$	$5.36 \cdot 10^{10}$
	b	3025	$3.60 \cdot 10^{10}$	$3.30 \cdot 10^{10}$
	c	1010	$1.00 \cdot 10^{10}$	$9.17 \cdot 10^{9}$
PG1700+518	a	15134	$2.39 \cdot 10^{11}$	$2.20 \cdot 10^{11}$
	b	6271	$7.23 \cdot 10^{10}$	$6.61 \cdot 10^{10}$
	c	2624	$1.69 \cdot 10^{10}$	$1.53 \cdot 10^{10}$
	d	1738	$1.53 \cdot 10^{10}$	$1.40 \cdot 10^{10}$
	e	1316	$7.58 \cdot 10^{9}$	$6.90 \cdot 10^{9}$
3C351	a	602	$7.27 \cdot 10^{9}$	$6.73 \cdot 10^{9}$
H1413+1143	a	7245	$1.19 \cdot 10^{11}$	$1.10 \cdot 10^{11}$
PG1254+047	a	3491	$1.73 \cdot 10^{10}$	$1.57 \cdot 10^{10}$

By applying the model proposed by Danezis et al. (2007) (GR model), we calculated the kinematical parameters such as the apparent rotational (V_{rot}) and radial (V_{rad}) velocities of the regions where the studied lines are created and the random velocities (V_{rand}) of the C IV ions. The calculated values are presented in Table 2. We also calculated the Full Width at Half Maximum (FWHM) and the column density (CD) (see Table 3). As one can see in Table 2, the C IV complex profiles are created by a number of SACs.

In some cases we observe that the calculated values of the random and/or the rotational velocities are too large (see Table 2), indicating that the region of origin of the components is close to the massive black hole. Such large rotational and random velocities are expected near the massive black hole, in difference with the large widths observed in stellar spectra (see Antoniou et al. 2008).

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References

Antoniou, A., Danezis, E., Lyratzi, E., Popović, L. Č., Dimitrijević, M. S.: 2008, *PASJ*, submited.

Danezis, E., Lyratzi, E., Popović, L. Č., Dimitrijević, M. S., Antoniou, A.: 2008, "Similarity between DACs/SACs phenomena in hot emission stars and quasars absorption lines", in *Proceedings of 19th ICSLS, Valladolid, Spain.*

Danezis, E., Nikolaidis, D., Lyratzi, E., Popović, L. Č., Dimitrijević, M. S., Antoniou, A., Theodossiou, E. : 2007, *PASJ*, **59**, 827.

Danezis, E., Popović, L. Č., Lyratzi E., Dimitrijević, M. S.: 2006, *AIP Conference Proceedings*, **876**, 373.

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STARK BROADENING OF Sn III LINES IN A TYPE STELLAR ATMOSPHERES

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Abstract. Here we present Stark broadening parameters for Sn III 6s $^1S_0 - 6p\ ^1P^o_1$ spectral line obtained by using semiclassical perturbation approach and Stark widths for this transition obtained by using modified semiempirical approach. Results obtained have been compared with available experimental data and used for the consideration of the influence of the Stark broadening effect in A type stellar atmospheres.

1. INTRODUCTION

With the development of new space tehniques, the quality and quantity of spectroscopic data for trace elements as tin has increased. Spectral lines of neutral tin are present in the spectra of A type stars, for example γ Equ (Adelman et al. 1979). Also, a Sn II spectral line is observed in Przybylski's star by Cowley et al. (2000).

For the considered Sn III 6s $^1S_0 - 6p\ ^1P^o_1$ spectral line, Kieft et al. (2004) measured Stark width and they also, obtained the first theoretical result by using semiempirical (Griem, 1968) approach.

Here we present Stark broadening parameters for Sn III 6s $^1S_0 - 6p\ ^1P^o_1$ as a function of temperature, obtained by using semiclassical perturbation (Sahal-Bréchot, 1969ab) approach and Stark widths for this transition as a function of temperature, obtained by using modified semiempirical (Dimitrijević & Konjević, 1980) approach.

2. RESULTS AND DISCUSSION

For Sn III spectral line Stark broadening parameters, the full semiclassical perturbation approach (Sahal−Bréchot, 1969ab) has been applied. A summary of the formalism for ionized emitters is given in Dimitrijević et al. (1991) and Dimitrijević & Sahal - Bréchot, (1996). Also, for Sn III spectral line Stark width, modified semiempirical approach (Dimitrijević & Konjević, 1980) has been applied. The needed energy levels have been taken from Moore (1971). The oscillator strengths have been calculated by

using the method of Bates & Damgaard, (1949), and the tables of Oertel & Shomo (1968). For higher levels, the method of Van Regemorter et al. (1979) has been used.

Our results for Sn III line are shown in Tables 1 and 2. We also specify a parameter C (Dimitrijević & Sahal−Bréchot 1984) which gives an estimate for the maximum perturber density for which the line may be treated as isolated, when it is divided by the corresponding full width at half maximum.

One can see from Table 3, a good agreement with experimental value of both our results for Stark width for Sn III 6s $^1S_0 - 6p\ ^1P^o_1$ obtained by using semiclassical and modified semiempirical approach. Obviously, this ratio is better for our values than for semiempirical one obtained by Kieft et al. (2004) using Griem (1968) method, not applicable for multiply charged ions (see Dimitrijević & Konjević, 1980).

Table 1: Electron- and proton-impact broadening parameters for Sn III 5226.2 Å obtained by using semiclassical perturbation approach for perturber density of 10^{17}cm^{-3} and temperatures from 10000 up to 150000 K.

Transition	T(K)	W_{e-} (Å)	d_{e-} (Å)	W_{p+} (Å)	d_{p+} (Å)
	10000	1.39	-0.149	0.391E-01	-0.207E-01
Sn III	20000	1.05	-0.987E-01	0.615E-01	-0.339E-01
6s $^1S_0 - 6p\ ^1P^o_1$	30000	0.907	-0.886E-01	0.758E-01	-0.426E-01
5226.2 Å	50000	0.788	-0.900E-01	0.869E-01	-0.513E-01
C= 0.24E+21	100000	0.676	-0.846E-01	0.102	-0.619E-01
	150000	0.626	-0.788E-01	0.111	-0.686E-01

Table 2: Stark widths for Sn III 5226.2 Å obtained by using modified semiempirical approach for perturber density of 10^{17}cm^{-3} and temperatures from 2500 up to 50000 K.

Transition	T(K)	W(Å)
	2500	2.217
	5000	1.567
6s $^1S_0 - 6p\ ^1P^o_1$	10000	1.108
5226.2Å	20000	0.784
	30000	0.640
	50000	0.514

Table 3: Comparison between W_m-experimental Stark width with theoretical: W_{se}-semiempirical, W_{sc}-semiclassical and W_{mse}-modified semiempirical.

Transition	W_m(Å)	Rel. error	$\frac{W_m}{W_{se}}$	$\frac{W_m}{W_{sc}}$	$\frac{W_m}{W_{mse}}$
Sn III 6s $^1S_0 - 6p\ ^1P^o_1$ 5226.2 Å	1.22	50%	1.70	0.92	1.15

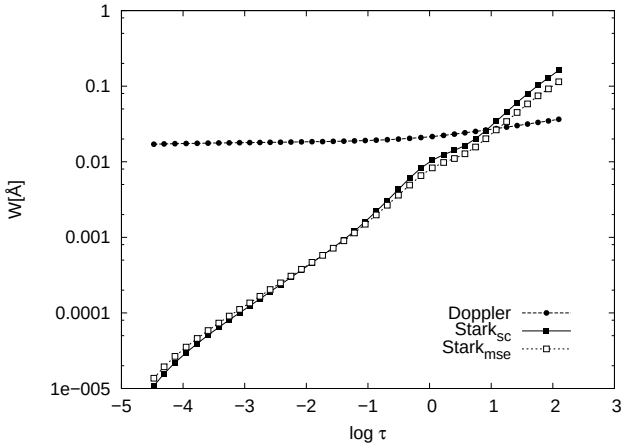

Figure 1: Thermal Doppler and Stark widths (sc-semiclassical, mse-modified semiempirical) for Sn III 6s $^1\mathrm{S}_0 - 6\mathrm{p}\ ^1\mathrm{P}^{\mathrm{o}}_1$ line as functions of optical depth for an A type star ($\mathrm{T_{eff}} = 10000$ K, $\log\ g = 4.5$).

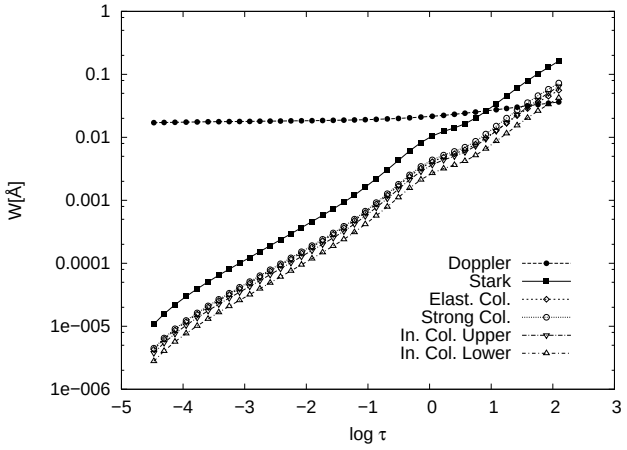

Figure 2: Thermal Doppler, Stark and contributions of different collision processes to the total Stark width of Sn III 6s $^1\mathrm{S}_0 - 6\mathrm{p}\ ^1\mathrm{P}^{\mathrm{o}}_1$ line as functions of optical depth for an A type star ($\mathrm{T_{eff}} = 10000$ K, $\log\ g = 4.5$).

In order to see the influence of Stark broadening mechanism for Sn III spectral line in stellar plasma conditions, we have calculated Stark widths for a Kurucz's (1979) A type star ($T_{\rm eff} = 10000$ K, $\log g = 4.5$) atmosphere model and compared them with Doppler ones. Obtained results in function of the Rosseland optical depth are presented in Fig. 1. One can see, that exist photospheric layers where Doppler and Stark widths are comparable and even where the Stark width is dominant and must be taken into account. Also, in Fig. 2, for the same atmosphere model, we presented Stark widths and contributions of different collision processes to the total Stark width in comparison with Doppler one. In this case, elastic and strong collisions and inelastic collision from upper levels have a similar contribution to the full Stark width as well as the similar behaviour with temperature.

References

Adelman, J., Bidelman, P., Pyper, M.: 1979, *ApJ SS*, **40**, 371.
Bates, D.R., Damgaard, A.: 1949, *Phyl. Trans. Roy. Soc.*, **A242**, 101.
Cowley, C. R., Ryabchikova, T., Kupka, F., Bord, D. J., Mathys, G., Bidelman, W. P.: 2000, *MNRAS*, **317**, 299.
Dimitrijević, M. S., Konjević, N.: 1980, *JQSRT*, **24**, 451.
Dimitrijević, M. S., Sahal-Bréchot, S.: 1984, *JQSRT*, **31**, 301.
Dimitrijević, M. S., Sahal-Bréchot, S.: 1996, *Physica Scripta*, **54**, 50.
Dimitrijević, M. S., Sahal-Bréchot, S., Bomier, V.: 1991, *A&AS*, **89**, 581.
Griem, H.R.: 1968, *Phys. Rev.*, **165**, 258.
Kieft, E. R., van der Mullen, J. J. A. M., Kroesen, G. M. W., Banine, V., Koshelev, K. N.: 2004, *Physical Review*, **E 70**, 066402.
Kurucz, R. L.: 1979, *ApJS*, **40**, 1.
Moore, C. E.: 1971, *Atomic Energy Levels*, **Vol. III**, NSRDS-NBS.
Oertel, G. K., Shomo, L. P.: 1968, *ApJS*, **16**, 175.
Sahal-Bréchot, S.: 1969a, *A&A*, **1**, 91.
Sahal-Bréchot, S.: 1969b, *A&A*, **2**, 322.
van Regemorter, H., Hoang Binh D., Prud′homme, M.: 1979, *J. Phys.*, **B12**, 1053.

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ASTROPHYSICAL SIGNIFICANCE OF SPECTRAL LINE SHAPES INVESTIGATION

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SUMMARY *The astrophysical implications of the spectral line shapes investigation are briefly reviewed. A short survey of results reached by Yugoslav researchers connected with the subject is also given.*

1. INTRODUCTION

Due to great importance of theoretical investigations of the physical processes, special laboratories and institutes have been founded with the objective to provide basic data to astronomers. Such are, e.g.: JILA (Joint Institute for Laboratory Astrophysics) in Boulder (Colorado, USA), established in 1962, or Departement d'Astrophysique Fondamentale at the Paris Observatory.

As the typical astrophysical information is acquired by analysing the stellar radiation, the understanding of stellar spectra, of the spectral line shapes in particular, assumes great importance. The purpose of this article is not, though, to discuss in detail the significance of all effects influencing spectral line shapes. Only astrophysical problems connected with the pressure broadened line shapes will be considered.

2. PRESSURE BROADENING

Typical astrophysical topics wherein the pressure broadening is significant can be divided into following categories:

a) Understanding of qualitative effects encountered in the spectrograms.
b) Determination of temperature (T) and electron concentration (N_e) in astrophysical plasma and surface gravity in stars.
c) Determination of abundances of elements by the profiles or equivalent widths of absorption lines.

d) Radiative transfer through astrophysical plasmas.
e) Investigation of profiles of radio recombination lines originating in molecular and ionized hydrogen regions.

The expalanation of astrophysical spectra implies often the knowledge of the pressure broadening. A recent instance is presented by the Stark shift in the spectra of white dwarfs where difficulties were met at interpreting the Einstein shift, brought out by using the helium lines (Wiese and Keller, 1971).

Observed spectral lines can be used also for determining the electron temperature and concentration in the astrophysical sources. Balmer line profiles in particular are a powerful diagnostic tool in studying stellar atmospheres. In cooler stars, such as the Sun, the line intensity is a good measure of effective temperature. As apparent from Fig. 1,

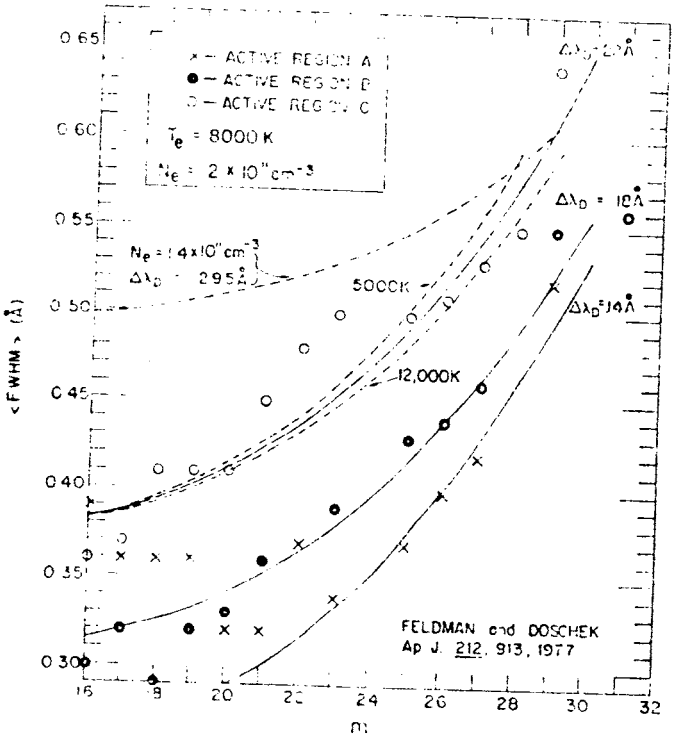

Fig. 1 Stark broadening of high member series lines at 2" above the limb over active regions. The density of 2 x 10^{11} cm^{-3} is an average of the actual values. The dashed curve with a density of 1.4 x 10^{11} cm^{-3} is fitted to the data at m = 29

line widths of higher members of the Balmer sequence are very sensitive to the variation of electron density. In the atmospheres of O and B stars, as well as in those of some white dwarfs and A0 type stars ($T_{eff} \geq 10^4$ K) hydrogen is on the whole ionized and the main collisional broadening mechanism of the spectral lines is presented by the electron impact broadening (Stark broadening). In such a case the atmospheric pressure P is proportional to the electron concentration N_e at a fixed temperature. Now we are able to deduce the surface gravity g using the hydrostatic equation. The total pressure P is given by $P \sim g/k$ $\sim g$, where the mass absorption coefficient k is typically about 1 $cm^2 g^{-1}$.

The important problem requiring good pressure broadening data is that of determining abundances of elements from equivalent widths (W) of absorption lines. When the line is a weak one the problem is quite straightforward since W (in wavelength units) is proportional to the element to hydrogen abundance ratio, multiplied by the oscillator strength of the transition

$$\left(\frac{W}{\lambda}\right)_{weak} = X \equiv \frac{N_M}{N_H} f \lambda \int_0^{\infty} \Phi(\tau)\, d\tau$$

where $\Phi(\tau)$ is a contribution function depending on the structure of the stellar atmosphere and the relevant states of excitation and ionization and τ is the optical depth in the continuum. However, if the line is not a weak one, the situation gets much more complicated. The relationship between X and (W/λ) is described by the curve of growth, the shape of which depends on the amount of the line broadening due to both Doppler and pressure effects. The curve has three branches:

Linear (unsaturated): $(W/\lambda) = X$
Flat (saturated): $(W/\lambda) \sim 3v_D/c$
Damping branch: $(W/\lambda) = (\lambda X \gamma/\pi c)^{1/2}$

Here, γ is the damping (pressure broadening) constant and v_D the velocity corresponding to the given Doppler width.

Pressure broadening data are also necessary at estimating the radiative transfer through the stellar plasma. Here, data on a large number of lines are often needed. In such large scale calculations high accuracy of every particular quantity is not so important. Tedious calculations can thereby be avoided by using simple approximative formulae affording good average accuracy (for Stark broadening see e.g. Dimitrijević, 1982 and references therein).

The investigation of radio recombination lines presents a special topic for pressure broadening application. The range of principal quantum numbers over which radio recombination hydrogen lines have been observed is $56 \leqslant n \leqslant 253$, corresponding to a frequency range 37.5 to 0.40 GHz. In such atoms the optical electron is at long distance from the nucleus and higly sensitive to the weak electric field fluctuations. The Stark broadening forms here the main collisional broadening mechanism.

3. LINE SHAPES INVESTIGATION IN YUGOSLAVIA IN 1962–1981

Following the appearance of the first article on this subject (Vujnović et al., 1962), 102 papers dealing with the line shapes investigation have been published by 46 Yugoslav authors. The number of papers published, the number of authors and the number of papers published in international journals are given in Table 1 for every year. We can see that up to date 102 papers have been published, all dealing with the line shapes investigation. Out of these 69 articles are published in international journals. In addition, 4 doctoral and 7 MSc theses have been elaborated over this period. Among the published articles, 14 appear in the astronomical publications (7 in Astron. Astrophys. and 1 in Astrophys. J.).

Table 1: Number of articles, authors and articles in international journals, published by yugoslav research workers in the period 1962–1981

Year	Number of articles published	Number of authors	Number of articles in international journals
1962	1	1	1
1963	0	0	0
1964	2	2	0
1965	1	1	1
1966	0	0	0
1967	0	0	0
1968	1	4	1
1969	2	4	0
1970	15	11	4
1971	10	8	4
1972	10	12	4
1973	9	14	3
1974	14	15	4
1975	11	14	5
1976	21	15	4
1977	12	12	7
1978	22	17	8
1979	13	13	5
1980	27	19	6
1981	21	14	12
Total	192		69

REFERENCES

Dimitrijević, M.S.: 1982, Astron. Astrophys. *112*, 251
Feldman, U., Doschek, G.A.: 1977, Astrophys. J. *212*, 913
Vujnović, V., Harrison, J.A., Crags, J.D.: 1962, Proc. Phys. Soc. (London) *80*, 516
Wiese, W.L., Kelleher, D.E.: 1971, Astrophys. J. *166*, L59

ASTROFIZIČKE PRIMENE IZUČAVANJA PROFILA SPEKTRALNIH LINIJA

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REZIME: Razmotrene su primene izučavanja oblika spektralnih linija u astrofizici i to: (a) za interpretaciju pojava koje se vide na spektrogramima; (b) određivanje temperature i koncentracije elektrona u zvezdanim atmosferama kao i površinske gravitacije; (c) određivanje hemijskih sastava zvezdane plazme; (d) proučavanje transfera zračenja; (e) istraživanje radio rekombinacionih linija u oblastima jonizovanog i molekularnog vodonika. Takođe je dat kratak pregled rada jugoslovenskih istraživača na području istraživanja oblika spektralnih linija.

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ON THE STARK BROADENING OF Se I SPECTRAL LINES

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Abstract. Using a semiclassical approach, we have calculated electron-, proton-, and ionized argon- impact line widths and shifts for 31 Se I multiplets. The results have been compared with existing theoretical estimates.

1. INTRODUCTION

In order to try to provide an as much as possible more complete set of semiclassical Stark-broadening parameters needed for research of astrophysical, laboratory and laser produced plasma we obtained such data for large number of different emitter lines (see Dimitrijević, 1996 and references therein). Such set of data is not only of interest *e.g.* for stellar plasma diagnostic, opacity calculations or the investigation/modelling of stellar spectra or a particular line, but as well for different examinations of regularities and systematic trends for e.g. homologous atoms (Dimitrijević and Popović, 1989) or in general (Purić *et al.* 1991). Moreover, we do not know *a priori* the chemical composition of a star and with the developement of space born techniques the astrophysical importance of up to now often astrophysically meaningless lines increases.

By using the semiclassical-perturbation formalism (Sahal-Bréchot, 1969ab), we have calculated electron-, proton-, and ionized argon- impact line widths and shifts for 31 multiplets of neutral selenium. The obtained results will be presented elsewhere (Dimitrijević and Sahal-Bréchot, 1996). Here, only a part of the results will be shown as an illustration, as well as the comparison with simple estimates (Lakićević, 1983).

2. RESULTS AND DISCUSSION

The semiclassical perturbation method used here, has been discussed in detail in Sahal - Bréchot (1969ab) and a brief summary is given in Dimitrijević *et al.* (1991). Energy levels for Se I lines have been taken from Moore (1971). Oscillator strengths have been calculated by using the method of Bates and Damgaard (1949) and tables of Oertel and Shomo (1968). For higher levels, the method described in Van Regemorter *et al.* (1979) has been used. For $4p^4\ ^3P$ - $4p^3(^4S^o)5s^3S^o$, $4p^4\ ^3P$ - $4p^3(^2D^o)5s'^3D^o$ and $4p^4\ ^3P$ - $4p^3(^2P^o)5s''^3P^o$ the oscillator strengths calculated by Gruzdev (1969) Ref. 15

Table 1. This Table shows electron-, and proton- impact broadening parameters for Se I for a perturber density of 10^{16} cm^{-3} and temperatures from 2,500 up to 50,000 K. Transitions and averaged wavelengths for the multiplet (in Å) are also given. If one divides c value with the linewidth value, we obtain an estimate for the maximum perturber density (in cm^{-3}) for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the collision volume multiplied by the perturber density (the condition for validity of the impact approximation) lies between 0.1 and 0.5.

PERTURBER DENSITY= 1xE+16cm-3					
PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
4P - 5S	2500.	0.294E-02	0.256E-02	0.786E-03	0.690E-03
1997.9Å	5000.	0.352E-02	0.298E-02	0.882E-03	0.796E-03
C= 0.39E+19	10000.	0.418E-02	0.350E-02	0.990E-03	0.910E-03
	20000.	0.466E-02	0.395E-02	0.111E-02	0.103E-02
	30000.	0.481E-02	0.406E-02	0.119E-02	0.111E-02
	50000.	0.508E-02	0.387E-02	0.129E-02	0.121E-02
4P - 6S	2500.	0.117E-01	0.851E-02	0.263E-02	0.206E-02
1522.6Å	5000.	0.137E-01	0.103E-01	0.295E-02	0.249E-02
C= 0.69E+18	10000.	0.153E-01	0.121E-01	0.331E-02	0.292E-02
	20000.	0.161E-01	0.125E-01	0.372E-02	0.337E-02
	30000.	0.168E-01	0.121E-01	0.398E-02	0.364E-02
	50000.	0.175E-01	0.105E-01	0.433E-02	0.401E-02
4P - 7S	2500.	0.411E-01	0.293E-01	*0.886E-02	*0.553E-02
1409.5Å	5000.	0.474E-01	0.344E-01	*0.999E-02	*0.741E-02
C= 0.23E+18	10000.	0.506E-01	0.382E-01	*0.112E-01	*0.917E-02
	20000.	0.549E-01	0.375E-01	*0.126E-01	*0.109E-01
	30000.	0.560E-01	0.332E-01	*0.135E-01	*0.119E-01
	50000.	0.614E-01	0.278E-01	0.147E-01	0.132E-01
5P - 6S	2500.	1.36	0.904	0.323	0.215
16773.0Å	5000.	1.57	1.11	0.351	0.258
C= 0.84E+20	10000.	1.79	1.19	0.384	0.302
	20000.	2.13	1.17	0.421	0.347
	30000.	2.36	1.02	0.446	0.375
	50000.	2.76	0.849	0.479	0.412
5P - 7S	2500.	1.64	1.13	*0.350	*0.218
8905.4Å	5000.	1.88	1.40	*0.394	*0.291
C= 0.92E+19	10000.	2.01	1.43	*0.442	*0.360
	20000.	2.19	1.40	*0.496	*0.427
	30000.	2.35	1.22	*0.530	*0.467
	50000.	2.65	1.03	0.577	0.519

PERTURBER DENSITY= 1xE+16cm-3

PERTURBERS ARE: TRANSITION	T(K)	ELECTRONS WIDTH(Å)	SHIFT(Å)	PROTONS WIDTH(Å)	SHIFT(Å)
4P - 4D	2500.	0.433E-02	-0.160E-02	0.186E-02	-0.405E-03
1553.6Å	5000.	0.458E-02	-0.185E-02	0.188E-02	-0.468E-03
C= 0.10E+19	10000.	0.500E-02	-0.192E-02	0.189E-02	-0.534E-03
	20000.	0.561E-02	-0.178E-02	0.190E-02	-0.606E-03
	30000.	0.603E-02	-0.157E-02	0.192E-02	-0.652E-03
	50000.	0.656E-02	-0.134E-02	0.193E-02	-0.712E-03
4P - 5D	2500.	0.150E-01	-0.643E-02	*0.627E-02	-0.156E-02
1424.9Å	5000.	0.168E-01	-0.629E-02	*0.647E-02	-0.188E-02
C= 0.31E+18	10000.	0.195E-01	-0.451E-02	0.659E-02	-0.220E-02
	20000.	0.235E-01	-0.311E-02	0.669E-02	-0.253E-02
	30000.	0.258E-01	-0.278E-02	0.675E-02	-0.273E-02
	50000.	0.282E-01	-0.218E-02	0.685E-02	-0.300E-02
4P - 6D	2500.	0.806E-01	0.514E-01		
1371.7Å	5000.	0.910E-01	0.535E-01		
C= 0.73E+17	10000.	0.106	0.448E-01		
	20000.	0.125	0.350E-01	*0.274E-01	*0.195E-01
	30000.	0.133	0.300E-01	*0.288E-01	*0.215E-01
	50000.	0.139	0.220E-01	*0.308E-01	*0.241E-01
5P - 5D	2500.	0.769	-0.359	*0.300	-0.815E-01
9556.1Å	5000.	0.866	-0.394	*0.310	-0.986E-01
C= 0.14E+20	10000.	1.01	-0.389	0.317	-0.116
	20000.	1.22	-0.335	0.323	-0.134
	30000.	1.35	-0.305	0.327	-0.144
	50000.	1.50	-0.259	0.333	-0.159
5P - 6D	2500.	2.47	1.54		
7583.5Å	5000.	2.80	1.60		
C= 0.22E+19	10000.	3.27	1.27		
	20000.	3.90	0.952	*0.837	*0.591
	30000.	4.16	0.807	*0.881	*0.653
	50000.	4.39	0.559	*0.941	*0.732

have been used, by using a semiempirical approximation based on the intermediate coupling scheme and the quantum deffect method. In addition to electron-impact full halfwidths and shifts, Stark-broadening parameters due to proton- and ionized argon-impacts have been calculated. As the illustration, one part of our results is shown in Table 1 for a perturber density of 10^{16} cm^{-3} and temperatures T = 2,500 - 50,000 K. For each value given in Table 1, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid (Sahal - Bréchot, 1969ab). Values for $0.1 < \mathrm{NV} \leq 0.5$ are denoted with an asterisk.

With the help of regularities and systematic trends the Stark width and shift for the resonant Se I $4p^4\ ^3P$ - $4p^3(^4S^o)5s^3S^o$ multiplet have been estimated to be W = 0.058 Å and |d| = 0.033 Å for T = 20,000 K and an electron density of 10^{17} cm^{-3} (Lakićević, 1983). Our calculations give W = 0.047 Å and |d| = 0.040 Å, which is an encouraging agreement.

We hope that the presented Stark broadening data will be of help for consideration of various scientific problems.

References

Bates, D.R. and Damgaard, A.: 1949, *Trans.Roy.Soc. London, Ser. A* **242**, 101.
Dimitrijević, M.S.: 1996, *Zh. Prikl. Spektrosk* in press.
Dimitrijević, M.S. and Popović, M.M.: 1989, *Astron. Astrohys.* **217**, 201.
Dimitrijević M.S. and Sahal-Bréchot, S.: 1996, *Zh. Prikl. Spektrosk.*, in press.
Dimitrijević, M.S., Sahal-Bréchot, S., and Bommier, V.: 1991, *Astron. Astrophys. Suppl. Series* **89**, 581.
Gruzdev, P.F.: 1969, *Opt. Spectrosc.* **27**, 479.
Lakićević, I.S.: 1983, *Astron.Astrophys* **127**, 37.
Moore, C.E.: 1971, Atomic Energy Levels Vol. II, NSRDS-NBS 35, U.S. Govt. Print. Office, Washington.
Oertel, G.K. and Shomo, L.P.: 1968, *Astrophys. J. Suppl. Series* **16**, 175.
Purić, J., Dimitrijević, M.S. and Lesage,A.: 1991, *Astrophys. J.* **382**, 353.
Sahal-Bréchot, S.: 1969a, *Astron.Astrophys.* **1**, 91.
Sahal-Bréchot, S.: 1969b, *Astron.Astrophys.* **2**, 322.
Van Regemorter, H., Hoang Binh Dy, and Prud'homme, M.: 1979, *J.Phys.B* **12**, 1073.

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CHEMI-IONIZATION AND CHEMI-RECOMBINATION PROCESSES IN SOLAR AND STELLAR ATMOSPHERES

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Abstract. Within the semi-classical approximation, chemi-ionization processes during symmetrical atom-Rydberg atom collisions were considered, as well as the inverse chemi-recombination processes during the scattering of free electrons by corresponding collisional ion-atom complexes and molecular ions. It was shown that these processes must be taken into account when modelling the low-temperature layers of solar atmosphere and atmospheres of some helium- rich stars.

In Mihajlov and Janev (1981) and Mihajlov *et al.* (1992) a semi-classical theory of chemi-ionization processes during symmetrical atom-Rydberg atom collisions has been developed, as well as a theory of their inverse chemi-recombination processes during the scattering of free electrons by the collisional quasi-molecular ion-atom complexes and the weakly bound molecular ions. These processes are

$$A^*(n) + A \Rightarrow \begin{cases} A_2^+ + e, \\ A + A^+ + e, \end{cases} \tag{1}$$

and the inverse recombination processes are

$$\left.\begin{matrix} A_2^+ + e \\ A + A^+ + e \end{matrix}\right\} \Rightarrow A^*(n) + A, \tag{2}$$

where A, A^+ and A_2^+ denote atom, atomic ion and molecular ion in the corresponding ground electronic states, $A^*(n)$ - atom in the Rydberg state with the principal quantum number n, and e - free electron. A_2^+ is taken to be in one of the weakly bound rotational - vibrational states. Then, in Mihajlov *et al.* (1996ab), it was shown that in the nonequilibrium plasmas with the degree of ionization 10^{-2}, influence of processes (1) and (2) on the populations of the atoms $A^*(n)$ is comparable or even dominant in comparison with the influence of known Bates *et al.* (1962ab) electron-atom ionization processes

$$A^*(n) + e \Rightarrow A^+ + e + e, \tag{3}$$

and the electron-electron-ion recombination processes

$$A^+ + e + e \Rightarrow A^*(n) + e. \tag{4}$$

Besides the extremely nonequilibrium plasmas, our discussion also refers to the plasmas whose state, in relation to many parameters, can be treated as the state of LTE, but where the populations of atoms $A^*(n)$ are still quite different from the equilibrium ones. Here, we have in mind on the the equilibrium populations determined for the given temperature T and the given concentrations of electrons and ions A^+. These are just the plasmas that we encounter at considering of the weakly ionized layers in the outer regions of different stellar atmospheres, where the deviations of the populations of the excited atoms $A^*(n)$ from their equilibrium values are caused by the absence of equilibrium between the atomic component of the stellar atmosphere and the radiation. Certain layers in the outer region of the solar atmosphere, as well as in the outer regions of the atmospheres of some helium-rich stars (DB white dwarfs), for which the relevant data on their optical depths exist (Vernazza *et al.* 1981, Koester 1980), fall into this group. In accordance with the present discussion, it is clear that in the case of these layers, the role of the processes (1) and (2), for $A = H$ or $A = He$, can be of great importance. Concretely, the relative importance of these processes, compared with the processes (3) and (4), depends on the behaviour of the ratios

$$I^{(1)}_{i;n}(h)/I^{(3)}_{i;n}(h),$$

$$I^{(2)}_{r;n}(h)/I^{(4)}_{r;n}(h),$$

where $I^{(1)}_{i;n}(h)$ and $I^{(2)}_{r;n}(h)$ denote the ionization and recombination fluxes caused by the chemi-ionization processes (1) and the chemi-recombination processes (2), $I^{(3)}_{i;n}(h)$ and $I^{(4)}_{r;n}(h)$ denote the ionization and recombination fluxes caused by the concurrent processes (3) and (4), and h is the corresponding height. By the definition, these fluxes are given by the expressions

$$\begin{aligned}
I^{(1)}_{i;n}(h) &= K^{(1)}_i(T(h))N(A^*(n);h)N(A;h),\\
I^{(2)}_{r;n}(h) &= K^{(2)}_r(T(h))N(e;h)N(A^+;h)N(A;h),\\
I^{(3)}_{i;n}(h) &= K^{(3)}_i(T(h))N(A^*(n);h)N(e;h)),\\
I^{(4)}_{r;n}(h) &= K^{(4)}_r(T(h))N(A^+;h)N(e;h)N(e;h),
\end{aligned}$$

where $K^{(1)}_i(T)$ and $K^{(2)}_r(T)$ represent the semi-classical rate coefficients for the processes (1) and (2), and they are given in Mihajlov *et al.* (1996ab), while $K^{(3)}_i(T)$ and $K^{(4)}_r(T)$ represent the rate coefficients for the processes (3) and (4) which are given in Vriens and Smeets (1980). Here, by $T(h)$, $N(A^*(n);h)$, $N(A;h)$, $N(A^+;h)$ and $N(n;h)$ we have denoted temperatures and concentrations of the atoms $A^*(n)$, atoms A, ions A^+ and the electrons on the height h, respectively.

On the quantitative level, importance of the processes (1) and (2) can be directly verified on the basis of standard chromospheric model (model C in Vernazza *et al.* 1981), where all the data needed for the calculation of the ionization and recombination fluxes (as the functions of h), for $n \leq 8$, are given. The deviations of the atoms $H^*(n)$ populations from the equilibrium values are illustrated in the Table 1, where the values of the quantity $1 - N_{eq}(H^*(n);h)/N(H^*(n);h)$ are given, and $N_{eq}(H^*(n);h)$ represents the equilibrium concentration of the atoms $H^*(n)$. Table 2 shows the behaviour of the ratio of the ionization fluxes $I^{(1)}_{i;n}(h)/I^{(3)}_{i;n}(h)$ as the function of h. This Table clearly shows that the influence of the processes (1), in the wide range of h, is comparable or even dominant in comparison with the processes (3). Our calculations show that, in the case of solar photosphere, similar situation exists for the processes (2) and (4).

Table 1. Values of ratio $1 - N_{eq}(H^*(n);h)/N(H^*(n);h)$

		n				
h(km)	T(K)	4	5	6	7	8
755	5280	.0425	-.0475	-.0751	-.1237	-.1250
705	5030	-.0681	-.1370	-.1537	-.2021	-.2018
655	4730	-.2483	-.2694	-.1697	-.3087	-.3057
605	4420	-.4810	-.4277	-.3880	-.4324	-.4255
555	4230	-.6155	-.5014	-.4418	-.4881	-.4804
515	4170	-.6143	-.4826	-.4223	-.4716	-.4646
450	4220	-.4527	-.3504	-.3079	-.3593	-.3549
350	4465	-.1739	-.1348	-.1189	-.1677	-.1665
250	4780	-.0234	-.0140	-.0103	-.0550	-.0551
150	5180	.0313	.0382	.0382	-.0027	-.0033
100	5455	.0282	.0419	.0426	.0042	.0035
50	5840	.0266	.0254	.0400	.0039	.0034
0	6420	.0188	.0347	.0353	.0029	.0024
-25	6910	.0165	.0316	.0325	.0022	.0016
-50	7610	.0158	.0294	.0300	.0024	.0021
-75	8320	.0152	.0278	.0283	.0030	.0027

Table 2. Value of ratio $I^{(1)}_{i;n}(h)/I^{(3)}_{i;n}(h)$

h(km)	T(K)	n				
		4	5	6	7	8
755	5280	.1187E+02	.2317E+01	.6442E+00	.2263E+00	.9374E−01
705	5030	.2243E+02	.4298E+01	.1182E+01	.4130E+00	.1702E+00
655	4730	.3662E+02	.6848E+01	.1857E+01	.6430E+00	.2636E+00
605	4420	.4803E+02	.8727E+01	.2328E+01	.7978E+00	.3249E+00
555	4230	.5479E+02	.9761E+01	.2574E+01	.8761E+00	.3553E+00
515	4170	.5860E+02	.1037E+02	.2724E+01	.9252E+00	.3747E+00
450	4220	.6084E+02	.1083E+02	.2853E+01	.9708E+00	.3936E+00
350	4465	.5857E+02	.1069E+02	.2858E+01	.9811E+00	.4000E+00
250	4780	.5297E+02	.9948E+01	.2705E+01	.9378E+00	.3848E+00
150	5180	.4341E+02	.8412E+01	.2330E+01	.8161E+00	.3376E+00
100	5455	.3536E+02	.6985E+01	.1956E+01	.6899E+00	.2866E+00
50	5840	.2266E+02	.4583E+01	.1301E+01	.4629E+00	.1934E+00
0	6420	.8895E+01	.1855E+01	.5362E+00	.1929E+00	.8120E−01
−25	6910	.3826E+01	.8153E+00	.2388E+00	.8664E−01	.3666E−01
−50	7610	.1262E+01	.2762E+00	.8211E−01	.3010E−01	.1282E−01
−75	8320	.4806E+00	.1076E+00	.3247E−01	.1200E−01	.5142E−02

References

Bates, D. R., Kingston, A. E. and McWhirter, R. W. P.: 1962a, *Proc. Roy. Soc.* **A267**, 297.

Bates, D. R., Kingston, A. E. and McWhirter, R. W. P.: 1962b *Proc. Roy. Soc.* **A270**, 155.

Koester, D.: 1980, *Astron. Astrophys.*, **39**, 401.

Mihajlov, A. A., Dimitrijević, M. S. and Djurić, Z.: 1996a, *Physica Scripta*, **53**, 159.

Mihajlov, A. A., Djurić, Z. and Dimitrijević, M. S.: 1996b, *J. Quant. Spectrosc. Radiat. Transfer* **55**, 141.

Mihajlov, A. A. and Janev, R. K.: 1981, *J. Phys. B.*, **14**, 1639.

Mihajlov, A. A., Ljepojević, N. N. and Dimitrijević, M. S.: 1992, *J. Phys. B: At. Mol. Opt. Phys.* **25**, 5121.

Vernazza, J. E., Avrett, E. H. and Loeser, R.: 1981, ApJS **45**, 635.

Vriens, L. and Smeets, A. H. M.: 1980, *Phys. Rev.* **A22**, 940.

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ON THE STARK BROADENING OF Ba I SPECTRAL LINES

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Abstract. Using a semiclassical approach, we have calculated electron-, proton-, and ionized helium- impact line widths and shifts for 14 Ba I multiplets. The results have been compared with existing theoretical estimates.

1. INTRODUCTION

Barium is important for investigation of nuclear reactions in stellar interiors, since it is one of thermonuclear s - processes product in stars and its overabundance is observed in CH subgiants, characterized by enhanced Sr and Ba lines, and in metal deficient barium stars, giants showing overabundance of s-processes elements (Šleivyté & Bartkevičius, 1995). Moreover, barium lines are observed in solar and stellar spectra (e.g. Komarov & Basak 1993, and Anders & Grevesse, 1989).

Barium lines are also of interest for the investigation of laboratory plasmas. Consequently, Aulehla & Herman (1958) have determined neutral barium Stark effect constants by investigating metallic lines broadened by an intermolecular field. Kato et al. (1984) investigated wavelength shifts of Ba I lines emitted by an inductively coupled plasma.

Theoretically, Ba I lines have been investigated by Grechikhin (1969), considering their applicability to plasma diagnostics, and by Davis (1972), for research of a laser - generated barium plasma. Lakićević (1983) estimated line widths and shifts for Ba I $6s^2{}^1S$ - $6p{}^1P^o$ multiplet for T = 20000 K, on the basis of the Stark broadening parameter dependence on the ionization potential from the lower level of the corresponding transition.

In order to continue our research of Stark broadening parameters needed for the investigation of astrophysical and laboratory plasmas and to provide the needed Stark broadening data, we have calculated within the semiclassical-perturbation formalism (Sahal–Bréchot, 1969ab) electron-, proton-, and ionized helium- impact line widths and shifts for 14 Ba I multiplets. A summary of the formalism is given in Dimitrijević & Sahal-Bréchot (1984). We note here that the inelastic collision contribution is included in the ion-impact line widths.

Table 1. This Table shows electron-, and proton- impact broadening parameters for Ba I for a perturber density of 10^{16} cm^{-3} and temperatures from 2,500 up to 50,000 K. Transitions and averaged wavelengths for the multiplet (in Å) are also given. If one divides c value with the linewidth value, we obtain an estimate for the maximum perturber density (in cm^{-3}) for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the collision volume multiplied by the perturber density (the condition for validity of the impact approximation) lies between 0.1 and 0.5.

PERTURBER DENSITY= 1xE+16cm-3					
PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
6S - 6P	2500.	0.231E-01	0.402E-02	0.115E-01	0.108E-02
5537.0 Å	5000.	0.228E-01	0.433E-02	0.115E-01	0.123E-02
C= 0.20E+20	10000.	0.246E-01	0.397E-02	0.115E-01	0.139E-02
	20000.	0.301E-01	0.204E-02	0.115E-01	0.157E-02
	30000.	0.353E-01	0.104E-02	0.115E-01	0.168E-02
	50000.	0.432E-01	0.300E-03	0.116E-01	0.183E-02
6S - 7P	2500.	0.516E-01	-0.240E-01	*0.259E-01	-0.586E-02
3072.5 Å	5000.	0.560E-01	-0.281E-01	*0.266E-01	-0.699E-02
C= 0.22E+19	10000.	0.607E-01	-0.313E-01	0.270E-01	-0.813E-02
	20000.	0.658E-01	-0.317E-01	0.273E-01	-0.933E-02
	30000.	0.688E-01	-0.305E-01	0.275E-01	-0.101E-01
	50000.	0.725E-01	-0.276E-01	0.278E-01	-0.111E-01
7S - 7P	2500.	3.74	-1.98	*1.51	-0.482
23164.3 Å	5000.	4.30	-2.33	*1.57	-0.584
C= 0.12E+21	10000.	4.97	-2.72	1.61	-0.685
	20000.	5.60	-3.00	1.65	-0.790
	30000.	5.93	-3.01	1.68	-0.855
	50000.	6.27	-2.86	1.73	-0.940
6P - 7S	2500.	0.317	0.212	0.728E-01	0.536E-01
9833.0 Å	5000.	0.366	0.257	0.801E-01	0.637E-01
C= 0.42E+20	10000.	0.413	0.310	0.884E-01	0.739E-01
	20000.	0.449	0.312	0.979E-01	0.847E-01
	30000.	0.480	0.320	0.104	0.913E-01
	50000.	0.512	0.276	0.113	0.100
6P - 8S	2500.	1.09	0.700		
5268.5 Å	5000.	1.23	0.844		
C= 0.20E+19	10000.	1.34	0.881	*0.283	*0.219
	20000.	1.49	0.810	*0.318	*0.266
	30000.	1.64	0.692	*0.340	*0.294
	50000.	1.84	0.574	*0.371	*0.329

PERTURBER DENSITY= 1xE+16cm-3					
PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
6P - 9S	2500.	1.66	-0.974		
4948.7 Å	5000.	1.78	-1.18		
C= 0.12E+19	10000.	1.85	-1.18		
	20000.	1.92	-1.03		
	30000.	2.05	-0.872		
	50000.	2.19	-0.701	*0.530	-0.461
7P - 8S	2500.	20.6	12.6		
22252.3 Å	5000.	23.6	15.3		
C= 0.36E+20	10000.	26.4	16.4		
	20000.	29.8	15.5	*5.91	*4.83
	30000.	32.5	13.8	*6.31	*5.34
	50000.	36.0	11.6	*6.85	*5.97
7P - 9S	2500.	20.9	-12.2		
17480.9 Å	5000.	22.3	-14.5		
C= 0.15E+20	10000.	23.8	-14.9		
	20000.	25.0	-11.8		
	30000.	27.0	-10.00		
	50000.	29.0	-8.18	*6.59	-5.70
6P - 6D	2500.	0.261	0.173	0.893E-01	0.423E-01
8212.5 Å	5000.	0.303	0.206	0.935E-01	0.504E-01
C= 0.16E+20	10000.	0.343	0.241	0.980E-01	0.586E-01
	20000.	0.380	0.242	0.103	0.673E-01
	30000.	0.405	0.235	0.107	0.726E-01
	50000.	0.437	0.198	0.112	0.797E-01
6P - 7D	2500.	1.76	-0.265		
5161.4 Å	5000.	2.15	-0.161		
C= 0.41E+18	10000.	2.43	-0.821E-01		
	20000.	2.67	-0.172E-01		
	30000.	2.74	0.245E-01		
	50000.	2.77	0.465E-01	*0.574	-0.430

The obtained results will be presented elsewhere (Dimitrijević and Sahal-Bréchot, 1996). Here, only a part of the results will be shown as an illustration, as well as the comparison with simple estimates (Lakićević, 1983).

2. RESULTS AND DISCUSSION

Energy levels for Ba I lines have been taken from Moore (1971). Oscillator strengths have been calculated by using the method of Bates & Damgaard (1949) and the tables of Oertel & Shomo (1968). For higher levels, the method described by Van Regemorter et al. (1979) has been used.

In addition to electron-impact full halfwidths and shifts, Stark-broadening parameters due to proton-, and He II- impacts have been calculated.

As the illustration, one part of our results is shown in Table 1 for a perturber density of 10^{16} cm^{-3} and temperatures T = 2,500 - 50,000 K. For each value given in Table 1, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid (Sahal - Bréchot, 1969ab). Values for $0.1 < NV \leq 0.5$ are denoted with an asterisk.

Our results for Stark width are in agreement with the simple Stark width estimates of Lakićević (1983), on the basis of the Stark broadening parameter dependence on the ionization potential from the lower level of the corresponding transition. For Ba I $6s^2\,^1S$ - $6p\,^1P^o$ Lakićević (1983) obtained FWHM = 0.48 Å at an electron density of $N_e = 10^{17}$ cm^{-3} and electron temperature T=20000 K, and our result is 0.30 Å, which is good accordance.

On the other hand, our results for the shift are in strong desagreement with simple estimates of Lakićević (1983). Reliable experimental data for Ba I Stark broadening parameters will be of interest for the development of theoretical methods for heavy atoms and ions.

References

Anders, E. and Grevesse, N.: 1989, *Geochim. et Cosmochim. Acta*, **53**, 197.
Aulehla, E. and Herman, L.: 1958, *C.R.H.Acad.Sci.* **246**, 1676.
Bates, D. R. and Damgaard, A.: 1949, *Trans. Roy. Soc. London, Ser. A* **242**, 101.
Davis, J.: 1972, *JQSRT*, **12**, 1351.
Dimitrijević, M. S. and Sahal–Bréchot, S.: 1984, *JQSRT*, **31**, 301.
Dimitrijević, M. S. and Sahal-Bréchot, S.: 1996, *Astron. Astrophys. Suppl. Series*, submitted.
Grechikhin, L. I.: 1969, *J. Appl. Spectrosc. (USSR)* **10**, 870.
Kato, K., Fukushima, H., Nakajima, T.: 1984, *Spectrochim. Acta B* **39**, 979.
Komarov, N.S. and Basak, N. Yu.: 1993, *Astron. Zh.* **70**, 111.
Lakićević, I. S.: 1983, *Astron. Astrophys.* **127**, 37.
Moore, C. E.: 1971, Atomic Energy Levels Vol. II, NSRDS-NBS 35, U.S. Govt. Print. Office, Washington.
Oertel, G. K. and Shomo, L. P.: 1968, *Astrophys. J. Suppl. Series*, **16**, 175.
Sahal-Bréchot, S.: 1969a, *Astron. Astrophys.* **1**, 91.
Sahal-Bréchot, S.: 1969b, *Astron. Astrophys.* **2**, 322.
Sleivytė, J., Bartkevičius, A.: 1995, *Vilniaus Astronomijos Observatorijos Biuletenis*, **85**, 3.
Van Regemorter, H., Hoang Binh Dy, and Prud'homme, M.: 1979, *J. Phys. B* **12**, 1073.

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BROADENING DUE TO COLLISIONS WITH CHARGED PARTICLES OF V V AND V XIII SPECTRAL LINES

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Abstract. Using a semiclassical approach, we have calculated electron-, proton-, and He III-impact line widths and shifts for 33 vanadium V multiplets, for perturber densities 10^{14}– 10^{21} cm^{-3} and temperatures T = 50,000 – 500,000 K, and 26 vanadium XIII multiplets, for perturber densities 10^{18}– 10^{22} cm^{-3} and temperatures T = 500,000 – 5,000,000 K.

1. INTRODUCTION

Vanadium is present in stellar and solar plasma, and broadening parameters of its spectral lines for various ionization stages are of interest for the investigation and modelling of such plasma. For stellar plasma conditions with $T_{eff} \geq 10000$K hydrogen is mostly ionized and Stark broadening is the main pressure broadening mechanism. Lines of fourtly charged ions are present in e.g. PG 1159 star atmospheres (Werner et al., 1991), and with the development of space born techniques, the interest for lines of not abundant ions increases. Moreover, for the modelling of subphotospheric layers, higher ionization stages are of interest as well (Seaton, 1997). Consequently, Stark broadening parameters for multiply charged vanadium ion lines are of interest not only for the laboratory plasma research, testing and developping of the Stark broadening theory for shapes of multicharged ion lines, and investigations of regularities and systematic trends (particularly along isoelectronic sequences), but as well for the consideration of stellar plasma.

By using the semiclassical-perturbation formalism (Sahal-Bréchot 1969ab), we have calculated electron-, proton-, and He III-impact line widths and shifts for 33 vanadium V and 26 vanadium XIII multiplets. A short review of the formalism is given e.g. in Dimitrijević *et al.* (1991).

2. RESULTS AND DISCUSSION

Energy levels for vanadium V and vanadium XIII lines have been taken from Bashkin and Stoner (1981). All other details of calculations are given in Dimitrijević and Sahal-Bréchot (1997). Our results for electron-, proton-, and He III-impact line widths

and shifts for 33 vanadium V multiplets, for perturber densities 10^{14}– 10^{21} cm^{-3} and temperatures T = 50,000 – 500,000 K, and 26 vanadium XIII multiplets, for perturber densities 10^{18}– 10^{22} cm^{-3} and temperatures T = 500,000 – 5,000,000 K, will be published elsewhere (Dimitrijević and Sahal-Bréchot, 1997). A sample of results is presented in Tables 1 and 2 for vanadium V and vanadium XIII respectively. We also specify a parameter C (Dimitrijević and S.Sahal-Bréchot, 1984), which gives an estimate for the maximum perturber density for which the line may be treated as isolated when it is divided by the corresponding full width at half maximum.

Table 1

This table shows electron- and proton-impact broadening full half-widths (FWHM) and shifts for V V for a perturber density of 10^{16} cm^{-3} and temperatures from 50,000 up to 500,000 K. By deviding C with the full linewidth, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used.

PERTURBER DENSITY = 1.E+16cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
V V 4S 4P	50000.	0.237E-02	-0.417E-04	0.480E-04	-0.210E-04
1692.2 A	100000.	0.171E-02	-0.382E-04	0.879E-04	-0.368E-04
C= 0.17E+20	150000.	0.144E-02	-0.452E-04	0.109E-03	-0.479E-04
	200000.	0.128E-02	-0.527E-04	0.127E-03	-0.543E-04
	300000.	0.111E-02	-0.528E-04	0.146E-03	-0.664E-04
	500000.	0.941E-03	-0.466E-04	0.163E-03	-0.771E-04
V V 4S 5P	50000.	0.420E-03	0.173E-05	0.276E-04	0.333E-06
490.9 A	100000.	0.324E-03	0.873E-06	0.384E-04	0.651E-06
C= 0.57E+18	150000.	0.283E-03	0.231E-05	0.422E-04	0.924E-06
	200000.	0.259E-03	0.318E-05	0.447E-04	0.114E-05
	300000.	0.231E-03	0.171E-05	0.478E-04	0.148E-05
	500000.	0.204E-03	0.214E-05	0.516E-04	0.188E-05
V V 5S 5P	50000.	0.420E-01	-0.159E-02	0.215E-02	-0.108E-02
4232.2 A	100000.	0.325E-01	-0.180E-02	0.308E-02	-0.153E-02
C= 0.42E+20	150000.	0.285E-01	-0.192E-02	0.342E-02	-0.181E-02
	200000.	0.262E-01	-0.171E-02	0.367E-02	-0.193E-02
	300000.	0.235E-01	-0.171E-02	0.400E-02	-0.217E-02
	500000.	0.208E-01	-0.160E-02	0.444E-02	-0.246E-02

Table 1 continued

PERTURBER DENSITY = 1.E+16cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
V V 4P 5S	50000.	0.102E-02	0.808E-04	0.271E-04	0.454E-04
826.6 A	100000.	0.756E-03	0.829E-04	0.505E-04	0.637E-04
C= 0.16E+19	150000.	0.647E-03	0.919E-04	0.692E-04	0.746E-04
	200000.	0.587E-03	0.881E-04	0.780E-04	0.799E-04
	300000.	0.517E-03	0.836E-04	0.917E-04	0.891E-04
	500000.	0.445E-03	0.788E-04	0.109E-03	0.101E-03
V V 4P 4D	50000.	0.142E-02	0.211E-04	0.539E-04	0.118E-04
1152.7 A	100000.	0.104E-02	0.172E-04	0.841E-04	0.203E-04
C= 0.74E+19	150000.	0.878E-03	0.229E-04	0.103E-03	0.260E-04
	200000.	0.789E-03	0.272E-04	0.113E-03	0.296E-04
	300000.	0.688E-03	0.257E-04	0.122E-03	0.357E-04
	500000.	0.593E-03	0.220E-04	0.134E-03	0.413E-04
V V 4P 5D	50000.	0.627E-03	0.237E-04	0.484E-04	0.134E-04
553.2 A	100000.	0.482E-03	0.229E-04	0.660E-04	0.196E-04
C= 0.84E+18	150000.	0.423E-03	0.263E-04	0.714E-04	0.236E-04
	200000.	0.389E-03	0.263E-04	0.755E-04	0.258E-04
	300000.	0.350E-03	0.244E-04	0.813E-04	0.287E-04
	500000.	0.312E-03	0.232E-04	0.875E-04	0.328E-04

Table 2

This table shows electron- and proton-impact broadening full half-widths (FWHM) and shifts for V XIII for a perturber density of 10^{19} cm^{-3}.

PERTURBER DENSITY = 1.E+19cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
V XIII3S 3P	500000.	0.154E-01	-0.176E-03	0.162E-03	-0.161E-03
429.5 A	1000000.	0.112E-01	-0.211E-03	0.385E-03	-0.306E-03
C=0.43E+20	1500000.	0.932E-02	-0.228E-03	0.566E-03	-0.413E-03
	2000000.	0.824E-02	-0.207E-03	0.702E-03	-0.501E-03
	3000000.	0.698E-02	-0.205E-03	0.893E-03	-0.604E-03
	5000000.	0.573E-02	-0.194E-03	0.115E-02	-0.765E-03
V XIII3S 4P	500000.	0.106E-02	0.436E-05	0.449E-04	0.592E-05
71.9 A	1000000.	0.785E-03	0.689E-05	0.731E-04	0.111E-04
C=0.47E+20	1500000.	0.665E-03	0.530E-05	0.900E-04	0.148E-04
	2000000.	0.595E-03	0.585E-05	0.101E-03	0.175E-04
	3000000.	0.512E-03	0.578E-05	0.110E-03	0.213E-04
	5000000.	0.430E-03	0.561E-05	0.124E-03	0.261E-04

V XIII3S 5P	500000.	0.122E-02	0.208E-04	0.104E-03	0.283E-04
52.9 A	1000000.	0.922E-03	0.212E-04	0.145E-03	0.422E-04
C=0.13E+20	1500000.	0.794E-03	0.207E-04	0.159E-03	0.517E-04
	2000000.	0.719E-03	0.201E-04	0.170E-03	0.572E-04
	3000000.	0.630E-03	0.200E-04	0.186E-03	0.637E-04
	5000000.	0.540E-03	0.177E-04	0.209E-03	0.725E-04
V XIII4S 4P	500000.	0.297	-0.624E-02	0.114E-01	-0.841E-02
1100.4 A	1000000.	0.222	-0.635E-02	0.191E-01	-0.132E-01
C=0.11E+20	1500000.	0.190	-0.635E-02	0.243E-01	-0.160E-01
	2000000.	0.170	-0.619E-02	0.278E-01	-0.182E-01
	3000000.	0.148	-0.594E-02	0.315E-01	-0.202E-01
	5000000.	0.125	-0.550E-02	0.371E-01	-0.232E-01
V XIII4S 5P	500000.	0.136E-01	0.408E-04	0.106E-02	0.812E-04
169.4 A	1000000.	0.104E-01	0.282E-04	0.146E-02	0.140E-03
C=0.13E+20	1500000.	0.895E-02	0.328E-04	0.160E-02	0.177E-03
	2000000.	0.811E-02	0.269E-04	0.170E-02	0.203E-03
	3000000.	0.712E-02	0.326E-04	0.186E-02	0.243E-03
	5000000.	0.612E-02	0.198E-04	0.210E-02	0.280E-03
V XIII5S 5P	500000.	2.86	-0.923E-01	0.207	-0.144
2237.5 A	1000000.	2.20	-0.844E-01	0.303	-0.201
C=0.22E+20	1500000.	1.91	-0.826E-01	0.341	-0.225
	2000000.	1.74	-0.816E-01	0.373	-0.244
	3000000.	1.53	-0.763E-01	0.425	-0.272
	5000000.	1.32	-0.646E-01	0.508	-0.309

There is not measured or calculated vanadium V and XIII Stark broadening parameters. The corresponding experimental data will be very useful for further development and rafinement of the theory of multicharged ion lines.

References

Bashkin,S., Stoner, J.O.Jr.: 1981, "Atomic Energy Levels and Grotrian Diagrams", Vol. 3, North Holland, Amsterdam.

Dimitrijević, M.S., and Sahal-Bréchot,S.: 1984, *JQSRT* **31**, 301.

Dimitrijević M.S. and Sahal-Bréchot, S.: 1997, *Atomic Data and Nuclear Data Tables* submitted.

Dimitrijević, M.S., Sahal-Bréchot, S. and Bommier,V.: 1991, *Astron. Astrophys. Suppl. Series* **89**, 581.

Sahal-Bréchot, S.: 1969a, *Astron.Astrophys.* **1**, 91.

Sahal-Bréchot, S.: 1969b, *Astron.Astrophys.* **2**, 322.

Seaton, M.J., 1987, *J. Phys. B* **20**, 6363.

Werner, K., Heber, U., Hunger, K., 1991, *Astron. Astrophys.* **244**, 437.

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ON THE STARK BROADENING OF Si XIII LINES

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Abstract. Using a semiclassical approach, we have calculated electron-, proton-, and He III-impact line widths and shifts for 61 Si XIII multiplets.

1. INTRODUCTION

Silicon is important for the consideration of physical processes in stellar plasmas, and the corresponding data on spectral lines from its various ionization stages are consequently of particular astrophysical interest. Stark broadening parameters of Si XIII spectral lines are important not only for astrophysics, as e.g. for the consideration of radiative transfer through subphotospheric layers, but also for the fusion plasmas and laser produced plasmas research. The development of soft x-ray lasers, where Stark broadening data are needed to calculate gain values, model radiation trapping and to consider photoresonant pumping schemes (see e.g. Griem and Moreno, 1990; Fill and Schöning, 1994), provided an additional interest for such results.

In order to provide the needed Si XIII Stark broadening parameters,we have calculated within the semiclassical-perturbation formalism (Sahal-Bréchot 1969ab), electron-, proton-, and He III-impact line widths and shifts for 61 Si XIII multiplets. A summary of the formalism is given in Dimitrijević *et al.* (1991).

2. RESULTS AND DISCUSSION

As the continuation of our programme to provide to astrophysicists and plasma physicists the needed Stark-broadening parameters (see Dimitrijević 1996, Dimitrijević and Sahal-Bréchot 1995 and references therein), electron-, proton-, and He III- impact Si XIII line widths and shifts have been calculated. Energy levels for Si III have been taken from Martin and Zalubas (1983). Our results for 61 Si XIII multiplets, for perturber densities 10^{16} - 10^{23} cm^{-3} and temperatures T = 500,000 - 6,000,000K will be published in Dimitrijević and Sahal-Bréchot (1997a,b).

Table 1

This table shows electron- and proton-impact broadening full half-widths (FWHM) and shifts for Si III for a perturber density of 10^{19} cm^{-3} and temperatures from 500,000 up to 6,000,000 K. By deviding C with the full linewidth, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used.

PERTURBER DENSITY = 1.E+19cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Si XIII1S 2P	500000.	0.115E-05	-0.150E-07	0.265E-08	-0.103E-07
6.6 A	750000.	0.939E-06	-0.745E-08	0.519E-08	-0.156E-07
C=0.37E+18	1000000.	0.816E-06	-0.731E-08	0.847E-08	-0.206E-07
	2000000.	0.587E-06	-0.390E-08	0.261E-07	-0.376E-07
	4000000.	0.426E-06	-0.331E-08	0.625E-07	-0.587E-07
	6000000.	0.355E-06	-0.200E-08	0.897E-07	-0.713E-07
Si XIII1S 3P	500000.	0.363E-05	-0.137E-06	0.785E-06	-0.101E-05
5.7 A	750000.	0.306E-05	-0.124E-06	0.119E-05	-0.124E-05
C=0.12E+17	1000000.	0.271E-05	-0.120E-06	0.158E-05	-0.140E-05
	2000000.	0.205E-05	-0.105E-06	0.257E-05	-0.169E-05
	4000000.	0.156E-05	-0.841E-07	0.355E-05	-0.202E-05
	6000000.	0.134E-05	-0.699E-07	0.415E-05	-0.223E-05
Si XIII1S 4P	500000.	0.950E-05	-0.421E-06	0.646E-05	-0.548E-05
5.4 A	750000.	0.814E-05	-0.396E-06	0.835E-05	-0.624E-05
C=0.44E+16	1000000.	0.730E-05	-0.403E-06	0.977E-05	-0.674E-05
	2000000.	0.565E-05	-0.375E-06	0.136E-04	-0.804E-05
	4000000.	0.441E-05	-0.322E-06	0.175E-04	-0.912E-05
	6000000.	0.383E-05	-0.261E-06	0.197E-04	-0.981E-05
Si XIII2S 2P	500000.	0.454E-01	-0.103E-02	0.178E-03	-0.141E-02
1200.7 A	750000.	0.376E-01	-0.109E-02	0.455E-03	-0.208E-02
C=0.12E+23	1000000.	0.329E-01	-0.105E-02	0.829E-03	-0.266E-02
	2000000.	0.243E-01	-0.988E-03	0.263E-02	-0.429E-02
	4000000.	0.181E-01	-0.929E-03	0.548E-02	-0.597E-02
	6000000.	0.153E-01	-0.825E-03	0.810E-02	-0.679E-02
Si XIII2S 3P	500000.	0.169E-03	-0.659E-05	0.352E-04	-0.452E-04
37.8 A	750000.	0.143E-03	-0.632E-05	0.532E-04	-0.556E-04
C=0.55E+18	1000000.	0.127E-03	-0.613E-05	0.709E-04	-0.630E-04
	2000000.	0.958E-04	-0.552E-05	0.115E-03	-0.758E-04
	4000000.	0.733E-04	-0.454E-05	0.159E-03	-0.905E-04
	6000000.	0.631E-04	-0.385E-05	0.187E-03	-0.100E-03

Table 1 continued

PERTURBER DENSITY = 1.E+19cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Si XIII2S 4P	500000.	0.263E-03	-0.118E-04	0.176E-03	-0.149E-03
28.2 A	750000.	0.226E-03	-0.113E-04	0.228E-03	-0.170E-03
C=0.12E+18	1000000.	0.203E-03	-0.114E-04	0.267E-03	-0.184E-03
	2000000.	0.157E-03	-0.107E-04	0.370E-03	-0.219E-03
	4000000.	0.122E-03	-0.923E-05	0.476E-03	-0.249E-03
	6000000.	0.107E-03	-0.753E-05	0.537E-03	-0.268E-03
Si XIII3S 3P	500000.	2.54	-0.152	0.511	-0.662
4122.7 A	750000.	2.17	-0.149	0.760	-0.819
C=0.65E+22	1000000.	1.94	-0.147	1.02	-0.915
	2000000.	1.50	-0.136	1.61	-1.10
	4000000.	1.16	-0.112	2.23	-1.31
	6000000.	1.00	-0.959E-01	2.64	-1.43
Si XIII3S 4P	500000.	0.425E-02	-0.224E-03	0.265E-02	-0.225E-02
108.3 A	750000.	0.365E-02	-0.217E-03	0.340E-02	-0.255E-02
C=0.17E+19	1000000.	0.328E-02	-0.219E-03	0.399E-02	-0.275E-02
	2000000.	0.256E-02	-0.206E-03	0.557E-02	-0.328E-02
	4000000.	0.200E-02	-0.176E-03	0.720E-02	-0.372E-02
	6000000.	0.174E-02	-0.145E-03	0.814E-02	-0.401E-02
Si XIII2P 3S	500000.	0.978E-04	0.787E-05	0.776E-05	0.200E-04
39.4 A	750000.	0.838E-04	0.795E-05	0.151E-04	0.257E-04
C=0.38E+19	1000000.	0.753E-04	0.788E-05	0.192E-04	0.294E-04
	2000000.	0.587E-04	0.746E-05	0.377E-04	0.383E-04
	4000000.	0.460E-04	0.630E-05	0.559E-04	0.460E-04
	6000000.	0.398E-04	0.547E-05	0.685E-04	0.509E-04
Si XIII2P 4S	500000.	0.137E-03	0.170E-04	0.397E-04	0.571E-04
29.0 A	750000.	0.120E-03	0.169E-04	0.583E-04	0.683E-04
C=0.86E+18	1000000.	0.109E-03	0.168E-04	0.708E-04	0.731E-04
	2000000.	0.875E-04	0.147E-04	0.102E-03	0.882E-04
	4000000.	0.694E-04	0.120E-04	0.142E-03	0.105E-03
	6000000.	0.603E-04	0.106E-04	0.169E-03	0.114E-03

In Table 1, only a sample of results is shown. Parameter C (Dimitrijević and Sahal-Bréchot 1984), given also in Table 1, provides an estimate for the maximum perturber density for which the line may be treated as isolated when it is divided by the corresponding electron-impact full width at half maximum.

We hope that the present results will be of interest for the investigation of various problems concerning the stellar, laboratory, fusion and laser produced plasma, and soft x-ray lasers modeling and research. We hope as well that the presented results will be of interest for the investigation of behaviour of Stark broadening parameters along isoelectronic sequences.

References

Dimitrijević, M. S., 1996, *Zh. Prikl. Spektrosk.* **63**, 810.
Dimitrijević, M.S., and Sahal-Bréchot,S.: 1984, *JQSRT* **31**, 301.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1995, *Astron. Astrophys. Suppl. Series* **109**, 551.
Dimitrijević M.S. and Sahal-Bréchot, S.: 1997a, *Astron. Astrophys. Suppl. Series* submitted.
Dimitrijević M.S. and Sahal-Bréchot, S.: 1997b, *Bull. Astron. Belgrade* **156**, in press.
Dimitrijević, M.S., Sahal-Bréchot, S. and Bommier,V.: 1991, *Astron. Astrophys. Suppl. Series* **89**, 581.
Fill, E. E., Schöning, T.: 1994, *J. Appl. Phys.* **76**, 1423.
Griem, H. R., Moreno, J. C.: 1990, in: *X-Ray Lasers*, ed.G. Tallents, Institute of Physics, Bristol, 301.
Martin, W. C., Zalubas, R.: 1983, *J. Phys. Chem. Reference Data* **12**, 323.
Sahal-Bréchot, S.: 1969a, *Astron.Astrophys.* **1**, 91.
Sahal-Bréchot, S.: 1969b, *Astron.Astrophys.* **2**, 322.

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ON THE STARK BROADENING OF Y III SPECTRAL LINES

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Abstract. Using a semiclassical approach, we have considered electron-, proton-, and ionized helium-impact line widths and shifts for 32 Y III multiplets, for perturber densities 10^{14}– 10^{19} cm^{-3} and temperatures T = 10,000 – 300,000 K.

1. INTRODUCTION

Yttrium spectral lines are observed in spectra of hot stars, as e.g. in the spectrum of ϕ Her (T_{eff} = 11,500K, log$g$ = 3.5) and o And (T_{eff} = 9,500K, log$g$ =3.5) (Adelman and Lanz 1987). Sadakane and Ueta (1989) have found its overabundance in the spectrum of Sirius, and Van't Veer-Mennert, Coupry and Burkhart (1985) in the spectrum of Am star HR 178. Savanov (1985) reports high yttrium abundance in hot Am stars, where Stark broadening is the principal pressure broadening mechanism. Yttrium is additionally of interest for astrophysics, since it is commonly associated with slow-neutron-capture nucleosynthesis in stellar interiors (see e.g. Leckrone et al. 1993). Consequently, Y III lines are of interest for the diagnostic and modelling not only for laboratory plasma, but as well for stellar plasmas research.

Popović and Dimitrijević (1996) have published recently, electron - impact broadening parameters for astrophysically important ns-np transitions of singly charged yttrium ion, calculated within the modified semiempirical approach (Dimitrijević and Konjević, 1980). In order to provide the corresponding Stark broadening data for yttrium III spectral lines, we have calculated within the semiclassical-perturbation formalism (Sahal-Bréchot 1969ab) electron-, proton-, and ionized - helium-impact line widths and shifts for 32 Y III multiplets.

2. RESULTS AND DISCUSSION

Energy levels for yttrium III have been taken from Epstein and Reader (1975). Details of calculations will be published in Dimitrijević and S.Sahal-Bréchot (1997). Our results for electron-, proton-, and helium ion-impact line widths and shifts for 32 Y III multiplets, for perturber densities 10^{14}– 10^{19} cm^{-3} and temperatures T = 10,000 – 300,000 K, will be published elsewhere (Dimitrijević and Sahal-Bréchot, 1997). A sample of results is presented in Table 1.

Table 1

This table shows electron- and proton-impact broadening parameters for Y III for a perturber density of 10^{15} cm^{-3} and temperatures from 10,000 up to 300,000 K. Transitions and averaged wavelengths for the multiplet (in Å) are also given. If one divides C value with the linewidth value, we obtain an estimate for the maximum perturber density (in cm^{-3}) for which the line may be treated as isolated and tabulated data may be used.

PERTURBER DENSITY = 1.E+15cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Y III 6d-6f	10000.	0.758E-01	-0.308E-02	0.627E-02	0.370E-02
5585.7 A	20000.	0.700E-01	-0.192E-02	0.745E-02	0.450E-02
C= 0.34E+18	50000.	0.657E-01	-0.123E-02	0.901E-02	0.568E-02
	100000.	0.619E-01	-0.804E-03	0.102E-01	0.655E-02
	150000.	0.588E-01	-0.111E-02	0.111E-01	0.714E-02
	300000.	0.521E-01	-0.950E-03	0.117E-01	0.794E-02
Y III 4f-5d	10000.	0.331E-01	0.193E-02	0.119E-02	0.561E-03
7942.3 A	20000.	0.249E-01	0.185E-02	0.179E-02	0.846E-03
C= 0.71E+19	50000.	0.191E-01	0.188E-02	0.238E-02	0.122E-02
	100000.	0.165E-01	0.159E-02	0.274E-02	0.146E-02
	150000.	0.153E-01	0.156E-02	0.298E-02	0.163E-02
	300000.	0.135E-01	0.144E-02	0.320E-02	0.186E-02
Y III 4f-6d	10000.	0.285E-01	0.105E-01	0.204E-02	0.146E-02
5585.7 A	20000.	0.235E-01	0.766E-02	0.277E-02	0.196E-02
C= 0.15E+19	50000.	0.206E-01	0.563E-02	0.352E-02	0.249E-02
	100000.	0.189E-01	0.432E-02	0.409E-02	0.290E-02
	150000.	0.180E-01	0.388E-02	0.437E-02	0.316E-02
	300000.	0.162E-01	0.315E-02	0.508E-02	0.360E-02
Y III 4f-7d	10000.	0.153E-01	0.791E-02	0.178E-02	0.131E-02
3016.8 A	20000.	0.137E-01	0.637E-02	0.216E-02	0.160E-02
C= 0.24E+18	50000.	0.126E-01	0.463E-02	0.273E-02	0.200E-02
	100000.	0.121E-01	0.364E-02	0.307E-02	0.231E-02
	150000.	0.116E-01	0.315E-02	0.320E-02	0.244E-02
	300000.	0.105E-01	0.240E-02	0.376E-02	0.282E-02
Y III 5f-6d	10000.	0.611	0.109	0.378E-01	0.853E-02
20955.3 A	20000.	0.533	0.747E-01	0.460E-01	0.120E-01
C= 0.91E+19	50000.	0.489	0.587E-01	0.545E-01	0.159E-01
	100000.	0.453	0.432E-01	0.594E-01	0.190E-01
	150000.	0.430	0.384E-01	0.613E-01	0.210E-01
	300000.	0.383	0.342E-01	0.663E-01	0.234E-01

Table 1 continued

PERTURBER DENSITY = 1.E+15cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Y III 5f-7d	10000.	0.192	0.727E-01	0.184E-01	0.116E-01
9548.4 A	20000.	0.176	0.572E-01	0.219E-01	0.141E-01
C= 0.19E+19	50000.	0.165	0.417E-01	0.269E-01	0.179E-01
	100000.	0.158	0.326E-01	0.299E-01	0.203E-01
	150000.	0.152	0.286E-01	0.320E-01	0.217E-01
	300000.	0.137	0.218E-01	0.349E-01	0.253E-01
Y III 6f-7d	10000.	4.37	0.876	0.342	0.118E-02
37626.1 A	20000.	4.13	0.699	0.387	0.223E-02
C= 0.15E+20	50000.	3.92	0.508	0.437	0.408E-02
	100000.	3.76	0.399	0.459	0.562E-02
	150000.	3.59	0.364	0.471	0.623E-02
	300000.	3.21	0.271	0.508	0.749E-02
Y III 4f-5g	10000.	0.162E-01	-0.255E-03	0.825E-03	-0.518E-03
4041.0 A	20000.	0.127E-01	-0.363E-03	0.115E-02	-0.717E-03
C= 0.34E+18	50000.	0.101E-01	-0.207E-03	0.145E-02	-0.918E-03
	100000.	0.887E-02	-0.248E-03	0.169E-02	-0.109E-02
	150000.	0.825E-02	-0.164E-03	0.179E-02	-0.117E-02
	300000.	0.731E-02	-0.416E-04	0.208E-02	-0.134E-02
Y III 4f-6g	10000.	0.257E-01	0.917E-03	0.436E-02	0.418E-02
2711.2 A	20000.	0.217E-01	0.803E-03	0.573E-02	0.507E-02
C= 0.71E+16	50000.	0.178E-01	0.569E-03	0.771E-02	0.604E-02
	100000.	0.154E-01	0.385E-03	0.963E-02	0.689E-02
	150000.	0.140E-01	0.335E-03	0.114E-01	0.733E-02
	300000.	0.118E-01	0.236E-03	0.137E-01	0.807E-02
Y III 5f-5g	10000.	3.45	-0.121	0.205	-0.134
48267.9 A	20000.	2.92	-0.167	0.264	-0.173
C= 0.48E+20	50000.	2.51	-0.122	0.334	-0.222
	100000.	2.27	-0.115	0.381	-0.258
	150000.	2.13	-0.902E-01	0.413	-0.278
	300000.	1.88	-0.589E-01	0.459	-0.316

Table 1 continued

PERTURBER DENSITY = 1.E+15cm-3					
PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Y III 5f-6g	10000.	0.196	0.413E-02	0.293E-01	0.278E-01
7037.7 A	20000.	0.168	0.288E-02	0.382E-01	0.337E-01
C= 0.48E+17	50000.	0.142	0.184E-02	0.519E-01	0.403E-01
	100000.	0.124	0.891E-03	0.648E-01	0.459E-01
	150000.	0.114	0.832E-03	0.761E-01	0.486E-01
	300000.	0.963E-01	0.462E-03	0.927E-01	0.540E-01
Y III 5g-6f	10000.	0.203	0.159E-01	0.177E-01	0.129E-01
9042.4 A	20000.	0.185	0.133E-01	0.215E-01	0.157E-01
C= 0.88E+18	50000.	0.169	0.120E-01	0.269E-01	0.198E-01
	100000.	0.158	0.971E-02	0.314E-01	0.224E-01
	150000.	0.149	0.786E-02	0.328E-01	0.246E-01
	300000.	0.131	0.593E-02	0.397E-01	0.273E-01

There is not measured or calculated Y III Stark broadening parameters. The corresponding experimental data will be very useful for further development and rafinement of the theory of multicharged ion lines.

References

Adelman, S.J., Lanz, T. eds.: 1987, Elemental abundance analyses, Institut d'Astronomie de l'Université de Lausanne.

Dimitrijević, M.S., Konjević, N.: 1980, *J.Quant.Spectrosc.Radiat.Transfer* **24**, 451.

Dimitrijević M.S. and Sahal-Bréchot, S.: 1997, *Astron. Astrophys. Transactions* submitted.

Epstein, G.L., Reader, J.: 1975,*J. Opt. Soc. of America* **65**, 310.

Leckrone, D.S., Wahlgren, G.M., Johansson, S.G., Adelman, S.J.: 1993, in Peculiar versus Normal Phenomena in A-Type and Related Stars, eds. M.M. Dworetsky, F. Castelli, R. Faraggiana, ASP Conference Series **44**, 42. Sadakane, K., Ueta, M.: 1989, *PASPJ* **41**, 279.

Popović, L. Č., Dimitrijević, M.S.: 1996, *Astron. Astrophys. Suppl. Series* **120**, 373.

Sahal-Bréchot, S.: 1969a, *Astron.Astrophys.* **1**, 91.

Sahal-Bréchot, S.: 1969b, *Astron.Astrophys.* **2**, 322.

Savanov, I.S.: 1985, *Izv. Krym. Astrofiz. Obs.* **73**, 92.

Van't Veer-Mennert, C., Coupry, M.F., Burkhart, C.: 1985, *Astron. Astrophys.* **146**, 139 .

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STARK BROADENING OF Ca X LINES

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Abstract. Using a semiclassical approach, we have calculated electron-, proton-, and He III-impact line widths and shifts for 48 Ca X multiplets.

1. INTRODUCTION

Investigation of Stark widths and shifts of Ca X is obviously of interest for the laboratory plasmas, fusion plasmas and laser produced plasmas research as well as for testing and developping of the Stark broadening theory for multicharged ion lines. Due to the abundance of calcium, such data are of interest as well for the consideration of solar and stellar plasma, particularly for subphotosperic layers as well as radiative transfer considerations. They are also of importance for the investigations of regularities and systematic trends particularly along isoelectronic sequences.

This contribution is the continuation of our efforts to provide needed data for the analysis of laboratory and astrophysical plasmas (see Dimitrijević 1996, Dimitrijević and Sahal-Bréchot 1995 and references therein). By using the semiclassical-perturbation formalism (Sahal-Bréchot 1969ab), we have calculated electron-, proton-, and He III-impact line widths and shifts for 48 Ca X multiplets. A summary of the formalism is given in Dimitrijević *et al.* (1991).

2. RESULTS AND DISCUSSION

Energy levels for Ca X lines have been taken from Bashkin and Stoner (1975). Oscillator strengths have been calculated by using the method of Bates and Damgaard (1949) and the tables of Oertel and Shomo (1968). For higher levels, the method described by Van Regemorter *et al.* (1979) has been used. In addition to electron-impact full halfwidths and shifts, Stark-broadening parameters due to proton-, and He III-impacts have been calculated. Our results for 48 Ca X multiplets, for perturber densities 10^{18} - 10^{22} cm^{-3} and temperatures T = 200,000 - 2,000,000K will be published in Dimitrijević and Sahal-Bréchot (1997a,b).

Table 1

This table shows electron- and proton-impact broadening full half-widths (FWHM) and shifts for Ca X for a perturber density of 10^{18} cm^{-3} and temperatures from 200,000 up to 2,000,000 K. By deviding C with the full linewidth, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used.

PERTURBER DENSITY = 1.E+18cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Ca X 3S 3P	200000.	0.498E-02	-0.601E-04	0.302E-04	-0.282E-04
563.1 A	500000.	0.322E-02	-0.532E-04	0.983E-04	-0.676E-04
C=0.56E+21	1000000.	0.238E-02	-0.679E-04	0.179E-03	-0.113E-03
	2000000.	0.180E-02	-0.605E-04	0.264E-03	-0.160E-03
	3000000.	0.155E-02	-0.581E-04	0.303E-03	-0.188E-03
	5000000.	0.130E-02	-0.561E-04	0.351E-03	-0.214E-03
Ca X 3S 4P	200000.	0.481E-03	0.314E-05	0.138E-04	0.190E-05
111.0 A	500000.	0.321E-03	0.343E-05	0.279E-04	0.438E-05
C=0.84E+19	1000000.	0.244E-03	0.303E-05	0.383E-04	0.691E-05
	2000000.	0.191E-03	0.315E-05	0.441E-04	0.951E-05
	3000000.	0.168E-03	0.310E-05	0.477E-04	0.107E-04
	5000000.	0.145E-03	0.267E-05	0.529E-04	0.123E-04
Ca X 3S 5P	200000.	0.571E-03	0.831E-05	0.366E-04	0.857E-05
82.8 A	500000.	0.395E-03	0.112E-04	0.574E-04	0.152E-04
C=0.22E+19	1000000.	0.310E-03	0.103E-04	0.666E-04	0.208E-04
	2000000.	0.250E-03	0.994E-05	0.761E-04	0.249E-04
	3000000.	0.224E-03	0.910E-05	0.817E-04	0.275E-04
	5000000.	0.196E-03	0.773E-05	0.890E-04	0.310E-04
Ca X 3S 6P	200000.	0.858E-03	0.227E-04	0.830E-04	0.230E-04
73.2 A	500000.	0.614E-03	0.238E-04	0.111E-03	0.358E-04
C=0.97E+18	1000000.	0.494E-03	0.221E-04	0.126E-03	0.432E-04
	2000000.	0.408E-03	0.206E-04	0.142E-03	0.515E-04
	3000000.	0.369E-03	0.185E-04	0.151E-03	0.573E-04
	5000000.	0.327E-03	0.151E-04	0.164E-03	0.632E-04
Ca X 4S 4P	200000.	0.103	-0.161E-02	0.259E-02	-0.175E-02
1475.2 A	500000.	0.698E-01	-0.234E-02	0.534E-02	-0.336E-02
C=0.15E+22	1000000.	0.539E-01	-0.209E-02	0.766E-02	-0.463E-02
	2000000.	0.428E-01	-0.194E-02	0.919E-02	-0.565E-02
	3000000.	0.378E-01	-0.185E-02	0.103E-01	-0.626E-02
	5000000.	0.326E-01	-0.157E-02	0.120E-01	-0.711E-02

Table 1 continued

PERTURBER DENSITY = 1.E+18cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Ca X 4S 5P	200000.	0.651E-02	0.153E-04	0.377E-03	0.250E-04
267.0 A	500000.	0.453E-02	0.195E-04	0.588E-03	0.531E-04
C=0.23E+20	1000000.	0.357E-02	0.214E-04	0.678E-03	0.771E-04
	2000000.	0.290E-02	0.217E-04	0.772E-03	0.101E-03
	3000000.	0.259E-02	0.159E-04	0.830E-03	0.112E-03
	5000000.	0.227E-02	0.134E-04	0.906E-03	0.128E-03
Ca X 4S 6P	200000.	0.591E-02	0.114E-03	0.542E-03	0.127E-03
187.4 A	500000.	0.424E-02	0.109E-03	0.719E-03	0.202E-03
C=0.64E+19	1000000.	0.341E-02	0.102E-03	0.821E-03	0.247E-03
	2000000.	0.282E-02	0.952E-04	0.921E-03	0.295E-03
	3000000.	0.255E-02	0.826E-04	0.972E-03	0.324E-03
	5000000.	0.226E-02	0.661E-04	0.106E-02	0.360E-03
Ca X 5S 5P	200000.	1.05	-0.299E-01	0.545E-01	-0.355E-01
3061.4 A	500000.	0.745	-0.305E-01	0.892E-01	-0.560E-01
C=0.31E+22	1000000.	0.593	-0.296E-01	0.107	-0.685E-01
	2000000.	0.483	-0.271E-01	0.129	-0.815E-01
	3000000.	0.432	-0.236E-01	0.146	-0.900E-01
	5000000.	0.378	-0.195E-01	0.166	-0.986E-01
Ca X 5S 6P	200000.	0.514E-01	-0.467E-04	0.415E-02	-0.159E-03
521.4 A	500000.	0.371E-01	-0.117E-03	0.548E-02	-0.320E-03
C=0.49E+20	1000000.	0.300E-01	-0.148E-03	0.623E-02	-0.446E-03
	2000000.	0.248E-01	-0.131E-03	0.700E-02	-0.557E-03
	3000000.	0.224E-01	-0.106E-03	0.745E-02	-0.618E-03
	5000000.	0.198E-01	-0.105E-03	0.818E-02	-0.703E-03
Ca X 6S 6P	200000.	7.11	-0.279	0.540	-0.350
5528.8 A	500000.	5.19	-0.266	0.754	-0.493
C=0.55E+22	1000000.	4.22	-0.257	0.905	-0.594
	2000000.	3.50	-0.208	1.08	-0.696
	3000000.	3.15	-0.179	1.20	-0.755
	5000000.	2.77	-0.151	1.37	-0.814
Ca X 3P 4S	200000.	0.561E-03	0.277E-04	0.704E-05	0.237E-04
152.6 A	500000.	0.380E-03	0.355E-04	0.282E-04	0.436E-04
C=0.16E+20	1000000.	0.292E-03	0.331E-04	0.495E-04	0.601E-04
	2000000.	0.230E-03	0.311E-04	0.712E-04	0.720E-04
	3000000.	0.202E-03	0.300E-04	0.835E-04	0.801E-04
	5000000.	0.172E-03	0.260E-04	0.102E-03	0.913E-04

Here, in Table 1, we present only a sample of results obtained. We also specify a parameter C (Dimitrijević and Sahal-Bréchot 1984), which gives an estimate for the maximum perturber density for which the line may be treated as isolated when it is divided by the corresponding electron-impact full width at half maximum. For each value given in Table 1, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid (Sahal-Bréchot, 1969ab). When the impact approximation is not valid, the ion broadening contribution may be estimated by using quasistatic estimations (Sahal-Bréchot 1991 and Griem 1974). The accuracy of the results obtained decreases when broadening by ion interactions becomes important.

We hope that the present results will be of interest for the the stellar, laboratory, fusion and laser produced plasma investigation and modeling.

References

Bashkin,S., Stoner, J.O.Jr.: 1975, "Atomic Energy Levels and Grotrian Diagrams", Vol. 1, North Holland, Amsterdam.
Bates,D.R. and Damgaard,A.: 1949, *Trans.Roy.Soc. London, Ser. A* **242**, 101.
Dimitrijević, M. S., 1996, *Zh. Prikl. Spektrosk.* **63**, 810.
Dimitrijević, M.S., and Sahal-Bréchot,S.: 1984, *JQSRT* **31**, 301.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1995, *Astron. Astrophys. Suppl. Series* **109**, 551.
Dimitrijević M.S. and Sahal-Bréchot, S.: 1997a, *Astron. Astrophys. Suppl. Series* submitted.
Dimitrijević M.S. and Sahal-Bréchot, S.: 1997b, *Bull. Astron. Belgrade* **152**, in press.
Dimitrijević, M.S., Sahal-Bréchot, S. and Bommier,V.: 1991, *Astron. Astrophys. Suppl. Series* **89**, 581.
Griem, H.R.: 1974, "Spectral Line Broadening by Plasmas", Academic Press, New York.
Oertel,G.K. and Shomo,L.P.: 1968, *Astrophys.J. Suppl. Series* **16**, 175.
Sahal-Bréchot, S.: 1969a, *Astron.Astrophys.* **1**, 91.
Sahal-Bréchot, S.: 1969b, *Astron.Astrophys.* **2**, 322.
Sahal-Bréchot, S.: 1991, *Astron.Astrophys.* **245**, 322.
Van Regemorter,H., Hoang Binh Dy, and Prud'homme,M.: 1979, *J.Phys.B* **12**, 1073.

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DIFFUSE BANDS IN INTERSTELLAR SPECTRA AND FULLERENES

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The problem of carriers of a number of Difuse Bands in interstellar spectra is a long-standing astrophysical problem. The discovery of C_{60} molecule and other molecules of such type - fullerenes lead to a spectacular progress in our understanding of the origin of such features in astrophysical spectra.

In this lecture, the discovery of fullerenes and its applications to the interpretation of astrophysical spectra will be discussed. The existence of fullerenes and its derrivatives in the space, their formation in the outflows of mass losing stsars and in different interstellar processes and their presence in the meteorites will be discussed as well.

We will discuss also the investigation of spectra of molecules including carbon chains-polyynes and its presence and identification in interstellar space.

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ON THE VARIATION OF STARK LINE SHIFTS WITHIN A SUPERMULTIPLET

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Abstract. In order to find out if regularities and systematic trends found to be apparent among experimental Stark line shifts allow the accurate interpolation of new data and critical evaluation of experimental results, the exceptions to the established regularities have been analysed on the basis of critical reviews of experimental data, and reasons for this situation have been discussed.

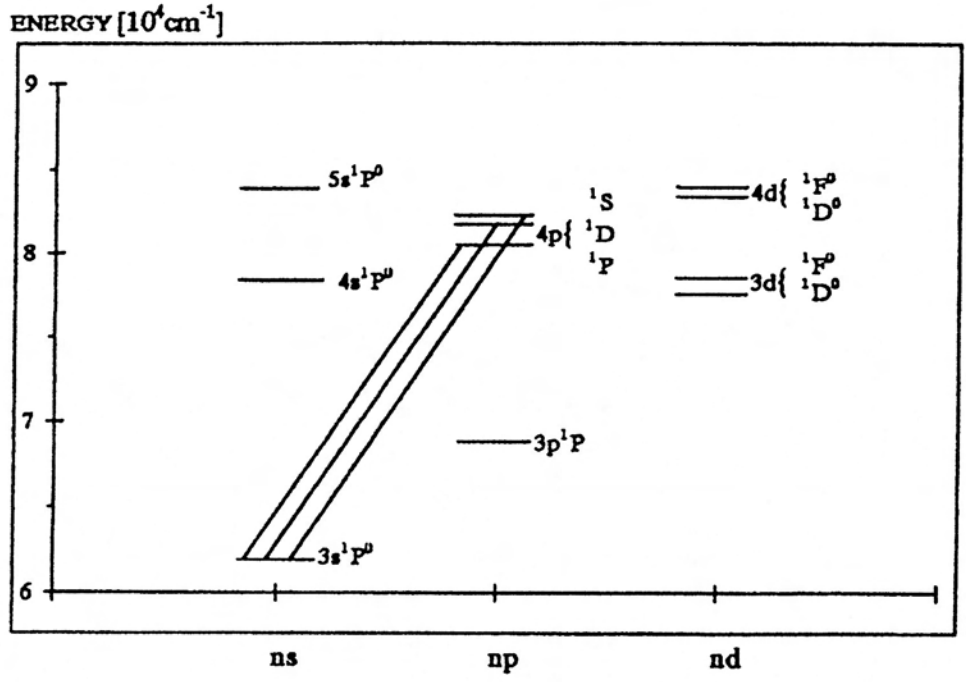
1. INTRODUCTION

Wiese and Konjević (1982) carried out a study of regularities in Stark widths of non-hydrogenic lines and they found similarities (see as well references in Wiese and Konjević, 1982 and Dimitrijević, 1982) of line widths within multiplets, supermultiplets, transition arrays and for analogous transitions of homologous atoms and ions. They found as well systematic trends along spectral series. Dimitrijević (1982) analysed the exceptions of the established regularities and he found that the reasons for such exceptions may be divided in two categories: (i) irregular atomic energy level structure and (ii) inadequacy of the used model of the emitter structure. In 1992, Wiese and Konjević published results of similar investigations of experimental Stark line shifts and they showed on the numerous examples the same regularities and systematic trends. The aim of this investigation is to analyze the exceptions of the established regularities and systematic trends for Stark line shifts.

2. RESULTS AND DISCUSSION

In order to examin if regularities and systematic trends found to be apparent among experimental Stark line shifts allow the accurate interpolation of new data and critical evaluation of experimental results, as well as the check of the consistency of a theoretical data set, the exceptions to the established regularities have been analysed on the basis of critical reviews of experimental data (Konjević and Roberts, 1976; Konjević and Wiese, 1976; Konjević, Dimitrijević, Wiese 1984ab; Konjević and Wiese, 1990) and reasons for this situation have been discussed.

The complete analysis will be published elsewhere. Here, we present two such examples.



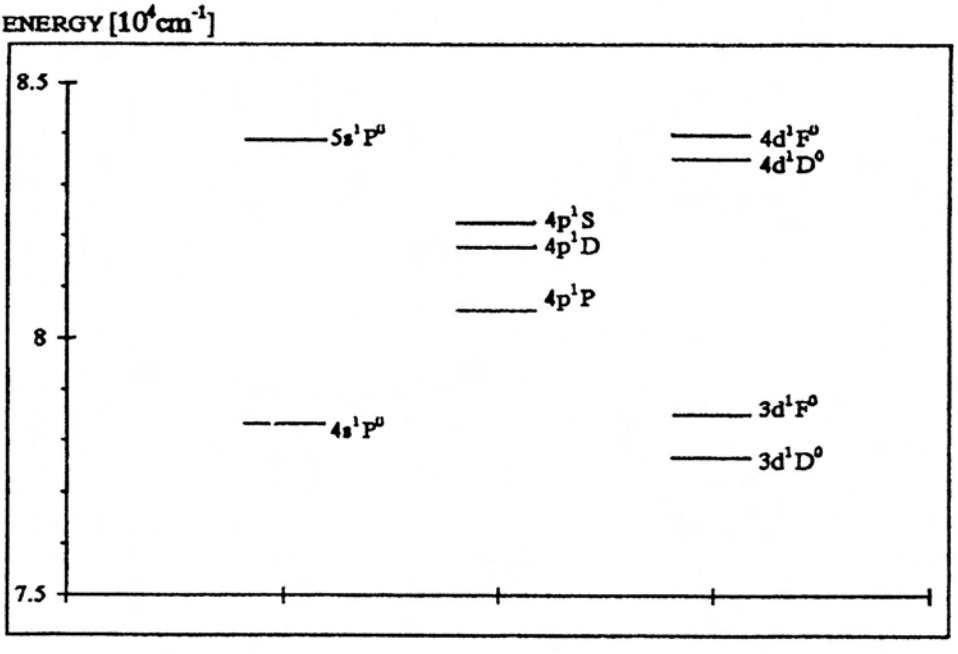


Fig. 1. Partial Grotrian diagram for C I (2p3s-2p(^{2}P°)4p)

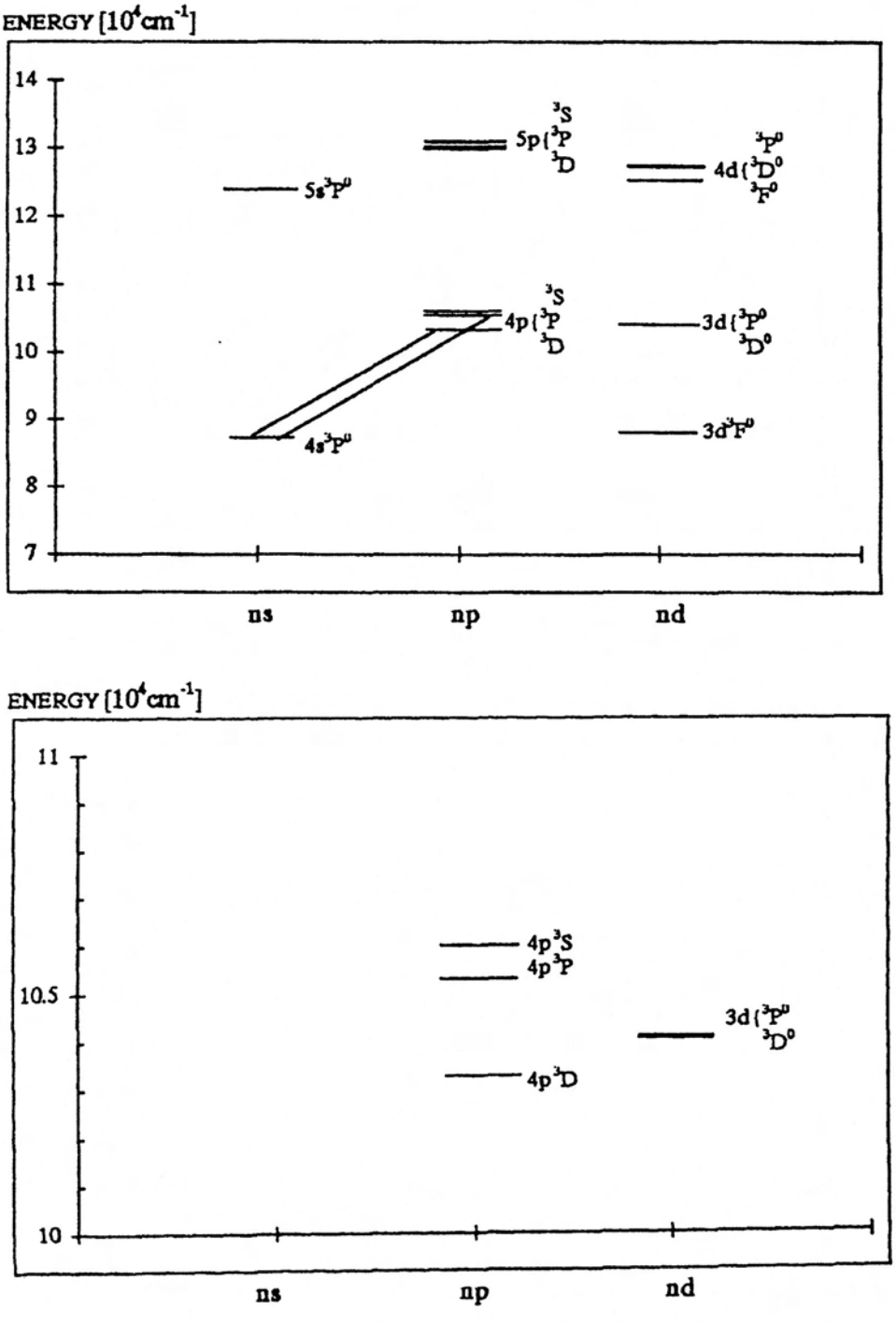


Fig. 1. Partial Grotrian diagram for P II (3p4s-3p(^{2}P°)4p)

The example of Stark line shifts from C I 3s - 4p (singlets) supermultiplet, illustrates the case when the energy gap between upper atomic energy levels for particular members of a supermultiplet is equal or comparable to the energy gap to perturbing levels. One can see that the difference of shift values in the examined example is one order of magnitude due to the different influence of perturbing 4d levels,

The example of Stark line shifts from P II 4s - 4p (triplets) supermultiplet, illustrates the case when the most important perturbing levels (3d levels in the examined case), are embeded between the energy levels (4p levels in the examined case) of upper/lower terms of the supermultiplet. One can see that in such a case even the sign of shift is different for different members of the examined supermultiplet.

Table 1

This table shows experimental (Miller and Bengston, 1970) Stark line shifts for C I 3s - 4p supermultiplet (singlets) for a perturber density of 10^{17} cm^{-3} and a temperature of 11 000 K.

Transition	j_i	j_f	λ(Å)	Shift(Å)	Accuracy
$3s^1P^o$-$4p^1P$	1	1	5380.3	0.3	C
$3s^1P^o$-$4p^1D$	2	1	5052.1	2.2	C
$3s^1P^o$-$4p^1S$	0	1	4932.0	3.0	C

Table 2

This table shows experimental (Purić et al., 1985) Stark line shifts for P II 4s - 4p supermultiplet (triplets) for a perturber density of 10^{17} cm^{-3} and a temperature of 20 000 K.

Transition	j_i	j_f	λ(Å)	Shift(Å)	Accuracy
$4s^3P^o$-$4p^3D$	2	3	6043.12	0.35	C
$4s^3P^o$-$4p^3D$	1	2	6024.18	0.31	C
$4s^3P^o$-$4p^3D$	0	1	6034.04	0.35	C
$4s^3P^o$-$4p^3P$	2	2	5425.91	-0.46	C

References

Dimitrijević, M. S.: 1982, *Astron. Astrophys.* **112**, 251.
Konjević, N., Roberts, J. R.: 1976, *J. Phys. Chem. Ref. Data* **5**, 209.
Konjević, N., Wiese, W. L.: 1976, *J. Phys. Chem. Ref. Data* **5**, 259.
Konjević, N., Dimitrijević, M. S., Wiese, W. L.: 1984a, *J. Phys. Chem. Ref. Data* **13**, 619.
Konjević, N., Dimitrijević, M. S., Wiese, W. L.: 1984b, *J. Phys. Chem. Ref. Data* **13**, 649.
Konjević, N., Wiese, W. L.: 1990, *J. Phys. Chem. Ref. Data* **19**, 1307.
Miller, M. H., Bengston, R. D.: 1970, *Phys. Rev. A* **1**, 983.
Purić, J., Ćuk, M., Lakićević, I.: 1985, *Phys. Rev. A* **32**, 1106.
Wiese, W. L., Konjević, N.: 1982, *JQSRT* **28**, 301.
Wiese, W. L., Konjević, N.: 1992, *JQSRT* **47**, 185.

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LINE SHAPES INVESTIGATIONS IN YUGOSLAVIA 1962 – 1997

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Since the first article published in 1962 by Vladis Vujnović, the spectral line shapes investigations in Yugoslavia has been developed during past 35 years (1962-1997), so that up to 1997, 1129 bibliographic items (926 by serbian authors) have been published by 146 Yugoslav authors. Among them 119 authors are from Serbia, 26 from Croatia and one Macedonian leaving in France. First paper on this subject in Serbia has been published in 1964 by M. D. Marinković.

In this contribution the history of the spectral line shapes investigations in Yugoslavia will be reviewed and various problems investigated by yugoslav authors will be discussed. Moreover a citation analysis of the most cited papers will be presented.

References

Mazing, M.A., Marinković, M.D., Vrublevskay, N.A.: 1964, Broadening and Shift of the Al III Spectral Lines in Strongly Ionized Plasma, Bull. Boris Kidrič Inst. Nucl. Sci. **15**, 15.

Vujnović, V., Harrison, J.A., Craggs, J.D.: 1962, Balmer Line Profiles in a Capillary Discharge, Proc. Phys. Soc. London, **80**, 516.

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EMISSION/ABSORPTION BANDS IN OPTICAL AND VUV SPECTRA OF PARTIALLY IONIZED PLASMA GENERATED BY ION-ATOM COLLISIONS

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In this lecture we will consider the origin of specific emission/absorption bands in EM spectra of partially ionized laboratory and astrophysical plasmas. Such bands are located in the optical part of the spectrum and are generated by the radiative ion-atom collisional processes. The shape of such bands in relation with the situation that we have symmetrical, wekly asymmetrical or pronounced asymmetrical ion-atom collisions, will be discussed. Also, we will analyse the role of plasma composition in connection with the influence of considered ion-tom processes on the plasma EM spectra. In connection with the laboratory plasmas,the possibility of the use of these processes for diagnostic purposes by probing a plasma with an intermediate energy ion beam, will be considered.

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ELECTRON IMPACT BROADENING PARAMETERS FOR IONIZED RARE-EARTHS: La II AND La III

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Abstract. The atomic data for ionized rare-earth elements are important for many astrophysical problems. Here we present the calculated electron impact parameters for three La II and six La III lines. Calculation was performed by using the modified semiempirical approach.

1. INTRODUCTION

The spectral lines of rare-earth elements are present in Solar as well as in stellar spectra (see e.g. Grevesse & Blanquet 1969, Molnar 1972, Adelman 1987, Mathys & Cowley 1992, Sadakane 1993, etc.). Principally, these lines are originated in layers (photosphere or subphotosphere) of stellar atmospheres with higher electron density. Consequently, electron impact broadening mechanism can be important, especialy for hot stars (A and B stars) as well as white dwarfs. La II lines in stellar spectra are discussed e.g. in Sadakane (1993) who suggested overabundance of La in α CM and o Peg, two hot Am stars. On the basis of regularities and systematic trends Lakićević (1983) estimated stark widths and shifts for La II $5d^2\ ^3F - 4f^3F^0$ transition. Due to the lack of known energy levels as well as transition probabilities for these elements, for Stark broadening calculations only the approximative method can be applied. Here we have applied the modified semiempirical approach (Dimitrijević & Konjević 1980).

In order to provide a set of atomic data needed for different astrophysical problems, as e.g. opacity calculations, we have calculated the Stark broadening for many astrophysically important elements (see e.g. Popović & Dimitrijević 1996ab, 1997ab). Here we present our calculation of three La II and six La III lines. The calculations were performed by using the modified semiempirical approach (Dimitrijević & Konjević 1980, for emiters with complex spectra see also Popović & Dimitrijević 1996a)

2. RESULTS AND DISCUSSION

The results our calculation are presented in Table 1.

Table 1. Stark full widths (FWHM) for La II and La III lines. The electron density is $10^{23}\mathrm{m}^{-3}$. The avaraged wavelength of the multiplet is denoted by $\overline{\lambda}$.

Transition	T (K)	W (nm)
La II	5000.	.219E-01
$a^3F - y^3D^0$	10000.	.152E-01
	20000.	.104E-01
	30000.	.853E-02
$\overline{\lambda} = 379.44$ nm	40000.	.756E-02
	50000.	.707E-02
La II	5000.	.493E-01
$a^3D - y^3D^0$	10000.	.348E-01
	20000.	.246E-01
	30000.	.201E-01
$\overline{\lambda} = 403.58$ nm	40000.	.174E-01
	50000.	.148E-01
La II	5000.	.336E-01
$a^3P - y^3D^0$	10000.	.232E-01
	20000.	.160E-01
	30000.	.131E-01
$\overline{\lambda} = 463.20$ nm	40000.	.116E-01
	50000.	.109E-01
La III	5000.	.260E-01
$6s^2S - 6p^2P^0$	10000.	.182E-01
	20000.	.126E-01
	30000.	.103E-01
$\overline{\lambda} = 328.01$ nm	40000.	.892E-02
	50000.	.807E-02
La III	5000.	.105E-01
$6s^2S - 7p^2P^0$	10000.	.734E-02
	20000.	.522E-02
	30000.	.440E-02
$\overline{\lambda} = 124.28$ nm	40000.	.400E-02
	50000.	.376E-02
La III	5000.	.231E-01
$6p^2P^0 - 6d^2D$	10000.	.161E-01
	20000.	.115E-01
	30000.	.978E-02
$\overline{\lambda} = 259.32$ nm	40000.	.889E-02
	50000.	.839E-02

The atomic energy levels needed for calculations were taken from Moore (1971). Oscillator strengths have been calculated by using the method of Bates & Damgaard (1949) and the tables of Oertel & Shomo (1968). The results of our calculation are presented in Table 1. Besides the estimate of Lakićević (1983) based on regularities, this is the first quantitative atempt to calculate rare-earth's Stark broadening parameters.

Table 1 (continued)

Transition	T (K)	W (nm)
La III	5000.	.453E-01
$6p^2P^0 - 7s^2S$	10000.	.317E-01
	20000.	.226E-01
	30000.	.191E-01
$\overline{\lambda} = 261.31$ nm	40000.	.173E-01
	50000.	.162E-01
La III	5000.	.747
$7s^2S - 7p^2P^0$	10000.	.522
	20000.	.374
	30000.	.320
$\overline{\lambda} = 854.39$ nm	40000.	.295
	50000.	.281
La III	5000.	.556
$6d^2D - 6p^2P^0$	10000.	.388
	20000.	.278
	30000.	.238
$\overline{\lambda} = 876.37$ nm	40000.	.220
	50000.	.210

References

Adelman S. J., 1987, *in Elemental Abundance Analyses*, Proc. of the IAU working group on Ap stars Workshop (Eds. S.J. Adelman and T. Lanz).

Bates,D.R., & Damgaard A., 1949, *Phil. Trans. Roy. Soc. London*, Ser. A, **242**, 101.

Dimitrijević, M.S., Konjević, N., 1980, *J. Quant. Spectrosc. Radiat. Transfer*, **24**, 451.

Grevesse N. & Blanquet G., 1969, *Solar Phys.* **8**, 5.

Lakićević I. S., 1983, *Astron. Astrophys.* **127**, 37.

Mathys G. Cowley C. R., 1992, *Astron. Astrophys.* **253**, 199.

Molnar H. 1972, *Astron. Astrophys.* **20**, 69.

Moore, C., E., 1971, *Atomic Energy Levels*, NSRDS-NBS, Vol. **2**, Washington D.C.

Oertel,G.K., Shomo,L.P., 1968, *ApJS*, **16**, 175.

Popović L. Č. and Dimitrijević M. S., 1996a, *Phys. Scr.* **53**, 325.

Popović, L. Č., Dimitrijević, M. S., 1996b, *A&AS*, **120**, 373.

Popović L. Č. and Dimitrijević M. S., 1997a, *Astron. Astrophys.* (in press).

Popović L. Č. and Dimitrijević M. S., 1997b, *Astron. Astrophys.* (in press).

Sadakane K., 1993, in Peculiar Versus Normal Phenomena in A-type and Related Stars, *ASP Conf. Series*, **44** (Eds. M. M. Dworetsky, F. Gastelli, R. Forragiona), 72.

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ON THE STARK BROADENING OF Sc X LINES

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Abstract. Using a semiclassical approach, we have calculated electron-, proton-, and ionized helium-impact line widths and shifts for 4 Sc X multiplets, for perturber densities $10^{19}-10^{22}$ cm^{-3} and temperatures T = 200,000 − 5,000,000 K.

1. INTRODUCTION

Scandium is present in stellar and solar plasma, so that the various atomic data concerning this element, including Stark broadening parameters of its spectral lines for various ionization stages are of interest for stellar and solar physics. Particularly for the modelling and theoretical considerations of subphotospheric layers, atomic data on higher ionization stages are of interest (Seaton, 1997). Of course, Stark broadening parameters for multiply charged scandium ion lines are as well of interest for the laboratory plasma research, testing and developping of the Stark broadening theory for multicharged ion lines, and investigations of systematic trends along isoelectronic sequences.

By using the semiclassical-perturbation formalism (Sahal-Bréchot 1969ab), we have calculated electron-, proton-, and He III-impact line widths and shifts for 4 scandium X multiplets. A short review of the formalism is given e.g. in Dimitrijević *et al.* (1991) and Dimitrijević and Sahal - Bréchot (1996).

2. RESULTS AND DISCUSSION

Energy levels for scandium X lines have been taken from Bashkin and Stoner (1978). All other details of calculations are given in Dimitrijević and Sahal-Bréchot (1998). Our results for electron-, proton-, and He III-impact line widths and shifts for 4 scandium X multiplets, for perturber densities $10^{19}-10^{22}$ cm^{-3} and temperatures T = 200,000 − 5,000,000 K, will be published elsewhere (Dimitrijević and Sahal-Bréchot, 1998). We present here in Table 1, only data for perturber density of 10^{19} cm^{-3}. We also specify a parameter C (Dimitrijević and S.Sahal-Bréchot, 1984), which gives an estimate for the maximum perturber density for which the line may be treated as isolated when it is divided by the corresponding full width at half maximum.

Table 1. This table shows electron- and proton-impact broadening full half-widths (FWHM) and shifts for Sc X for a perturber density of 10^{19} cm^{-3} and temperatures from 200,000 up to 5,000,000 K. By deviding C with the full linewidth, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used.

PERTURBER DENSITY = 1.E+19cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Sc X 3S-3P	200000.	0.257E-01	-0.164E-03	0.146E-03	-0.876E-04
422.9 A	500000.	0.165E-01	-0.196E-03	0.473E-03	-0.225E-03
C=0.42E+22	1000000.	0.121E-01	-0.259E-03	0.871E-03	-0.393E-03
	2000000.	0.916E-02	-0.244E-03	0.127E-02	-0.579E-03
	3000000.	0.787E-02	-0.238E-03	0.146E-02	-0.706E-03
	5000000.	0.661E-02	-0.231E-03	0.165E-02	-0.815E-03
Sc X 3P-4S	200000.	0.499E-02	0.227E-03	0.606E-04	0.201E-03
147.3 A	500000.	0.337E-02	0.299E-03	0.251E-03	0.390E-03
C=0.14E+21	1000000.	0.258E-02	0.284E-03	0.440E-03	0.542E-03
	2000000.	0.203E-02	0.270E-03	0.643E-03	0.652E-03
	3000000.	0.178E-02	0.258E-03	0.756E-03	0.722E-03
	5000000.	0.151E-02	0.223E-03	0.915E-03	0.821E-03
Sc X 3P-5S	200000.	0.399E-02	0.376E-03	0.193E-03	0.380E-03
96.3 A	500000.	0.283E-02	0.427E-03	0.478E-03	0.622E-03
C=0.32E+20	1000000.	0.225E-02	0.425E-03	0.720E-03	0.760E-03
	2000000.	0.182E-02	0.401E-03	0.933E-03	0.910E-03
	3000000.	0.161E-02	0.358E-03	0.110E-02	0.101E-02
	5000000.	0.139E-02	0.301E-03	0.133E-02	0.111E-02
Sc X 3P-3D	200000.	0.206E-01	-0.669E-04	0.204E-03	-0.321E-04
357.5 A	500000.	0.133E-01	-0.681E-04	0.591E-03	-0.835E-04
C=0.30E+22	1000000.	0.970E-02	-0.969E-04	0.971E-03	-0.156E-03
	2000000.	0.731E-02	-0.794E-04	0.134E-02	-0.247E-03
	3000000.	0.629E-02	-0.788E-04	0.146E-02	-0.299E-03
	5000000.	0.530E-02	-0.730E-04	0.160E-02	-0.367E-03

Experimental data or other theoretical data on the scandium X Stark broadening parameters do not exist. The corresponding experimental data will be of course very useful for checking and further development and rafinement of the theory of multicharged ion lines.

References

Bashkin, S., Stoner, J.O.Jr.: 1978, "Atomic Energy Levels and Grotrian Diagrams", Vol. 2, North Holland, Amsterdam.

Dimitrijević, M.S. and Sahal-Bréchot, S.: 1984, *JQSRT*, **31**, 301.

Dimitrijević, M.S. and Sahal-Bréchot,S.: 1996, *Physica Scripta*, **54**, 50.

Dimitrijević, M.S. and Sahal-Bréchot, S.: 1998, *Astron. Astrophys. Suppl. Series* to be submitted.

Dimitrijević, M.S., Sahal-Bréchot, S. and Bommier, V.: 1991, *Astron. Astrophys. Suppl. Series*, **89**, 581.

Sahal-Bréchot, S.: 1969a, *Astron.Astrophys.* **1**, 91.

Sahal-Bréchot, S.: 1969b, *Astron.Astrophys.* **2**, 322.

Seaton, M.J.: 1987, *J. Phys. B* **20**, 6363.

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ON THE STARK BROADENING OF Mg XI LINES

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Abstract. Using a semiclassical approach, we have calculated electron-, proton-, and He III-impact line widths and shifts for 18 Mg XI multiplets.

1. INTRODUCTION

Data on magnesium spectral lines as well as on its various ionization stages are of interest for investigation of a number of physical processes in stellar, laboratory and technological plasmas. Data on Mg XI spectral lines are as well of interest for the study of systematic trends along helium isoelectronic sequence and for testing and developing of the Stark broadening theory for multicharged ions.

We have calculated here within the semiclassical-perturbation formalism (Sahal-Bréchot 1969ab), electron-, proton-, and He III-impact line widths and shifts for 18 Mg XI multiplets. A summary of the formalism is given e.g. in Dimitrijević *et al.* (1991) and will not be repeated here.

2. RESULTS AND DISCUSSION

As a continuation of our project to provide to astrophysicists and plasma physicists the needed Stark-broadening parameters (see Dimitrijević 1996, Dimitrijević and Sahal-Bréchot 1995 and references therein), electron-, proton-, and He III- impact Mg XI line widths and shifts have been calculated. Energy levels for Mg XI have been taken from Martin and Zalubas (1980). Our results for 18 Mg XI multiplets, for perturber densities 10^{18} - 10^{24} cm^{-3} and temperatures T = 500,000 - 5,000,000K will be published in Dimitrijević and Sahal-Bréchot (1998a,b).

Table 1

This table shows electron- and proton-impact broadening full half-widths (FWHM) and shifts for Mg XI (singlets) for a perturber density of 10^{19} cm^{-3} and temperatures from 500,000 up to 5,000,000 K. By deviding C with the full linewidth, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the collision volume multiplied by the perturber density (the condition for validity of the impact approximation) lies between 0.1 and 0.5.

PERTURBER DENSITY = 1.E+19cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Mg XI 1S 2P	500000.	0.250E-05	-0.347E-07	0.147E-07	-0.400E-07
9.2 A	750000.	0.205E-05	-0.163E-07	0.287E-07	-0.594E-07
C=0.57E+18	1000000.	0.179E-05	-0.158E-07	0.451E-07	-0.768E-07
	2000000.	0.129E-05	-0.111E-07	0.116E-06	-0.129E-06
	3000000.	0.108E-05	-0.931E-08	0.171E-06	-0.158E-06
	5000000.	0.862E-06	-0.427E-08	0.268E-06	-0.201E-06
Mg XI 1S 3P	500000.	0.843E-05	-0.379E-06	0.235E-05	-0.276E-05
7.9 A	750000.	0.714E-05	-0.352E-06	0.355E-05	-0.330E-05
C=0.23E+17	1000000.	0.637E-05	-0.335E-06	0.444E-05	-0.354E-05
	2000000.	0.486E-05	-0.299E-06	0.652E-05	-0.428E-05
	3000000.	0.418E-05	-0.255E-06	0.795E-05	-0.473E-05
	5000000.	0.347E-05	-0.202E-06	0.971E-05	-0.529E-05
Mg XI 2S 2P	500000.	0.819E-01	-0.257E-02	0.984E-03	-0.425E-02
1473.6 A	750000.	0.681E-01	-0.247E-02	0.223E-02	-0.599E-02
C=0.15E+23	1000000.	0.600E-01	-0.241E-02	0.339E-02	-0.734E-02
	2000000.	0.446E-01	-0.231E-02	0.800E-02	-0.106E-01
	3000000.	0.378E-01	-0.222E-02	0.122E-01	-0.128E-01
	5000000.	0.309E-01	-0.191E-02	0.178E-01	-0.147E-01
Mg XI 2S 3P	500000.	0.401E-03	-0.192E-04	0.107E-03	-0.126E-03
52.7 A	750000.	0.341E-03	-0.185E-04	0.162E-03	-0.151E-03
C=0.11E+19	1000000.	0.304E-03	-0.176E-04	0.201E-03	-0.161E-03
	2000000.	0.233E-03	-0.160E-04	0.298E-03	-0.196E-03
	3000000.	0.201E-03	-0.140E-04	0.361E-03	-0.215E-03
	5000000.	0.167E-03	-0.114E-04	0.447E-03	-0.242E-03
Mg XI 3S 3P	500000.	4.89	-0.355	1.26	-1.49
5065.9 A	750000.	4.19	-0.347	1.89	-1.75
C=0.98E+22	1000000.	3.77	-0.336	2.26	-1.89
	2000000.	2.94	-0.308	3.34	-2.26
	3000000.	2.55	-0.270	4.06	-2.48
	5000000.	2.14	-0.222	5.06	-2.76

Table 1 continued

PERTURBER DENSITY = 1.E+19cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Mg XI 2P 3S	500000.	0.254E-03	0.246E-04	0.404E-04	0.676E-04
55.2 A	750000.	0.219E-03	0.244E-04	0.578E-04	0.830E-04
C=0.60E+19	1000000.	0.198E-03	0.239E-04	0.760E-04	0.940E-04
	2000000.	0.156E-03	0.222E-04	0.122E-03	0.113E-03
	3000000.	0.135E-03	0.198E-04	0.150E-03	0.125E-03
	5000000.	0.113E-03	0.166E-04	0.191E-03	0.142E-03
Mg XI 2P 4S	500000.	0.310E-03	0.432E-04	0.667E-04	0.952E-04
40.7 A	750000.	0.270E-03	0.427E-04	0.971E-04	0.112E-03
C=0.32E+19	1000000.	0.246E-03	0.422E-04	0.112E-03	0.121E-03
	2000000.	0.197E-03	0.389E-04	0.156E-03	0.144E-03
	3000000.	0.173E-03	0.344E-04	0.186E-03	0.159E-03
	5000000.	0.147E-03	0.289E-04	0.231E-03	0.177E-03
Mg XI 2P 5S	500000.	0.748E-03	0.109E-03	*0.440E-03	*0.426E-03
36.1 A	750000.	0.660E-03	0.105E-03	*0.530E-03	*0.485E-03
C=0.55E+18	1000000.	0.603E-03	0.979E-04	*0.601E-03	*0.520E-03
	2000000.	0.481E-03	0.896E-04	*0.793E-03	*0.602E-03
	3000000.	0.419E-03	0.789E-04	*0.928E-03	*0.659E-03
	5000000.	0.350E-03	0.641E-04	0.113E-02	0.734E-03
Mg XI 3P 4S	500000.	0.754E-02	0.816E-03	0.196E-02	0.224E-02
160.3 A	750000.	0.653E-02	0.803E-03	0.266E-02	0.252E-02
C=0.98E+19	1000000.	0.592E-02	0.788E-03	0.315E-02	0.273E-02
	2000000.	0.469E-02	0.723E-03	0.446E-02	0.326E-02
	3000000.	0.409E-02	0.637E-03	0.545E-02	0.360E-02
	5000000.	0.345E-02	0.530E-03	0.664E-02	0.391E-02
Mg XI 3P 5S	500000.	0.774E-02	0.102E-02	*0.409E-02	*0.388E-02
106.7 A	750000.	0.680E-02	0.978E-03	*0.494E-02	*0.441E-02
C=0.43E+19	1000000.	0.620E-02	0.914E-03	*0.560E-02	*0.473E-02
	2000000.	0.492E-02	0.836E-03	*0.757E-02	*0.554E-02
	3000000.	0.428E-02	0.735E-03	*0.895E-02	*0.591E-02
	5000000.	0.358E-02	0.597E-03	*0.110E-01	*0.658E-02
Mg XI 2P 3D	500000.	0.270E-03	0.103E-04	0.691E-04	0.806E-04
54.7 A	750000.	0.226E-03	0.999E-05	0.103E-03	0.994E-04
C=0.11E+19	1000000.	0.200E-03	0.924E-05	0.138E-03	0.111E-03
	2000000.	0.151E-03	0.930E-05	0.215E-03	0.134E-03
	3000000.	0.129E-03	0.857E-05	0.261E-03	0.148E-03
	5000000.	0.107E-03	0.718E-05	0.320E-03	0.167E-03

Here, only a sample of results is shown in Table 1. Parameter C (Dimitrijević and Sahal-Bréchot 1984), given also in Table 1, provides an estimate for the maximum perturber density for which the line may be treated as isolated when it is divided by the corresponding electron-impact full width at half maximum. For each Stark broadening parameter shown in Table 1, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid (Sahal−Bréchot, 1969ab). Values for $NV > 0.5$ are not given and values for $0.1 < NV \leq 0.5$ are denoted by an asterisk.

The presented values may be of interest for a number of problems concerning the stellar, laboratory, fusion and laser produced plasma, and soft x-ray lasers modeling and research. The obtained results are of interest as well for the investigation of behaviour of Stark broadening parameters along isoelectronic sequences.

References

Dimitrijević, M.S.: 1996, *Zh. Prikl. Spektrosk.* **63**, 810.
Dimitrijević, M.S., and Sahal-Bréchot, S.: 1984, *JQSRT*, **31**, 301.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1995, *Astron. Astrophys. Suppl. Series*, **109**, 551.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1998a, *Astron. Astrophys. Suppl. Series*, submitted.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1998b, *Bull. Astron. Belgrade*, **157**, in press.
Dimitrijević, M.S., Sahal-Bréchot, S. and Bommier, V.: 1991, *Astron. Astrophys. Suppl. Series*, **89**, 581.
Martin, W.C., Zalubas, R.: 1980, *J. Phys. Chem. Reference Data*, **9**, 1.
Sahal-Bréchot, S.: 1969a, *Astron.Astrophys.* **1**, 91.
Sahal-Bréchot, S.: 1969b, *Astron.Astrophys.* **2**, 322.

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ON THE STARK BROADENING OF Na X LINES

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Abstract. Using a semiclassical approach, we have calculated electron-, proton-, and He III-impact line widths and shifts for 57 Na X multiplets.

1. INTRODUCTION

For the consideration of physical processes in stellar, laboratory and technological plasmas, the data on spectral lines from sodium and its various ionization stages are of interest. Recently, Griem and Moreno (1990) and Fill and Schöning (1994) pointed out the importance of such results for the development of soft x-ray lasers, where Stark broadening data are needed to calculate gain values, model radiation trapping and to consider photoresonant pumping schemes.

In order to provide the Na X Stark broadening parameters,we have calculated within the semiclassical-perturbation formalism (Sahal-Bréchot 1969ab), electron-, proton-, and He III-impact line widths and shifts for 57 Na X multiplets. A summary of the formalism is given in Dimitrijević *et al.* (1991).

2. RESULTS AND DISCUSSION

In accordance with our project to provide to astrophysicists and plasma physicists the needed Stark-broadening parameters (see Dimitrijević 1996, Dimitrijević and Sahal-Bréchot 1995 and references therein), electron-, proton-, and He III- impact Na X line widths and shifts have been calculated. Energy levels for Na X have been taken from Martin and Zalubas (1981). Our results for 57 Na X multiplets, for perturber densities 10^{17} - 10^{24} cm^{-3} and temperatures T = 200,000 - 5,000,000K will be published in Dimitrijević and Sahal-Bréchot (1998a,b).

Table 1

This table shows electron- and proton-impact broadening full half-widths (FWHM) and shifts for Na X (singlets) for a perturber density of 10^{19} cm^{-3} and temperatures from 200,000 up to 5,000,000 K. By deviding C with the full linewidth, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used. The asterisk identifies cases for which the collision volume multiplied by the perturber density (the condition for validity of the impact approximation) lies between 0.1 and 0.5.

PERTURBER DENSITY = 1.E+19cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Na X 2S-2P	200000.	0.174	-0.351E-02	0.326E-03	-0.314E-02
1646.9 A	500000.	0.114	-0.421E-02	0.241E-02	-0.772E-02
C=0.16E+23	1000000.	0.839E-01	-0.387E-02	0.739E-02	-0.126E-01
	2000000.	0.629E-01	-0.371E-02	0.147E-01	-0.175E-01
	3000000.	0.536E-01	-0.348E-02	0.216E-01	-0.201E-01
	5000000.	0.441E-01	-0.296E-02	0.294E-01	-0.230E-01
Na X 3S-3P	200000.	10.1	-0.553	0.842	-1.46
5666.0 A	500000.	7.07	-0.564	2.23	-2.37
C=0.12E+23	1000000.	5.50	-0.554	3.58	-2.88
	2000000.	4.31	-0.478	5.12	-3.45
	3000000.	3.75	-0.415	6.27	-3.74
	5000000.	3.15	-0.343	7.63	-4.15
Na X 3S-4P	200000.	0.250E-01	-0.114E-02	*0.694E-02	-0.728E-02
182.2 A	500000.	0.179E-01	-0.119E-02	*0.131E-01	-0.103E-01
C=0.46E+19	1000000.	0.141E-01	-0.126E-02	*0.184E-01	-0.127E-01
	2000000.	0.111E-01	-0.114E-02	*0.250E-01	-0.146E-01
	3000000.	0.974E-02	-0.970E-03	*0.287E-01	-0.156E-01
	5000000.	0.825E-02	-0.760E-03	*0.340E-01	-0.171E-01
Na X 3P-4S	200000.	0.200E-01	0.166E-02	0.276E-02	0.392E-02
190.9 A	500000.	0.146E-01	0.172E-02	0.595E-02	0.588E-02
C=0.13E+20	1000000.	0.116E-01	0.165E-02	0.866E-02	0.718E-02
	2000000.	0.918E-02	0.139E-02	0.119E-01	0.853E-02
	3000000.	0.800E-02	0.122E-02	0.142E-01	0.924E-02
	5000000.	0.672E-02	0.101E-02	0.173E-01	0.992E-02
Na X 3P-5S	200000.	0.184E-01	0.173E-02	*0.481E-02	*0.504E-02
129.2 A	500000.	0.138E-01	0.185E-02	*0.776E-02	*0.707E-02
C=0.60E+19	1000000.	0.110E-01	0.176E-02	*0.105E-01	*0.859E-02
	2000000.	0.874E-02	0.152E-02	*0.141E-01	*0.101E-01
	3000000.	0.760E-02	0.132E-02	*0.159E-01	*0.107E-01
	5000000.	0.636E-02	0.107E-02	*0.200E-01	*0.116E-01

Table 1 continued

PERTURBER DENSITY = 1.E+19cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Na X 3P-6S	200000.	0.261E-01	0.223E-02		
110.0 A	500000.	0.198E-01	0.243E-02		
C=0.26E+19	1000000.	0.158E-01	0.249E-02		
	2000000.	0.125E-01	0.231E-02		
	3000000.	0.109E-01	0.195E-02		
	5000000.	0.907E-02	0.154E-02		
Na X 4P-5S	200000.	0.262	0.205E-01	*0.754E-01	*0.678E-01
412.4 A	500000.	0.195	0.220E-01	*0.120	*0.975E-01
C=0.23E+20	1000000.	0.155	0.215E-01	*0.166	*0.119
	2000000.	0.123	0.189E-01	*0.218	*0.137
	3000000.	0.107	0.162E-01	*0.254	*0.144
	5000000.	0.903E-01	0.129E-01	*0.309	*0.163
Na X 4P-6S	200000.	0.182	0.141E-01		
264.6 A	500000.	0.137	0.153E-01		
C=0.96E+19	1000000.	0.109	0.159E-01		
	2000000.	0.866E-01	0.147E-01		
	3000000.	0.753E-01	0.124E-01		
	5000000.	0.630E-01	0.977E-02		
Na X 4P-7S	200000.	0.204	0.138E-01		
217.6 A	500000.	0.155	0.151E-01		
C=0.65E+19	1000000.	0.124	0.180E-01		
	2000000.	0.984E-01	0.175E-01		
	3000000.	0.854E-01	0.146E-01		
	5000000.	0.712E-01	0.110E-01		
Na X 4P-8S	200000.	0.259	0.127E-01		
195.2 A	500000.	0.199	0.153E-01		
C=0.35E+19	1000000.	0.159	0.222E-01		
	2000000.	0.126	0.229E-01		
	3000000.	0.110	0.188E-01		
	5000000.	0.914E-01	0.138E-01		

In Table 1, only a sample of results is shown. Parameter C (Dimitrijević and Sahal-Bréchot 1984), given also in Table 1, provides an estimate for the maximum perturber density for which the line may be treated as isolated when it is divided by the corresponding electron-impact full width at half maximum. For each value given in Table 1, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid (Sahal–Bréchot, 1969ab). Values for NV > 0.5 are not given and values for $0.1 < \mathrm{NV} \leq 0.5$ are denoted by an asterisk.

We hope that the present results will be of interest for the investigation of Stark broadening theory, especially for the investigation of behaviour of Stark broadening parameters along isoelectronic sequences, as well as for the various problems concerning the stellar, laboratory, fusion and laser produced plasma, and soft x-ray lasers modeling and research.

References

Dimitrijević, M. S.: 1996, *Zh. Prikl. Spektrosk.* **63**, 810.

Dimitrijević, M.S., and Sahal-Bréchot, S.: 1984, *JQSRT*, **31**, 301.

Dimitrijević, M.S. and Sahal-Bréchot, S.: 1995, *Astron. Astrophys. Suppl. Series*, **109**, 551.

Dimitrijević, M.S. and Sahal-Bréchot, S.: 1998a, *Astron. Astrophys. Suppl. Series*, submitted.

Dimitrijević, M.S. and Sahal-Bréchot, S.: 1998b, *Bull. Astron. Belgrade*, **157**, in press.

Dimitrijević, M.S., Sahal-Bréchot, S. and Bommier, V.: 1991, *Astron. Astrophys. Suppl. Series*, **89**, 581.

Fill, E.E., Schöning, T.: 1994, *J. Appl. Phys.* **76**, 1423.

Griem, H.R., Moreno, J.C.: 1990, in: *X-Ray Lasers*, ed.G. Tallents, Institute of Physics, Bristol, 301.

Martin, W.C., Zalubas, R.: 1981, *J. Phys. Chem. Reference Data*, **10**, 153.

Sahal-Bréchot, S.: 1969a, *Astron.Astrophys.* **1**, 91.

Sahal-Bréchot, S.: 1969b, *Astron.Astrophys.* **2**, 322.

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THE ELECTRON-IMPACT WIDTHS FOR 4s-4p OF Sr III LINES

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Abstract. In this paper we present Stark widths for five $5s - 5p$ transitions of Sr III calculated by using the modified semiempirical approach and jK coupling approximation.

1. INTRODUCTION

The electron-emitter/absorber collisions are cause of the main pressure broadening mechanism in atmospheres of hot stars. Consequently, the knowledge of the Stark broadening parameters is needed for the stellar atmosphere investigations and modeling. Also, Stark broadening data are needed for investigations and diagnostic of laboratory plasma.

In the case of emitters with complex spectra, where the usual LS coupling scheme is not applicable, as well as the more sophisticated methods as the semiclassical approach (Sahal-Bréchot 1969ab) due to the lack of atomic data, the simpler methods should be used. One of such methods for Stark broadening parameter calculations is the modified semiempirical approach (Dimitrijević & Konjević 1980, Popović & Dimitrijević 1996). It was shown in several papers (Popović & Dimitrijević 1996ab, 1997) that for an emitter with the complex spectrum, the modified semiempirical approach gives a good average accuracy.

Here we present Stark broadening parameters for five Sr III 5s-5p transitions, calculated by using the modified semiempirical approach and assuming jK coupling approximation.

2. THEORETICAL REMARKS

According to the MSE approach (Dimitrijević & Konjević 1980, Popović & Dimitrijević 1996) the electron impact full width (FHWM) of an ion line is given as

$$w_{MSE} = N\frac{8\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}\cdot\{\sum_{\ell_i\pm1}\sum_{K_{i'}}\vec{\Re}^2[n_i\ell_iK_i,n_i(\ell_i\pm1)K_{i'}]\tilde{g}(\frac{E}{\Delta E_{\ell_i,\ell_i\pm1}})+$$

$$+\sum_{\ell_f\pm1}\sum_{K_{f'}}\vec{\Re}^2[n_f\ell_fK_f,n_f(\ell_f\pm1)K_{f'}]\tilde{g}(\frac{E}{\Delta E_{\ell_f,\ell_f\pm1}})+ \quad (1)$$

$$+(\sum_{i'}\vec{\Re}^2_{ii'})_{\Delta n\neq0}g(x_{n_i,n_i+1})+(\sum_{f'}\vec{\Re}^2_{ff'})_{\Delta n\neq0}g(x_{n_f,n_f+1})\},$$

where the initial level is denoted with i and the final one with f and the square of the matrix element $\{\vec{\Re}^2[n_k\ell_k K_{k'}, (\ell_k \pm 1)K_{k'}], \quad k = i, f\}$ is

$$\vec{\Re}^2[n_k\ell_k K_k, n_k(\ell_k \pm 1)K_{k'}] = \frac{\ell_>}{2J_k+1} Q(j_p K\ell', \ell K')[R^{n_k(\ell_k\pm1)}_{n_k\ell_k}]^2 \qquad (2)$$

and

$$(\sum_{k'} \vec{\Re}^2_{kk'})_{\Delta n\neq 0} = (\frac{3n_k}{2Z})^2 \frac{1}{9}(n_k^2 + 3\ell_k^2 + 3\ell_k + 11) \qquad (3)$$

where $\ell_> = \max(\ell_k, \ell_k \pm 1)$.

In Eqs. (1 – 3) N and T are electron density and temperature, respectively.

$$Q(j_p K\ell', \ell K') = (2K+1)(2K'+1)[W(j_p K\ell' 1; \ell K')]^2$$

is the multiplet factor for jK coupling approximation (see e.g. Sobelman 1992). The $[R^{n_k\ell_k\pm1}_{n\ell}]$ is the radial integral, $g(x)$, and $\tilde{g}(x)$ are the semiempirical (Griem 1968) and the modified semiempirical (Dimitrijević & Konjević 1980) Gaunt factors for Stark width and shift, respectively.

3. RESULTS AND DISCUSSION

Calculation of Stark widths for five Sr III lines was performed by using Eqs. 1-4. The atomic energy levels have been taken from Persson and Valind (1972). The necessary matrix elements have been calculated by using Eqs. 2 and 3. The data for the multiplet factor for jK coupling approximation were taken from Popović (1994).

Table 1. Stark width (FWHM) Sr III (5s – 5p) transitions for electron density of $10^{23}\mathrm{m}^{-3}$ as a function of temperature. The averaged wavelength of the multiplet is denoted as $\overline{\lambda}$. The jK coupling approximation was assumed.

Transition	T (K)	W (nm)
$(^2P_{3/2})\ 5s[3/2] - 5p[5/2]$	5000.	.172E-01
	10000.	.120E-01
	50000.	.530E-02
	100000.	.420E-02
$\overline{\lambda} = 309.62$ nm	250000.	.393E-02
	500000.	.387E-02
$(^2P_{3/2})\ 5s[3/2] - 5p[3/2]$	5000.	.153E-01
	10000.	.107E-01
	50000.	.471E-02
	100000.	.373E-02
$\overline{\lambda} = 287.08$ nm	250000.	.349E-02
	500000.	.344E-02

Table 1. continued

Transition	T (K)	W (nm)
$(^2P_{3/2})$ $5s[3/2] - 5p[1/2]$ $\overline{\lambda} = 321.63$ nm	5000.	.183E-01
	10000.	.128E-01
	50000.	.563E-02
	100000.	.446E-02
	250000.	.418E-02
	500000.	.412E-02
$(^2P_{1/2})$ $5s[1/2] - 5p[3/2]$ $\overline{\lambda} = 286.82$ nm	5000.	.154E-01
	10000.	.108E-01
	50000.	.473E-02
	100000.	.374E-02
	250000.	.349E-02
	500000.	.344E-02
$(^2P_{1/2})$ $5s[1/2] - 5p[1/2]$ $\overline{\lambda} = 286.82$ nm	5000.	.154E-01
	10000.	.107E-01
	50000.	.472E-02
	100000.	.373E-02
	250000.	.348E-02
	500000.	.344E-02

In Table 1 we present results of our calculation of Stark widths and shifts for Sr III 5s – 5p transitions assuming jK coupling approximation, respectively.

In the case of Sr III there is not measured and calculated data. Here we give first results, and we hope that the data will be of interest for stellar as well as laboratory plasma spectroscopy.

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References

Dimitrijević, M.S. and Konjević, N.: 1980 *JQSRT*, **24**, 451.
Griem, H.R.: 1968, *Phys. Rev.* **165**, 258.
Persson, W. and Valind, S.: 1972, *Phys. Scr.* **5**, 187.
Popović, L.Č.: 1994, *Publ. Obs. Astron. Belgrade*, **46**, 80.
Popović, L.Č. and Dimitrijević, M.S.: 1996a, *Phys. Scr.* **53**, 325.
Popović, L.Č. and Dimitrijević M.S.: 1996b, *Astron. Astrophys. Suppl. Series*, **116**, 359.
Popović, L.Č. and Dimitrijević, M.S.: 1997, in *The Physics of Ionized Gases* (eds. B. Vujičić, S. Djurović and J. Purić) pp.477-486
Sahal-Bréchot, S.: 1969a, *Astron. Astrophys.* **1**, 91.
Sahal-Bréchot, S.: 1969b, *Astron. Astrophys.* **2**, 322.

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THE ELECTRON-IMPACT BROADENING PARAMETERS FOR Ti II LINES

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Abstract. Here we present the electron-impact broadening parameters for Ti II lines. Calculation was performed by using the modified semiempirical approach.

1. INTRODUCTION

In order to provide to astrophysicists and physicists the needed electron-impact broadening parameters, a large set of such data, obtained by using the semiclassical perturbation formalism (see e.g. Dimitrijević *et al.* 1991) and the modified semiempirical approach (Dimitrijević and Konjević 1980, for emitters with complex spectra see also Popović and Dimitrijević 1996, 1997), has been created (see Dimitrijević 1996 and references therein). Here we present our results for Ti II lines. The calculations were performed by using the modified semiempirical approach.

2. RESULTS AND DISCUSSION

Energy levels for Ti II were taken from Wiese and Musgrove (1989). Oscillator strengths have been calculated by using Bates and Damgaard (1949) method. Here we present only Stark widths and shifts for the most intensive lines from $a^4F - z^4G^0$ and $a^4F - z^4F^0$ multiplets. The Stark widths (w_x) of other lines from these multiplets may by calculated as

$$w_x = w_l(\frac{\lambda_x}{\lambda_l})^2 \qquad (1)$$

with error bars of $\pm 30\%$. In Eq (1) w_l is the given Stark width and λ_l is the wavelength for the corresponding transition, while λ_x is the wavelength for the spectral line with width w_x. Besides the calculation with oscillator strengths within the Bates-Damgaard approximation, we performed as well, the same calculations by using different, calculated (Morton 1991) and measured (Danzmann and Kock 1980 and Blackwell *et al.* 1982, critically selected by Wiese and Musgrove 1989; Roberts *et al.* 1974) oscillator strengths, in order to analyze the influence of the different oscillator strengths values to electron-impact broadening parameters. The results of our investigation are

presented in Figs. 1 and 2. As we can see in Figs. 1 and 2 the differences between results obtained with the oscillator strengths from different sources give discrepancy between calculated Stark widths within the error bars of the MSE method in the case of $a^4F_{9/2} - z^4F^0_{9/2}$, while for the transition $a^4F_{3/2} - z^4G^0_{5/2}$ the Stark widths calculated within the Bates-Damgaard approximation are significantly smaller than those calculated with oscillator strengths from Morton (1991) and experimental oscillator strengths. Complete results of our calculations will be published elsewhere (Tankosić *et al.* 1998).

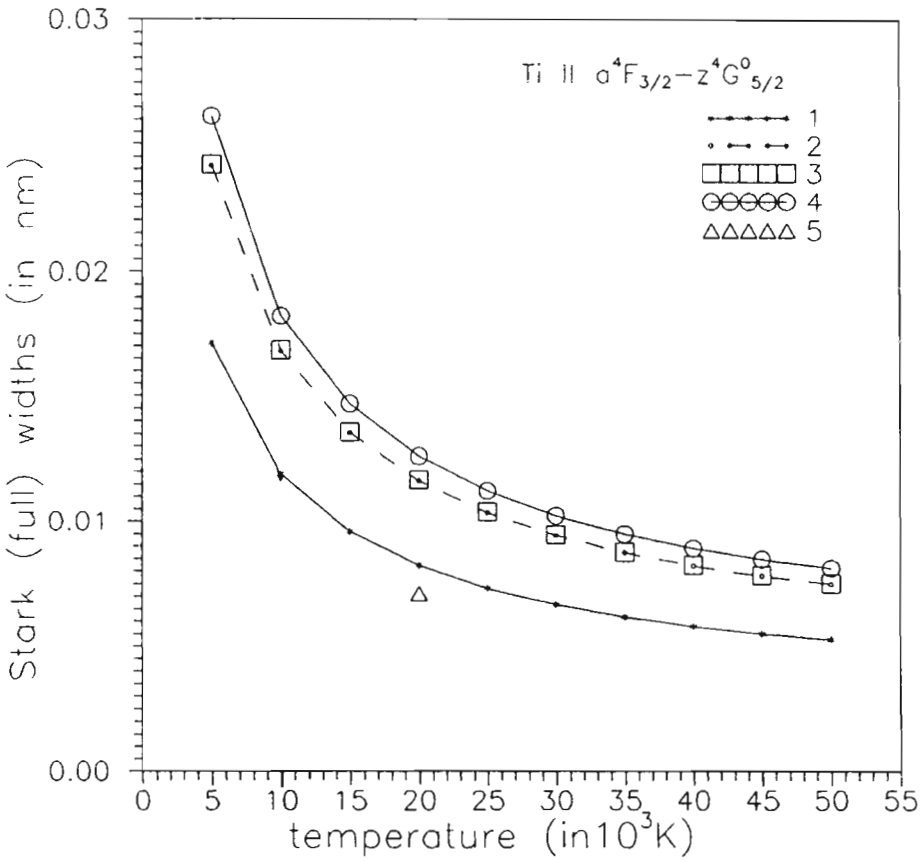

Fig. 1. Stark full width for Ti II $a^4F_{3/2} - z^4G^0_{5/2}$ (λ =338.47 nm) line as a function of temperature at an electron density of 10^{23}m^{-3}. Used notation: Results with- **1.**- oscillator strengths calculated by using the Bates-Damgaard method; **2.**- oscillator strengths given by Danzmann and Kock (1980) and Blackwell *et al.* (1982), critically selected by Wiese and Musgrove (1989); **3.**- oscillator strengths given by Roberts *et al.* (1974); **4.**- oscillator strengths given by Morton (1991). **5.**- The estimated Strak width on the basis of regularities and systematic trends given by Lakićević (1983)

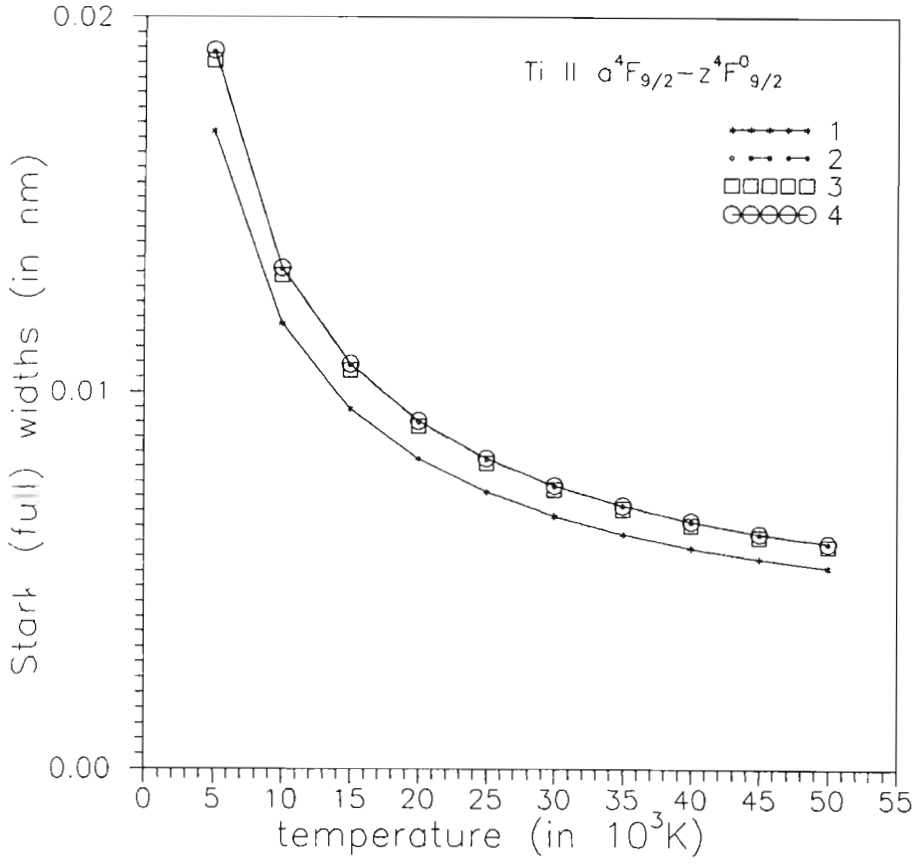

Fig. 2. Stark full width for Ti II $a^4F_{9/2} - z^4F^0_{9/2}$ (λ =323.55 nm) line as a function of temperature at an electron density of $10^{23}\mathrm{m}^{-3}$. Used notation: Results with- **1.**- oscillator strengths calculated by using Bates-Damgaard method; **2.**- oscillator strengths given by Danzmann and Kock (1980) and Blackwell *et al.* (1982), critically selected by Wiese and Musgrove (1989); **3.**- oscillator strengths given by Roberts *et al.* (1974); **4.**- oscillator strengths given by Morton (1991)

Table 1. Stark width (FWHM) and shift of Ti II lines at an electron density of $10^{23}\mathrm{m}^{-3}$ as a function of temperature. The oscillator strengths were calculated in Bates-Damgaard approximation (Bates-Damgaard 1949).

Transition	T (K)	W (nm)	d (nm)
$a^4F_{3/2} - z^4G^0_{5/2}$ $\lambda = 338.47$ nm	5000.	0.171E-01	-0.389E-02
	10000.	0.119E-01	-0.278E-02
	20000.	0.822E-02	-0.201E-02
	30000.	0.666E-02	-0.169E-02
	40000.	0.580E-02	-0.149E-02
	50000.	0.528E-02	-0.138E-02

Table 1. continued

Transition	T (K)	W (nm)	d (nm)
	5000.	0.170E-01	-0.337E-02
	10000.	0.118E-01	-0.241E-02
$a^4F_{9/2} - z^4F^0_{9/2}$	20000.	0.817E-02	-0.174E-02
	30000.	0.662E-02	-0.145E-02
$\lambda = 323.55$ nm	40000.	0.577E-02	-0.127E-02
	50000.	0.525E-02	-0.117E-02

References

Bates, D.R., Damgaard, A.: 1949, *Phil. Trans. Roy. Soc. London*, Ser. A, **242**, 101.

Blackwell, D.E., Menon, S.L.R., Petford, A.D.: 1982, *Mon. Not. R. Astron. Soc.*, **201**, 603.

Danzmann, K., Kock, M.: 1980, *J. Phys.*, **B 13**, 2051.

Dimitrijević, M.S., Konjević, N.: 1980, *JQSRT*, **24**, 454.

Dimitrijević, M.S., Bommier, V., Sahal-Bréchot, S.: 1991 *Astron. Astrophys. Suppl. Series*, **89**, 581.

Dimitrijević, M.S.: 1996, *Zh. Priklad. Spektrosk.*, **63**, 810.

Lakićević, I.S.: 1983, *Astron. Astrophys.*, **127**, 37.

Morton, D.S.: 1991, *Astrophys. J. Suppl. Series*, **77**, 119.

Popović, L.Č., Dimitrijević, M.S.: 1996, *Physica Scripta*, **53**, 325.

Popović, L.Č., Dimitrijević, M.S.: 1997, in The Physics of Ionized Gases, (eds. B. Vujičić, S. Djurović, J. Purić, Institute of Physics, Faculty of Siences University of Novi Sad, Yugoslavia.

Roberts, J.R., Voigt, P.A., Czernichowski, A.: 1974, *Astrophys. J.*, **197**, 791.

Tankosić, D., Popović, L.Č., Dimitrijević, M.S.: 1998, to be published

Wiese, W.L., Musgrove, A.: 1989, *Atomic Data for Fuson*-Vol. IV: Spectroscopic Data for Titanium, Chromium and Nickel, Vol. 1 Titanium, F-23.

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ON THE STARK BROADENING OF Kr VIII LINES

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Abstract. Using a semiclassical approach, we have calculated electron-, proton-, and He III-impact line widths and shifts for 6 Kr VIII multiplets.

1. INTRODUCTION

Spectral line parameters even for trace elements become of increasing interest for astrophysics, due to the development of observations from the space. By using the Goddard High Resolution Spectrograph on Hubble Space Telescope, Cardelli *et al.* (1991) have, for the first time, begun detecting elements such as krypton. Stark broadening data for higher ionization stages, may be of interest for the investigation of subphotospheric layers (Seaton, 1987), as well as for the investigation of regularities and systematic trends along isoelectronic sequences. Griem and Moreno (1990) and Fill and Schöning (1994) pointed out the importance of such results for the development of soft x-ray lasers, where Stark broadening data are needed to calculate gain values, model radiation trapping and to consider photoresonant pumping schemes.

In order to provide Stark broadening data needed for the investigation and modeling of astrophysical and laboratory plasmas, we have calculated within the semiclassical-perturbation formalism (Sahal–Bréchot 1969ab, Dimitrijević and Sahal - Bréchot, 1984, Dimitrijević *et al.* 1991, Dimitrijević and Sahal - Bréchot, 1995) electron-, proton-, and He III-impact line widths and shifts for 6 Kr VIII multiplets.

2. RESULTS AND DISCUSSION

As the continuation of our project to provide to astrophysicists and plasma physicists the needed Stark-broadening parameters (see Dimitrijević 1996, Dimitrijević and Sahal-Bréchot 1995 and references therein), electron-, proton-, and He III- impact line widths and shifts have been calculated for Kr VIII. Energy levels for Kr VIII are taken from Sugar and Musgrove (1991). Our results for 6 Kr VIII multiplets, for perturber densities 10^{17} - 10^{22} cm^{-3} and temperatures T = 200,000 -3,000,000K will be published in Dimitrijević and Sahal-Bréchot (1999a,b).

Table 1

This Table shows electron- and proton-impact broadening full half-widths (FWHM) and shifts for Kr VIII for a perturber density of 10^{17} cm^{-3} and temperatures from 200,000 up to 3,000,000 K. By deviding C with the full line width, we obtain an estimate for the maximum perturber density for which the line may be treated as isolated and tabulated data may be used.

PERTURBER DENSITY = 1.E+17cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Kr VIII4S 4P	200000.	0.991E-03	-0.143E-04	0.240E-04	-0.105E-04
665.7 A	500000.	0.656E-03	-0.169E-04	0.516E-04	-0.219E-04
C=0.67E+20	1000000.	0.499E-03	-0.155E-04	0.731E-04	-0.315E-04
	1500000.	0.432E-03	-0.157E-04	0.808E-04	-0.376E-04
	2000000.	0.393E-03	-0.152E-04	0.866E-04	-0.405E-04
	3000000.	0.347E-03	-0.145E-04	0.939E-04	-0.451E-04
Kr VIII4S 5P	200000.	0.175E-03	0.751E-06	0.134E-04	0.320E-06
182.1 A	500000.	0.121E-03	0.113E-05	0.201E-04	0.731E-06
C=0.20E+19	1000000.	0.956E-04	0.973E-06	0.228E-04	0.115E-05
	1500000.	0.848E-04	0.100E-05	0.243E-04	0.139E-05
	2000000.	0.785E-04	0.890E-06	0.254E-04	0.158E-05
	3000000.	0.709E-04	0.105E-05	0.265E-04	0.177E-05
Kr VIII5S 5P	200000.	0.185E-01	-0.514E-03	0.121E-02	-0.584E-03
1692.0 A	500000.	0.131E-01	-0.623E-03	0.187E-02	-0.929E-03
C=0.17E+21	1000000.	0.105E-01	-0.578E-03	0.218E-02	-0.114E-02
	1500000.	0.941E-02	-0.546E-03	0.237E-02	-0.126E-02
	2000000.	0.873E-02	-0.550E-03	0.251E-02	-0.136E-02
	3000000.	0.789E-02	-0.474E-03	0.269E-02	-0.150E-02
Kr VIII4P 5S	200000.	0.302E-03	0.204E-04	0.112E-04	0.198E-04
294.2 A	500000.	0.211E-03	0.252E-04	0.260E-04	0.309E-04
C=0.51E+19	1000000.	0.167E-03	0.231E-04	0.380E-04	0.378E-04
	1500000.	0.148E-03	0.222E-04	0.437E-04	0.419E-04
	2000000.	0.136E-03	0.219E-04	0.477E-04	0.449E-04
	3000000.	0.122E-03	0.199E-04	0.553E-04	0.497E-04
Kr VIII4P 6S	200000.	0.227E-03	0.327E-04	0.196E-04	0.295E-04
184.4 A	500000.	0.166E-03	0.320E-04	0.373E-04	0.401E-04
C=0.10E+19	1000000.	0.136E-03	0.298E-04	0.479E-04	0.478E-04
	1500000.	0.121E-03	0.286E-04	0.550E-04	0.526E-04
	2000000.	0.112E-03	0.263E-04	0.612E-04	0.560E-04
	3000000.	0.101E-03	0.231E-04	0.666E-04	0.597E-04

Table 1 continued

PERTURBER DENSITY = 1.E+17cm-3

PERTURBERS ARE:		ELECTRONS		PROTONS	
TRANSITION	T(K)	WIDTH(Å)	SHIFT(Å)	WIDTH(Å)	SHIFT(Å)
Kr VIII5P 6S	200000.	0.467E-02	0.439E-03	0.359E-03	0.416E-03
697.9 A	500000.	0.341E-02	0.421E-03	0.602E-03	0.565E-03
C=0.14E+20	1000000.	0.279E-02	0.395E-03	0.746E-03	0.671E-03
	1500000.	0.250E-02	0.377E-03	0.851E-03	0.739E-03
	2000000.	0.233E-02	0.347E-03	0.932E-03	0.788E-03
	3000000.	0.210E-02	0.299E-03	0.101E-02	0.839E-03

As a part of our results, the Stark broadening widths (FWHM) and shifts due to electron and proton impacts, for a perturber density of 10^{17} cm^{-3}, are shown in Table 1. Parameter C (Dimitrijević and Sahal-Bréchot 1984), given also in Table 1, provides an estimate for the maximum perturber density for which the line may be treated as isolated when divided by the corresponding electron-impact full width at half maximum. For each value given in Table 1, the collision volume (V) multiplied by the perturber density (N) is much less than one and the impact approximation is valid (Sahal–Bréchot, 1969ab). Values for NV $>$ 0.5 are not given and values for 0.1 $<$ NV $\leq$ 0.5 are denoted by an asterisk.

The complete results will be published in Dimitrijević and Sahal–Bréchot (1999ab).

References

Cardelli, J.A., Savage, B.D., Ebbets, D.C.: 1991, *Astrophys. J.*, **383**, L23.
Dimitrijević, M.S.: 1996, *Zh. Prikl. Spektrosk.* **63**, 810.
Dimitrijević, M.S., and Sahal-Bréchot, S.: 1984, *JQSRT* **31**, 301.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1995, *Astron. Astrophys. Suppl. Series* **109**, 551.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1999a, *Physica Scripta* submitted.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1999b, *Serb. Astron. J.* **159**, in press.
Dimitrijević, M.S., Sahal-Bréchot, S. and Bommier, V.: 1991, *Astron. Astrophys. Suppl. Series* **89**, 581.
Fill, E.E., Schöning, T.: 1994, *J. Appl. Phys.* **76**, 1423.
Griem, H.R., Moreno, J.C.: 1990, in: *X-Ray Lasers*, ed. G. Tallents, Institute of Physics, Bristol, 301.
Sahal-Bréchot, S.: 1969a, *Astron.Astrophys.* **1**, 91.
Sahal-Bréchot, S.: 1969b, *Astron.Astrophys.* **2**, 322.
Seaton, M.J.: 1987, *J. Phys. B*, **20**, 6363.
Sugar, J., Musgrove, A.: 1991, *J. Phys. Chem. Ref. Data*, **20**, 875.

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ON THE STARK BROADENING OF NEUTRAL ZINC SPECTRAL LINES

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Abstract. Using the semiclassical perturbation approach, we have calculated electron–, proton– and He II–impact line widths and shifts for 32 Zn I multiplets for perturber densities 10^{13}– 10^{19} cm^{-3} and temperatures T = 2,500 – 50,000 K. Obtained results have been compared with the existing theoretical and experimental data.

1. INTRODUCTION

The Zn I spectral lines have been observed in stellar (see *e.g.* Sneden *et al.* 1991) and solar (see *e.g.* Biémont and Godefroid 1980, Grevesse 1984) spectra, so that corresponding Stark broadening parameters are of interest for a number of astrophysical problems, as well as for laboratory plasma diagnostics.

Within the semiclassical-perturbation formalism (Sahal–Bréchot 1969ab, see also Dimitrijević and Sahal– Bréchot 1995, Dimitrijević and Sahal - Bréchot 1984), we have calculated electron-, proton-, and ionized helium-impact line widths and shifts for 32 Zn I multiplets, as the continuation of our project to create a large Stark broadening data set for astrophysical and laboratory plasma research purposes.

In this contribution, the comparison of our results with existing experimental (Kusch and Oberschelp 1987, Fishman *et al.* 1979, Rathore *et al.* 1985) and theoretical (Dimitrijević and Konjević 1983, Lakićević 1983), and Rathore *et al.* 1985) data is presented.

2. RESULTS AND DISCUSSION

A review of the used semiclassical perturbation formalism is given e. g. in Dimitrijević and Sahal-Bréchot 1984. Atomic energy levels needed for calculations are taken from Sugar and Musgrove (1995).

Our results for 32 neutral zinc spectral lines as a function of the perturber density and temperature will be published in Dimitrijević and Sahal-Bréchot (1999).

Table 1

Comparison between experimental and theoretical Stark full widths at half maximum for Zn I triplets. Experimental data: a-Kusch and Oberschelp (1967); b-Fishman, Semin and Desyatnik (1979); c-Rathore *et al.* (1985). Theoretical data: W1 - present results; W2 - Dimitrijević and Konjević (1983).

Transition	λ (Å)	T(K)	N/10^{+17} (cm^{-3}	Wm (Å)	Wm/W1	Wm/W2	Ref.
4p-5s	4810.53	11000	1.0	1.65	3.56	3.25	a
		11000	4.5	0.92	0.43	0.40	b
		13700	1.0	1.00	2.24	2.02	c
		14800	1.0	0.90	1.99	1.79	c
		16300	1.0	0.52	1.13	1.01	c
		18100	1.0	0.40	0.86	0.76	c
	4722.16	11000	1.0	1.57	3.39	3.09	a
		11000	4.5	1.20	0.58	0.52	b
		13700	1.0	1.00	2.24	2.02	c
		14800	1.0	0.64	1.42	1.27	c
		16300	1.0	0.42	0.92	0.82	c
		18100	1.0	0.36	0.77	0.69	c
	4680.14	11000	1.0	0.84	1.81	1.66	a
		11000	4.5	1.29	0.62	0.56	b
4p-6s	3072.06	11000	1.0	0.70	0.76	0.65	a
	3035.78	11000	1.0	0.61	0.66	0.57	a
	3018.36	11000	1.0	0.56	0.61	0.52	a
4p-4d	3345.02	11000	1.0	1.74	2.87	2.66	a
	3302.58	11000	1.0	1.40	2.31	2.14	a
	3282.33	11000	1.0	0.91	1.50	1.39	a
4p-5d	2800.9	11000	1.0	1.96	0.53	0.39	a
	2770.9	11000	1.0	2.49	0.67	0.50	a
	2756.45	11000	1.0	1.27	0.34	0.25	a

There are three experimental studies with data of Stark widths and shifts of neutral zinc lines (Kusch and Oberschelp 1987, Fishman *et al.* 1979, Rathore *et al.* 1985). Theoretical data suitable for comparison with our results are published in Dimitrijević and Konjević (1983), Lakićević (1983), and Rathore *et al.* (1985).

In Tables 1 and 2, experimental (Kusch and Oberschelp 1987, Fishman *et al.* 1979, Rathore *et al.* 1985) Stark widths (Table 1) and shifts (Table 2) are compared with present resuts and with semiclassical Stark broadening parameters from Dimitrijević and Konjević (1983). In experiments of Kusch and Oberschelp (1987) and Fishman *et al.* (1979), ion perturbers are protons, while in the experiment of Rathore *et al.* (1985) the carrier gas was neon. In order to make an adequate comparison, Stark

broadening of neutral zinc by impacts with neon ions is calculated and included in W1 and d1 (present calculation of Stark widths - W1 and shifts - d1) values in Tables 1 and 2. For $4p^3P^o$ - $5d^3D$ multiplet, the impact approximation is not valid for proton perturbers and the quasistatic ion broadening contribution is calculated according to Griem (1974). One can see in Table 1 that the agreement of all experiments with both calculations is very poor. The ratio of experimental widths of Kusch and Oberschelp (1967) and the theoretical ones vary from 0.25 up to 3.56. The experimental widths of Fishman *et al.* (1979) are two times larger than theoretically obtained within both approaches. The temperature trend of the experimental widths of Rathore *et al.* (1985) is in such disagreement with both theoretical approaches that the ratio of measured and calculated Stark widths vary *e.g.* for 4722.16 Å line from 2.24 for $T =$ 13,700 K up to 0.77 for $T = 18100$ K for present results, and from 2.02 up to 0.69 for theoretical values of Dimitrijević and Konjević (1983). For the shift, the ratio of experimental values of Rathore *et al.* (1985) and the results of present calculations vary from 1.24 up to 0.46 for the same spectral line.

Table 2

Comparison between experimental and theoretical Stark shifts for Zn I triplets. Experimental data: b-Fishman, Semin and Desyatnik (1979); c-Rathore *et al.* (1985). Theoretical data: d1 - present results; d2 - Dimitrijević and Konjević (1983).

Transition	λ (Å)	T(K)	$N/10^{+17}$ (cm^{-3}	dm (Å)	dm/d1	dm/d2	Ref.
4p-5s	4810.53	13700	1.0	0.44	1.24	1.58	c
		14800	1.0	0.35	0.97	1.24	c
		16300	1.0	0.25	0.66	0.87	c
		18100	1.0	0.21	0.55	0.72	c
	4722.16	11000	4.5	0.78	0.49	0.69	b
		13700	1.0	0.44	1.24	1.58	c
		14800	1.0	0.35	0.97	1.24	c
		16300	1.0	0.256	0.67	0.89	c
		18100	1.0	0.175	0.46	0.60	c

Experimental results of Fishman *et al.* (1979) and Rathore *et al.* (1985) are not selected for critical compilations of reliable Stark broadening experimental data (Konjević and Roberts 1976, Konjević *et al.* 1984, Konjević and Wiese 1990) and results of Kusch and Oberschelp (1967) are selected but with the atribution of the lowest accuracy (Konjević and Roberts 1976). In the analysis of the Kusch and Oberschelp (1967) experiment, Konjević and Roberts (1976) have found large variations of Stark widths within multiplets, and supposed that this may be caused by improper treatment of self-absorption. Moreover, Dimitrijević and Konjević (1983) have shown on the basis of the analysis of Stark width systematic trends within spectral series, that experimental results of Kusch and Oberschelp (1967) are in disagreement with such trends.

Lakićević (1983) estimated on the basis of regularities and systematic trends, Stark width and shift for Zn I $4s^2\ ^1S$ -$4p^1P^o$ transition for an electron temperature (T) of 20,000 K and an electron density of $10^{17}cm^{-3}$. He obtained the value of 0.066Å for full width at half maximum, and 0.035Å for the shift. We obtain the value of 0.039Å for the width and 0.029Å for the shift. On the basis of regularities and systematic trends as well, Stark widths and shifts for Zn I $4p^3P^o$ - $5s^3S$ transition for electron temperatures of 10,000 and 20,000 K and an electron density of $10^{17}cm^{-3}$, have been estimated by Rathore *et al.* (1985). They obtained the value of 0.60Å for full width at half maximum, and 0.36Å for the shift, for T = 10,000 K, and our results are 0.371Å for the width and 0.295Å for the shift. For T = 20,000 K, they obtained 0.61Å for the width and 0.30Å for the shift, and we 0.408Å for the width and 0.336Å for the shift. Particularly for the shift, this is in both cases an encouraging agreement of simple estimates with our semiclassical perturbation results.

Semiclassical perturbation method used here and the semiclassical method described in Griem (1974) and used in Dimitrijević and Konjević (1983) have been compared with critically selected experimental data for 13 He I multiplets (Dimitrijević and Sahal-Bréchot 1985) and it was found that the agreement between experimental data and both semiclassical methods is within the limits of 20 percent, which is the predicted accuracy of the semiclassical method (Griem 1974). Differences between our results and results for Zn I from Dimitrijević and Konjević (1983) are larger and increase with temperature, particularly for the shift. One must take into account, that more recent and more complete energy levels have been used in our calculations.

The obtained Stark broadening data are of interest for a number of problems in astrophysics and plasma physics as *e.g.* abundance determinations, stellar spectra analysis and laboratory plasma diagnostics. Reliable experimental determinations of neutral zinc Stark broadening parameters will be of interest for checking and development of Stark broadening theory.

References

Biémont, E. and Godefroid, M.: 1980, *Astron. Astrophys.* **84**, 361.
Dimitrijević, M. S. and Konjević, N.: 1983, *J. Quant. Spectrosc. Radiat. Transfer* **30**, 45.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1984, *JQSRT* **31**, 301.
Dimitrijević, M.S. and Sahal-Bréchot, S.: 1999, *Astron. Astrophys. Suppl. Series* submitted.
Dimitrijević, M. S. and Sahal–Bréchot, S.: 1985, *Phys. Rev. A* **31**, 316.
Dimitrijević, M.S. and Sahal–Bréchot, S.: 1995, *Phys. Scripta* **52**, 42.
Fishman, I.S., Semin, P.S. and Desyatnik, G.A.: 1979, *Opt. Spectrosc.* **47**, 245.
Grevesse, N.: 1984, *Phys. Scripta* **T8**, 49.
Griem, H.R.: 1974, Spectral Line Broadening by Plasmas, Academic Press, New York.
Konjević, N., Dimitrijević, M.S., Wiese, W.L.: 1984, *J. Phys. Chem. Ref. Data* **13**, 619.
Konjević, N., Roberts, J.R.: 1976, *J. Phys. Chem. Ref. Data* **5**, 209.
Konjević, N., Wiese, W.L.: 1990, *J. Phys. Chem. Ref. Data* **19**, 1307.
Kusch, H.J. and Oberschelp, E.: 1967, *Z. Astrophys.* **67**, 77.
Lakićević, I.S., 1983: *Astron. Astrophys.* **127**, 37.
Rathore, B.A., Purić, J. and Ćuk, M., Lakićević, I.S.: 1985, *Sing. J. Phys.* **2**, 105.
Sahal-Bréchot, S.: 1969a, *Astron. Astrophys.* **1**, 91.
Sahal-Bréchot, S.: 1969b, *Astron. Astrophys.* **2**, 322.
Sneden, C., Gratton, R.G. and Crocker, D.A.: 1991, *Astron. Astrophys.* **246**, 354.
Sugar, J. and Musgrove, A.: 1995, *J. Phys. Chem. Ref. Data* **24**, 1803.

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STARK SHIFT OF SEVERAL Kr II SPECTRAL LINES

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Abstract. Stark shifts of thirteen singly charged krypton (Kr II) ion spectral lines have been measured in the linear, low pressure, pulsed arc at 17 000 K electron temperature and 1.65×10^{23} m^{-3} electron density. The measured shift values have been compared to the theoretical data calculated by us by using the modified semiempirical method.

1. INTRODUCTION

For the first time by means of the Goddard high resolution spectrograph on the Hubble space telescope, krypton has been detected in the spectra of the interstellar medium (Cardelli et al. 1991, Cardelli and Mayer 1997) which represents the material from which the young early type stars (as e. g. Ap and Bp type stars where Stark broadening data are of interest) are formed (Leckrone at al. 1993). Moreover, krypton is present in many light sources and lasers as the working gas. If the Stark broadening is the principal pressure broadening mechanism in plasmas (with 10^{22} - 10^{27} m^{-3} electron density), it is possible to obtain from Stark width and shift values other basic plasma parameters as e.g. electron temperature (T) and density (N), essential for the stellar atmospheres modeling. Consequently, the knowledge of the Stark broadening parameters (the width and the shift) of ionized krypton (Kr II) spectral lines is of interest for plasma diagnostic purpose.

In the case of the Kr II Stark shift investigations the available literature is poor. Namely, since the first Kr II lines Stark shift investigation (Mandel'shtam 1962), only one experiment (Vitel and Skowronek 1987) provided reliable Stark line shifts of three Kr II spectral lines. In Di Rocco et al. (1989) Kr II line shifts have been investigated but without a reliable plasma parameter determination so that the comparison with our results is not possible. In this work we will present measured and calculated Stark shift (d) values of fourteen Kr II spectral lines. Stark shift values of eleven Kr II lines were not known before.

Measurements have been performed at 17 000 K electron temperature and 1.65×10^{23} m^{-3} electron density in krypton plasma created in the linear, low pressure, pulsed arc discharge. The d values have been calculated within the frame of the modified semiempirical method.

2. EXPERIMENT

The modified version of the linear low pressure pulsed arc (Djeniže et al. 1991 - Milosavljević and Djeniže 1998) has been used as a plasma source. The working gas was pure krypton at 130 Pa filling pressure in flowing regime. Spectroscopic observation of isolated spectral lines was made end-on along the axis of the discharge tube. A capacitor of 14 μF was charged up to 1.5 kV. The line profiles were recorded using a shot-by-shot technique with a photomultiplier (EMI 9789 QB) and a grating spectrograph (Zeiss PGS-2, reciprocal linear dispersion 0.73 nm/mm in first order) system. The spectrograph exit slit (10 μm) with the calibrated photomultiplier was micrometrically traversed along the spectral plane in small wavelength steps (0.0073 nm). The averaged photomultiplier signal (five shots at the same spectral range) was digitalized using an oscilloscope, interfaced to a computer.

The Stark shifts were measured relative to the unshifted spectral lines emitted by the same plasma and have been corrected for the electron temperature decay. Stark shift data are determined with ± 0.0008 nm error at given N and T. The electron temperature was determined from the ratios of the relative intensities of nine Kr II spectral lines with an estimated error of $\pm 9\%$, assuming the existence of LTE, according to the criterion from Griem (1974). The electron density decay was measured using the well known single laser interferometry technique (Ashby et al. 1965) for the 632.8 nm He-Ne laser wavelength with an estimated error of $\pm 7\%$. The electron density and temperature decay are presented in Milosavljević et al. (2000) (Fig. 5).

At 20μs and 300μs after the beginning of the discharge, when the Kr II spectral line center positions were obtained, the found electron densities were 1.65×10^{23} m^{-3} $\pm 7\%$ and 0.03×10^{23} m^{-3} $\pm 80\%$, respectively.

3. METHOD OF CALCULATION

According to the MSE approach (Dimitrijević and Kršljanin 1986) the electron Stark shift is given as

$$d = N\frac{4\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}\cdot\{\varepsilon_{\ell_i,\ell_i+1}\mathbf{R}^2[n_i\ell_i,n_i(\ell_i+1)]\widetilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_i,\ell_i+1}}\right)-$$

$$-\varepsilon_{\ell_i,\ell_i-1}\mathbf{R}^2[n_i\ell_i,n_i(\ell_i-1)]\widetilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_i,\ell_i-1}}\right)-$$

$$-\varepsilon_{\ell_f,\ell_f+1}\mathbf{R}^2[n_f\ell_f,n_f(\ell_f+1)]\widetilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_f,\ell_f+1}}\right)+$$

$$+\varepsilon_{\ell_f,\ell_f-1}\mathbf{R}^2[n_f\ell_f,n_f(\ell_f-1)]\widetilde{g}_{sh}\left(\frac{E}{\Delta E_{\ell_f,\ell_f-1}}\right)+\left(\sum_{i'}\mathbf{R}^2_{ii'}\right)_{\Delta n\neq 0}g_{sh}(x_{n_i},x_{n_i+1})-$$

$$-2\sum_{i'(\Delta E_{ii'}<0)}\mathbf{R}^2_{ii',\Delta n\neq 0}g_{sh}\left(\frac{E}{\Delta E_{n_i,\ell_i,n_{i'}\ell_{i'}}}\right)-\left(\sum_{f'}\mathbf{R}^2_{ff'}\right)_{\Delta n\neq 0}g_{sh}(x_{n_f},x_{n_f+1})+$$

$$+2 \sum_{f'(\Delta E_{ff'}<0)} \mathbf{R}^2_{ii',\Delta n\neq 0} g_{sh}\left(\frac{E}{\Delta E_{n_f,\ell_f,n_{f'}\ell_{f'}}}\right) + \sum_k \delta_k \} \tag{1}$$

where the initial level is denoted by i and the final one by f the square of the matrix element $\{\mathbf{R}^2[n_k\ell_k, n_k(\ell_k \pm 1)], \quad k = i, f\}$ being

$$\mathbf{R}^2[n_k\ell_k, n_k(\ell_k \pm 1)] = \left(\frac{3n_k^*}{2Z}\right)^2 \frac{\ell_>}{2\ell_k + 1}(n_k^{*2} - \ell_k^2)\Phi^2(n^{*2}_{\ell_k-1}, n^{*2}_{\ell_k}, \ell_k) \tag{2}$$

and

$$\left(\sum_{k'} \mathbf{R}^2_{kk'}\right)_{\Delta n\neq 0} = \left(\frac{3n_k^*}{2Z}\right)^2 \frac{1}{9}(n_k^{*2} + 3\ell_k^2 + 3\ell_k + 11) \tag{3}$$

where $\ell_> = \max(\ell_k, \ell_{k'})$, ℓ denoting the angular momentum quantum number.

In Eqs. (1 - 3) N and T are electron density and temperature, respectively, and Φ^2 is the Bates-Damgaard factor tabulated *e.g.* in Oertel and Shomo (1968). Here, $g(x), g_{sh}(x)_{sh}$ and $\widetilde{g}(x), \widetilde{g}_{sh}(x)$ are the semiempirical (Griem 1968) and the modified semiempirical (Dimitrijević and Konjević 1980, Dimitrijević and Kršljanin 1986) Gaunt factors for Stark width and shift, respectively. The factor $\varepsilon_{kk'} = (E_{k'} - E_k)/|E_{k'} - E_k|$, where E_k and $E_{k'}$ are respective energies of the considered and its perturbing level. The sum $\sum_k \delta_k$ is different from zero only if perturbing levels strongly violating the assumed approximations exist and may be evaluated as

$$\delta_i = \pm \mathbf{R}^2_{ii'}\left[g_{sh}\left(\frac{E}{\Delta E_{i,i'}}\right) \mp g_{sh}(x_{n_i,n_i+1})\right], \tag{4}$$

for upper level, and

$$\delta_f = \mp \mathbf{R}^2_{ff'}\left[g_{sh}\left(\frac{E}{\Delta E_{f,f'}}\right) \mp g_{sh}(x_{n_f,n_f+1})\right], \tag{5}$$

for lower level. In Eqs. (4) and (5) subscripts correspond to $\Delta E_{jj'} < 0$; $x_{n_k,n_k+1} \approx 3kTn_k^{*3}/(2Z^2E_H)$, where $\Delta E_{kk'} = |E_k - E_{k'}|$, n_k is the principal, n_k^* the effective principal quantum number, $E = 3kT/2$ and $(Z - 1)$ is the ionic charge.

4. RESULTS AND DISCUSSION

The needed atomic energy levels for Kr III have been taken from Sugar and Musgrove (1991). The results of the measured Stark shift (d_m) values at T=17 000 K electron temperature and 1.65x10^{23} m^{-3} electron density are shown in Table 1. Our theoretical d_{th} values are presented in Table 2.

Table 1. Measured Stark shift (d_m) values for the Kr II lines at the observed electron temperature (T) of 17 000 K and electron density (N) of 1.65×10^{23} m^{-3}. Positive shift is toward the red.

Transition	*Multiplet*	λ (nm)	d_m (nm)
5s-5p	$^4P_{5/2}$-$^4P^0_{3/2}$	465.89	-0.0010
	$^4P_{3/2}$-$^4P^0_{1/2}$	483.21	-0.0014
	$^4P_{5/2}$-$^4D^0_{7/2}$	435.55	-0.00
	$^4P_{5/2}$-$^4D^0_{5/2}$	473.90	-0.0014
	$^4P_{3/2}$-$^4D^0_{5/2}$	476.57	-0.00
	$^2P_{3/2}$-$^2P^0_{1/2}$	484.66	-0.00
	$^2P_{3/2}$-$^2P^0_{3/2}$	461.53	-0.00
	$^2P_{3/2}$-$^2D^0_{5/2}$	461.91	-0.00
5s′-5p′	$^2D_{3/2}$-$^2F^0_{5/2}$	463.39	-0.0018
	$^2D_{5/2}$-$^2F^0_{5/2}$	457.72	-0.00
	$^2D_{5/2}$-$^2P^0_{3/2}$	447.50	-0.0017
	$^2D_{5/2}$-$^2D^0_{5/2}$	408.83	-0.0017
5p-5d	$^4D^0_{5/2}$-$^4F_{7/2}$	377.81	0.0090

Table 2. Stark shift values (d in nm) calculated by using the modified semiempirical method (Eqs. 1-5) for the Kr II spectral lines, at 10^{23} m^{-3} electron density.

	T (10^4 K)				
λ (nm)	1	2	3	4	5
473.90	-0.0101	-0.0074	-0.0063	-0.0058	-0.0056
465.89	-0.0111	-0.0082	-0.0070	-0.0064	-0.0062
483.21	-0.0111	-0.0082	-0.0070	-0.0064	-0.0062
435.55	-0.0083	-0.0061	-0.0051	-0.0047	-0.0044
476.57	-0.0089	-0.0066	-0.0056	-0.0051	-0.0049
484.66	-0.0125	-0.0092	-0.0078	-0.0071	-0.0069
461.53	-0.0104	-0.0076	-0.0064	-0.0058	-0.0055
461.91	-0.0099	-0.0073	-0.0061	-0.0055	-0.0052
463.39	-0.0056	-0.0036	-0.0029	-0.0028	-0.0028
457.72	-0.0091	-0.0066	-0.0056	-0.0051	-0.0049
447.50	-0.0103	-0.0071	-0.0057	-0.0051	-0.0049
408.83	-0.0065	-0.0047	-0.0039	-0.0035	-0.0033
378.31	0.0057	0.0107	0.0134	0.0149	0.0154
377.81	0.0076	0.0128	0.0155	0.0168	0.0172

One can conclude on the basis of the Table 1. and Table 2., that the d_m values are very small. Within the accuracy of measurements (0.0008 nm) many of them were equal to zero. Our calculations give higher absolute d values than the measured ones. Our calculated and measured Stark shift values, in the case of the Kr II lines (Table 1. and Table 2.), have the same sign. For the lines that belong to the 5s-5p and 5s′-5p′ transitions d is negative and for lines from the 5p-5d transition d is positive. Our

measured d_m values confirm the observed negative sign by Vitel and Skowronek (1987) for three Kr II lines (473.90 nm, 465.89 nm and 435.55 nm). Evident Stark shift, in our measurements, was observed only for the 377.81 nm Kr II line which belongs to the higher lying 5p-5d transition. In all cases the shift values are considerably smaller than width values. This indicates that particular important contributions have different sign and that their mutual cancellation results in shifts much smaller than widths. Since the assumed accuracy of the method is ±50 % of the width value, the reliability of these small shifts is much lower. Therefore, d_m/d_{th} ratios are not presented in this paper.

References

Ashby, D. E. T. F., Jephcott, D.F., Malein, A. and Raynor, F. A.; 1965, *Appl. Phys.*, **36**, 29.
Cardelli, J. A., Mayer, S.; 1997, *Astrophys. J.*, **477**, L57.
Cardelli, J. A., Sarage, B. D., Ebbets, D. C.; 1991, *Astrophys. J.*, **383**, L23.
Dimitrijević, M. S., Konjević, N.; 1980, *JQSRT*, **24**, 451.
Dimitrijević, M. S., Kršljanin, V.; 1986, *Astron. Astrophys.*, **165**, 269.
Djeniže S., Srećković A., Labat J., Konjević R., Popović L. Č.; 1991, *Phys. Rev.*, **A44**, 410.
Djeniže S., Milosavljević V., Srećković A.; 1998, JQSRT **59**, 71.
Griem, H. R.; 1968, *Phys. Rev.*, **165**, 258.
Griem, H. R., "Spectral Line Broadening by Plasmas" (Acad.Press, New York, 1974)
Leckrone, D. S. et al.; 1993, in Peculiar Versus Normal Phenomena in A-type and Related Stars, ASP Conf. Ser. **44**, 42.
Mandel'shtam, S. L.; 1962, in Optik und Spektroskopie Aller Wellenlängen, Akademie Verlag, Berlin, **372**.
Milosavljević V., Djeniže S.; 1998, Astron. Astrophys. Suppl. Series. **128**, 197.
Milosavljević, V., Djeniže, S., Dimitrijević, M. S., Popović, L. Č; 2000, (submitted to *Phys. Rev.*)
Oertel, G. K., Shomo, L. P.; 1968, *Astrophys. J. Suppl. Series*, **16**, 175.
Rocco di H. O., Bertuccelli G., Almandos J. R., Bredice S., Gallardo M.; 1989, *JQSRT*, **41**, 161 (1989).
Sugar, J., Musgrove, A.; 1991, *J. Phys. Chem. Ref. Data*, **20**, 859.
Vitel, Y., Skowronek, M.; 1987, *J. Phys. B*, **20**, 6493.

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О ДОПРИНОСУ АСТРОНОМА ЂОРЂА СТАНОЈЕВИЋА РАЗВОЈУ ТЕКСТИЛНЕ ИНДУСТРИЈЕ ЛЕСКОВЦА

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Резиме. Први српски астрофизичар и други човек на челу Астрономске опсерваторије Ђорђе Станојевић, био је и један од пионира индустријализације у Србији. У раду је описана његова улога у оснивању Првог Лесковачког акционарског друштва за прераду кудеље и лана.

1. Увод

Да ли знате ко је увео електрично осветљење у Београду? Ко је саградио прву електричну централу у Србији? Ко је снимио прву фотографију у боји у нашој земљи? Споменик овоме човеку налази се у Београду у Масариковој улици испред зграде Електродистрибуције. Међу бројним занимањима ове ренесансне личности, Ђорђа Станојевића, била је и астрономија. Он је први српски астрофизичар, други директор Астрономске опсерваторије, ректор Универзитета у Београду, и наш први велики популаризатор науке у данашњем смислу.

Ђорђе Станојевић је и пионир индустријализације у Србији. За рад модерне фабрике потребна је електрична енергија, а он је по Србији градио електричне централе, међу којима и хидроцентралу у Вучју код Лесковца. Осим тога, као професор физике на Великој школи, схватајући значај коју електричне машине имају за индустријализацију земље, организује ремонтну службу за електромоторе. У Србији он покреће индустрију ледара и од 1907. године је на челу тада основане Комисије за "индустрију хладноће".

У заоставштини оца аутора овог прилога, Сергија Димитријевића, у архивском матерјалу који је он са супругом Надеждом прикупљао за рад на историји Лесковца, налазе се и документи везани за Ђорђа Станојевића, који осветљавају његову улогу у развоју текстилне индустрије овога града, а који ће овде бити изложени.

2. Ђорђе Станојевић

О животу и раду Ђорђа Станојевића и његовој улози у астрономији писано је опширно више пута (Димитријевић, 1997аб; Трифуновић, 1976, 1994, 1997; Шешић и Миљанић, 2001), тако да ћемо овде дати само краће биографске податке. Овај велики човек рођен је у Неготину 7 априла 1858. године. У родном граду, где је завршио основну школу и нижу гимназију, данас постоји његова спомен соба. У Београд прелази 1874. године и у Првој београдској гимназији полаже испит зрелости септембра 1877. године Исте године уписује се на Природно - математички одсек Филозофског факултета Велике школе у Београду, опредељујући се у току студија за физику. Студије завршава 1881. године, а Коста Алковић, који је на Великој школи предавао физику њему као и оснивачу Астрономске опсерваторије Милану Недељковићу, задржава га као асистента приправника на Катедри за физику, где следеће 1882. године бива постављен за његовог асистента. Станојевић је 1883. године постављен за професора физике у Првој београдској гимназији.

Као питомац Министарства војног у периоду од 1883. до 1887. био је на студијама, специјализацији и раду на најпознатијим астрономским и метеоролошким опсерваторијама Европе у Берлину (Универзитет), Потсдаму (астрофизичка опсерваторија), Хамбургу (метеоролошка централа), Паризу (Сорбона), Медону (Париска опсерваторија за физичку астрономију), Гриничу, Кју-у и Пулкову. У овом периоду, Станојевић се опредељује за астрофизику и бира физику Сунца за своју научну област.

Године 1887, по повратку у земљу, постаје професор физике и механике на Војној академији а 1893. године, после пензионисања Косте Алковића, професор експерименталне физике на Великој школи где постаје директор Физичког института. Када је Милан Недељковић први пут био у пензији од 5 јула 1899. до 31 октобра 1900. године, Управник Београдске опсерваторије постаје Ђорђе Станојевић, а поверена му је и катедра за астрономију са метеорологијом. У периоду од 1909. до 1913. био је декан Филозофског факултета а од 1913. до 1921. године ректор Универзитета у Београду. На улици у Паризу, где борави ради проучавања неких решења у ваздухопловној техници, умире изненада услед срчаног удара 24. децембра 1921. године

3. Електрификација Лесковца

Првог марта 1904. г. по први пут је Лесковац осветљен електричном светлошћу (Аноним., 1906). У "Писму из Лесковца" из 1906. г. (M.J., 1906) пише: "*Лесковчани су вредни и предузимљиви људи*! Они су претпрошле год. овде увели *електрично осветљење*. Погледај оне лампице на дирецима! - То су *електричне сијалице*. А она велика стаклена кугла што виси на оној пијаци, то је такође електрична лампа што осветљава целу пијацу... њих има на свакој пијаци и раскрсници по једна. Када се увече све запале, - по вароши се види као у сред дана..." После Београда и Ужица, Лесковац је трећи

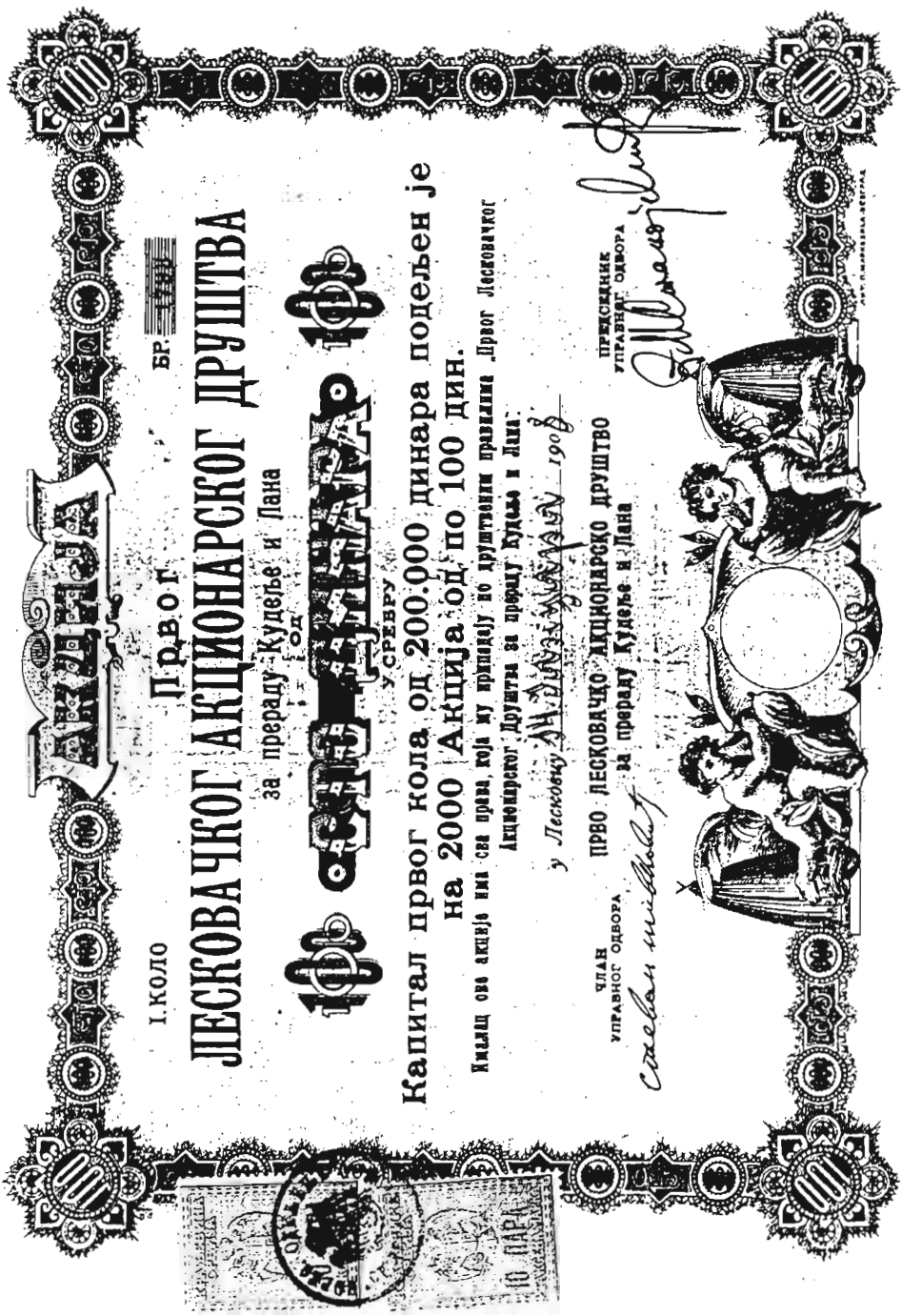
град у Србији који је добио електрично осветљење. Лесковачко електрично друштво основано је у августу 1901., радови на изградњи хидроцентрале у Вучју започети су у фебруару 1903. а завршени су крајем фебруара 1904. да би 1 марта 1904. Лесковац добио електрично осветљење (Аноним., 1906).

Председник Лесковачког електричног друштва, човек који је саградио хидроцентралу у Вучју и електрификирао Лесковац, је други руководилац Астрономске опсерваторије Ђорђе Станојевић. Он пише публикацију "Хидроелектрично постројење Вучје -Лесковац" (Станојевић, 1905), илустровану фотографијама које је сам снимио. Неке од ових фотографија, са његовим потписом излазе у Лесковачком часопису "Ђачки напредак". Тако у чланку "Електрично осветљење у Лесковцу" (Аноним., 1906) стоји: "Професор универзитета г. Ђока Станојевић, који је и председник "Лесков. Електричног Душтва" био је тако добар да је уступио Ђ. Напретку на послугу слике зграда и осталих постројења за потребе електричног осветљења. Благодарећи г. Станојевићу на учињеној доброти, ми у овом броју доносимо три слике, а доцније ћемо и остале донети." Станојевић, пише и "Статут Лесковачког електричног друштва" (Станојевић, 1921), а Лесковац и његова електрификација помињу се и у публикацији "Електрична индустрија у Србији" (Станојевић, 1901).

4. Оснивање Првог Лесковачког Акционарског друштва за прераду кудеље и лана

Заједно са радовима на изградњи прве хидроцентрале у Лесковцу, Ђорђе Станојевић покушава да добијену електричну енергију искористи за индустријску прераду кудеље и лана, и да од постојеће мануфактурне производње створи праву, модерну индустрију. У том циљу, он међу лесковачким газдама заговара оснивање акционарског друштва.

У заоставштини Сергија Димитријевића, налазе се преписи из архива Министарства Народне Привреде (у даљем току МНП), који осветљују ову активност другог руководиоца Астрономске опсерваторије. Овде у целини дајемо Изјаву Оснивача Првог Лесковачког Акционарског друштва о упису оснивачких акција и допис Министру Народне Привреде који је послат уз правила Друштва, где је први међу потписанима Станојевић, његову ургенцију Министру упућену 21. јануара 1904, нешто више од месец дана пре него што је прорадила Станојевићева хидроцентрала, коју потписује као Оснивач, као и његов допис Министру Народне Привреде од 12. јуна 1904. где је потписан као председник Оснивачког Одбора.



Слика 1. *Акција Првог Лесковачког акционарског друштва са потписом Ђорђа Станојевића.*

МНП, нефасциклирано, 1904.
(препис у заоставштини Сергија Димитријевића)

Изјава

Ми доле потписани оснивачи Првог Лесковачког Акционарског друштва за прераду кудеље и лана изјављујемо, да ћемо при упису акција тога Друштва, уписати сваки најмање по десет акција друштвених.

23. Новембра 1903.
У Лесковцу

Оснивачи Првог Лесков. Акц. Друштва за прераду кудеље и лана

Ђ. М. Станојевић, с.р.
С. Н. Тодоровић, с.р.
Лазар М. Николић, с.р.
Ђорђе М. Стојановић, с.р.
Сотир К. Илић, с.р.
Мика Цветковић, с.р.
Мих. М. Аранђеловић, с.р.
Сотир Томић, с.р.
Ђорђе Ј. Цекић, с.р.

МНП, нефасциклирано, 1904.
(препис у заоставштини Сергија Димитријевића)

Господину Министру Народне Привреде

Ми долепотписани ради смо да оснујемо друштво под именом:
"Прво Лесковачко Акционарско друштво за прераду кудеље и лана"
Прилажући правила друштвена у два егземплара, уверење о имовном стању и изјаву о упису одређеног броја акција, молимо Г. Министра Народне Привреде да нам друштвена правила потврди и одобри. Таксу ћемо платити кад будемо позвати.

23. Новембра 1903.
У Лесковцу

Оснивачи Првог Лесковачког Акционарског Друштва за прераду кудеље и лана

Ђ. М. Станојевић, проф. В. Шк. с.р.
С. Н. Тодоровић, трговац с.р.

Сотир Томић, трг. с.р.
Лазар М. Николић с.р.
Ђорђе М. Стојановић, с.р.
Мих. М. Аранђеловић, трг. с.р.
Ђорђе Ј. Цекић, трг. с.р.
Сотир К. Илић, трг. с.р.
Спира М. Стаменковић трг. с.р.
Мика Цветковић трг. с.р.

МНП, нефасциклирано, 1904.
(препис у заоставштини Сергија Димитријевића)

Министарство Народне Привреде
Одељење за трговину радиност и саобраћај

Т Бр. 461
21. јануара 1904. г
Београд

Господину Министру Народне Привреде

Од пре два месеца поднео сам правила Првог Лесковачког Акционарског друштва за прераду кудеље и лана", Г. Министру Народне Привреде на одобрење. Та су правила у Привредном Савету, који је данас у понедељак 19-ог ов. мес. једногласно усвојена и да би их Г. Министар могао одобрити треба да се сачека нов састанак Привр. Савета (месец дана или шест недеља) ради овере записника. Пошто се Савет врло ретко састаје а оснивачи Друштва хтели би што пре да приступе остварењу његовом да би још овога пролећа и лета могли припремити што треба за рад, то молим Г. Министра Народне Привреде, да из Савета изиште правила горњега Друштва и одобри их, јер му на то даје право сам пословник Савета и јер су правила једногласно усвојена.

21. Јануар 1904. год.
у Београду

С најодличнијим поштовањем
Ђ. М. Станојевић, с. р.
Оснивач I Леск. Др. за прераду куд. и лана

МНП, нефасциклирано, 1904.
(препис у заоставштини Сергија Димитријевића)

Господину Министру Народне Привреде

Част ми је спровести Г. Министру Народне Привреде два приложена идентична предлога оснивачког Одбора, Првог Лесковачког Друштва за прераду кудеље и лана за измену извесних чланова статута тога Друштва с молбом да Г. Министар предложену измену одобри.

12. јуна 1904.
у Београду

С најодличнијим поштовањем
председник Оснивачког Одбора
I Леск. Др. за прераду кудеље и лана
Ђ. М. Станојевић, с. р.

На списку депонованих признаница привремених акција Првог Лесковачког акционарског друштва за прераду кудеље и лана за Оснивачку скупштину (односно Претходни збор у ондашњој терминологији), која ће се држати 15. августа 1904. г. (МНП нефасциклирано 1904.) са датумом 12. август 1904. год. у Лесковцу, под редним бројем 16 забележено је да је Ђока Станојевић из Београда депоновао сто акција и има десет гласова. Према овом документу 114 акционара депоновало је 1222 акције са 755 гласова до шест сати после подне када је списак закључен.

Оснивачку скупштину одржану 15. августа 1904. односно "Претходни Збор" води Ђорђе Станојевић, Председник оснивачког одбора, који је на њему изабран у Управни одбор, и то као први на листи чланова, према записнику који је он потписао а овде га дајемо у целини.

МНП, нефасциклирано, 1904.
(препис у заоставштини Сергија Димитријевића)
Рађено 15. августа 1904. год. у Лесковцу

Записник Претходног збора
Првог Лесковачког Акционарског Друштва
за прераду кудеље и лана

I

Председник оснивачког одбора Г. Ђ. Станојевић, пошто је известио збор, да су господа која су од стране збора одређена констатовала да има довољан број акционара за решавање (а на име 83 акционара са 1145. ком. акција и 688 гласова) отворио је збор нагласивши значај овога Предузећа. После овога замолио је збор, да изабере себи председника, који ће руководити седницом.

Збор је једногласно изабрао за председника Г. Ђ. Станојевића, проф. Вел. школе.

II

После овога Председник збора представи збору изасланика Госп. Министра Народне Привреде Г. Тодора Наумовића судију лесковачког првост. суда.

Збор прими ово саопштење на знању.

III

Председник збора предложи а збор једногласно усвоји да сакупљени акционари са овога збора поздраве његово Величанство Краља Србије Петра I нарочитим телеграмом.

Телеграфским путем послат је поздрав и Господину Министру Народне Привреде.

IV

Збор је изабрао:

1) За бројање гласова Г. Г. Петра Константиновића трг. Тодора Н. Тодоровића трг, Трајка К. Митровића трг.

2) За оверење записника Г.Г. Јована К. Биволаревића учитеља, Глигорија С. Стојановића трг., Василија Дискића књижара.

3) За секретара Г. Глигорија Миленковића учитеља.

V

Приступљено је читању правила. Прочитани су чл. 1.2.3.4.5. Сви ови чланови примљени су без измене.

Прочитан је чл. 6. Овај је члан примљен са изменом коју је Госп. Министар Народне Привреде одобрио.

Чланови 7 и 8 примљени су са учињеним изменама.

Чл. 9. Код овога чл. Г. М. Петровић ср. економ учинио је примедбу да на одоцњене уплате акционари на име казне не плаћају по 0.10 дин. од сваке акције за сваку пропуштену недељу већ по 0.05 дин.

После објашњења од стране Г. председника збор је и овај члан усвојио како је у правилима.

И од 10-72 закључно збор је примио како су у правилима.

VI

Председник је дао 10 минута одмора ради споразума о кандидацији Управног и Надзорног одбора.

По свршеном одмору рад је настављен. Приступљено је избору чланова за Управни одбор.

Збор је једногласно изабрао ову Г. Г.

1 Ђорђа Станојевића, проф. В. Шк.
2 Тасу Петковића трг.
3 Михаила М. Аранђеловића
4 Ђорђа Ј. Цекића
5 Лазара М. Николића
6 Сотира Томића
7 Ђорђа М. Стојановића
8 Спиру М. Стаменковића
9 Косту П. Мазинића

2) За чланове Надзорног одбора збор је једногласно изабрао ову Г.Г.

1 Милана К. Илића трг.
2 Трајка Ђ. Калајџића трг.
3 Василија Ристића обућара
4 Трајка К. Митровића трг
5 Михајла Буринчића трг

Са овим је овај састанак закључен.

Секретар Гл. Миленковић учитељ
Председник збора Ђ. М. Станојевић

Јован К. Биволаревић, Глигорије С. Стојановић, Василије Дискић

Оверава Комесар Господ. Министра Народ. привреде
Судија Тодор Н. Наумовић

Први редовни збор Првог Лесковачког Акционарског Друштва за прераду кудеље и лана одржан је 9. марта 1905.(види МНП нефасциклирано Записник 1ог редовног збора) код "Српске круне" (види "Српске Новине", бр. 20, 1905). Председник Управног одбора Г. Ђорђе М. Станојевић отворио је овај скуп и изјавио да је 38 акционара депоновало 701 Акцију са 211 гласова и да се рад може одпочети. Затим је представио Комесара Министра Народне Привреде, Живојина Маринковића судију Лесковачког првостепеног суда. Ђорђе Станојевић је на збору са кога је записник потписао, прочитао извештај Управног одбора који је такође сам потписао и који у наставку наводимо у целини.

МНП, нефасциклирано, 1905.
(препис у заоставштини Сергија Димитријевића)

Извештај Управног Одбора
Првог Лесковачког Акционарског Друштва
за прераду кудеље и лана поднесен Првом
редовном збору тога Друштва на дан 9 марта 1905 г.

Господо Акционари.

Управном одбору "Првог Лесковачког Акционарског Друштва за прераду кудеље и лана", част је да на овом првом редовном Збору Акционара поднесе извештај о своме раду у протеклој години. Изабран у половини Августа месеца, његов је рад трајао само четири и по месеца и ограничио се на прво и основно уређење Друштва и друштвених послова.

Тако се одбор на првом свом састанку конституисао изабравши за председника Г. Боку М. Станојевића проф. Вел. школе у Београду; за п.председника Г. Сотира Томића, а за деловођу Г. Мих. М. Аранђеловића. Док се послови друштвени не развију, одбор је нашао, да није потребно узимати нарочитог благајника и одредио је, да благајном рукује члан Управног одбора Г. Лаза М. Николчић.

Одмах затим одбор је решио, да се позову Акционари да положе према чл. 14 закона о Акционарским Друштвима остатак од 5% и тако испунио прописе законске потребне за протоколисање друштвене фирме, што је и учињено онако како закон прописује. Исто тако је Управни Одбор уредио канцеларију друштвену узевши нарочити локал за то и снабдео га потребним канцелариским прибором.

Пошто је избор Управног одбора пао у време највеће сезоне за куповину кудеље, одбор је одмах приступио томе послу и после извесног времена а у границама својих средстава набавио извесну количину кудеље: Данас има друштво 71.156 ручица сирове кудеље у вредности Дин. 10.198.35 на своме слагалишту. Сва је та количина кудеље осигурана против пожара и смештена на земљишту, које је тога ради општина лесковачка бесплатно

уступила Друштву. Управни одбор сматра за своју дужност, да општини изјави у име Друштва нарочиту захвалност на таквој предусретљивости.

У току прошле године Управни је одбор држао и један заједнички састанак с Надзорним одбором, на коме је на основу чл. 7ог друштвених правила, решено да се позову Акционари, да положе још по 10% капитала у две рате као што је то објављено.

Једно од најважнијих питања по напредак Друштва јесте решење о набавци земљишта за Друштвену фабрику и Управни одбор приступио је томе послу свом збиљом и обазривошћу који он заслужује и у свему постигао пре кратког времена и извесне резултате. Но како дефинитивно решење тога питања прелази у ову годину, то ће се у њему поднети извештај на идућем редовном збору.

Управни је одбор имао у току прошле године осам својих и једну заједничку седницу, за свршавање горе поменутих и осталих текућих послова.

Коцком испадају из Управног одбора: Г. Сотир Томић, Г. Коста П. Мазнић и Г. Спира М. Стаменковић; а из Надзорног: Г. Трајко Калајџић и Василије Ристић, и Управни одбор моли Збор да њихова места попуни.

Господо Акционари.

Као што се из горњег извештаја види Управни се одбор старао, да свој посо упути онаквим правцем који ће бити од користи по наше предузеће и нада се, да је у томе успео. Будућем Управном одбору остаје, да ове започете послове доврши, те да ако Бог да наша фабрика дочека наступајућу сезону потпуно спремна за велике и важне послове који је очекују.

У Лесковцу Марта 1905 г.

Председник
Ђ. М. Станојевић, с.р.
чланови:
Лазар М. Николић с.р.
Мил. М. Аранђеловић с.р.
Ђорђе Ј. Цекић с.р.
Зар. М. Стојановић с.р.
Спира М. Стаменковић с.р.

Оригинал Извештаја Управног Одбора Првог Лесковачког акционарског друштва за прераду кудеље и лана поднесен на VII редовној скупштини акционара одржаној 24. фебруара 1911. године, а који је такође као председник Управног одбора потписао Ђорђе Станојевић, налази се у заоставштини Сергија Димитријевића. У њему Ђ. Станојевић, описујући прилике и односе у Друштву каже:

"Вама је познато да је у 1909. год. пожар ово друштво знатно оштетио тиме, што је уништио сву спремљену сировину - кудељну трску, те је

друштву било немогуће не само радити већ је услед оскудице новчане било немогуће и спремити исту трску, да би се у 1910 год. могло радити. Ова је новчана криза у овом друштву наступила услед тога што је Осигуравајуће Друштво исплатило вредност изгореле трске доцкан, дакле исплатило је кад се већ кудељна трска није могла ни набавити.

И у прошлој 1910. год. купљена је кудељна трска мало, пошто је друштво оскудевало у новцу, те се је усљед тога морала и друштвена управа у неколико изменити, али и ова измена није могла друштву помоћи, пошто је нова управа доцкан рад отпочела, - отпочела куповину трске онда, кад се већ није могло ништа купити јер је у брзо била сировина распродата.

И ово мало трске што је било, што је све потопљено за време док је још вода била погодна за рад, те је тако од исте добивено око:

80.000 кгр. кудеље
10.000 кгр. кудеље - абриса
40.000 кгр. кудељне опадине
10.000 кгр. градобитне опадине и
1.000 кгр. малтерске опадине

И ако је скоро сва кудеља и опадина добро продата ипак нису добри резултати показани пошто фабрика није имала сировина да ради преко целе године већ само 1/2 год.

Још један разлог што је закључен рачун "Губитака и Добитака" са штетом од дин 8.737.03 јесте тај, што је на закупном земљишту у Паланци изгубљено 13.481.26 дин. а тај је губитак морао настати услед поплаве засејаног земљишта. Ну, било је наде, да ће се поновним сејањем нешто постићи, те је поновно сејање и извршено; али на жалост ипак се је штета морала показати усљед тога што је добивена трска ниска остала.

Што се отписа у 16.475.73 тиче, то је учињено, да би се могло из биланса видети право стање овога друштва.

Саслушали сте рачунски део овог извештаја и молите се, да поклоните своју пажњу извештају у следећем:

Управни одбор желећи, да ово друштво неким новим начином рада унапреди, нашао је за корисно да закључи машине за израду канапа, што је у прошлој години и учинио и како је извештен исте ће машине бити испослане из Француске још у току овог месеца."

Оригинал Извештаја Управног Одбора Првог Лесковачког акционарског друштва за прераду кудеље и лана поднесен на VIII редовној скупштини акционара одржаној 8. априла 1912. године (такође у заоставштини Сергија Димитријевића). Њега је потписао и поднео скупштини нови Председник Управног одбора Сотир Илић, који у њему обавештава акционаре да је "Г. Ђока Станојевић дао оставку на чланство Управног одбора.

Да би се сагледале тешкоће у раду овога Друштва и назрели мотиви оставке Ђорђа Станојевића, који се не помиње ни у Извештају Управног одбора сада већ Краљевске Српске Повлаштене фабрике Првог Лесковачког акционарског друштва за прераду кудеље и лана, поднесеном IX редовном

збору акционара одржаном 5. маја 1913. године, а такође се налази у заоставштини Сергија Димитријевића, пренећемо део Извештаја у коме се описују прилике у Друштву.

"У прошлој 1911. год. купљено је и нађено је у закупном земљишту зв. Мира и у Паланци 2.058.240 Кгр. кудељне трске за Дин 127.148.28 од које смо прерадили у минулој 1911. год. 334.526 Кгр а ресто је остало за прераду у овој 1912. год.

Као што се види из биланса добит на земљишту под најам је свега Дин. 3356.75, с тога што је била штета на закупном земљишту у Паланци Дин. 12.133.15 те је штету покрило закупно земљиште зв. Мира и добит дало само Дин. 3356.75, и ми смо према томе у Јануару исто земљиште у Паланци предали другом лицу пошто је и 1910 год. било на истом земљишту штете 13481.26 дин.

Управни Одбор желећи да ово Друштво некм новим начином рада унапреди нашао је за корисно да поред одељења за израду канапа закључи машине за Кудељну Предионицу што је у прошлој години и учинио, и исте машине биће испослате из Енглеске у току месеца маја ове год. као и да се за исту Предионицу фабрична зграда продужи ка истоку са 56 мет. на које је рад отпочет и темељ већ готов.

Са израдом канапа отпочела је фабрика у другој половини 1911. год. и као почетак ишло је мало теже као и при сваком почетку..."

Из ових докумената видимо како је настајала и развијала се једна од првих модерних фабрика у нашој земљи и допринос другог руководиоца Астрономске опсерваторије увођењу модерних научних достигнућа заснованих на Теслиној наизменичној струји у привреду Србије. Овај велики човек, први српски астрофизичар, други руководилац Астрономске опсерваторије, ректор Универзитета у Београду, велики популаризатор астрономије и науке уопште, човек који је подарио светлост Београду, Ужицу, Лесковцу, Чачку, Зајечару, градитељ прве српске хидроцентрале, пионир индустрије расхладних уређаја и фотографије у боји, такође је и пионир индустријализације Србије. Његов стваралачки допринос читавом низу области наше науке, привреде и културе по својој разноврсности може да нађе веома мало сличних примера у историји наше отаџбине.

Референце

Аноним.: 1906, Електрично осветљење у Лесковцу, Бачки Напредак, Лесковац, Бр. 11, Год. II, 169.

Димитријевић Милан С.: 1997а, Ђорђе Станојевић први српски астрофизичар. у: Развој астрономије код Срба, Development of Astronomy among Serbs, еде. М. С. Димитријевић, Ј. Милоградов-Турин, Л. Ч. Поповић, Publ. Astron. Obs. Belgrade. **56**, 119.

Димитријевић Милан С.: 1997б, Ђорђе Станојевић човек који је Лесковцу дао светлост, Наше Стварање XLV, Нова Серија, Лесковац, Но. 4, 65.

М.Ј.: 1906, Писмо из Лесковца, Бачки Напредак, Лесковац, Бр. 12, Год. II, 178.

Станојевић М. Ђорђе: 1901, Електрична индустрија у Србији, Државна штампарија Краљевине Србије, Београд, стр, (10) + 68 (прештампано из Привредног гласника; са посветом Николи Тесли).

Станојевић М. Ђорђе: 1905, Хидроелектрично постројење Вучје - Лесковац, Београд, стр.10 + (22).
Станојевић М. Ђорђе: 1921, Статут Лесковачког електричног друштва, Лесковац, стр. 24.
Трифуновић Драган: 1976, Дело Ђорђа М. Станојевића у светлу открића Николе Тесле, у: Никола Тесла и његова открића (Ђорђе М. Станојевић), Београд.
Трифуновић Драган: 1994, Стваралаштво Ђорђа Станојевића у астрономским наукама, *Васиона*, **XLII**, Но. 1-2, 23.
Трифуновић Драган: 1997, Ђорђе Станојевић професор и ректор Универзитета у Београду - Живот и дело, Свеске књ. 1, Д. Трифуновић, Београд.
Шешић Марија, Миљанић Петар: 2001, Ђорђе М. Станојевић (1858 - 1921), у: Живот и дело српских научника VII, уредник М. Сарић, Биографије и Библиографије VII, САНУ, Београд, 29.

ON THE SHARE OF ASTRONOMER DJORDJE STANOJEVIĆ IN THE DEVELOPMENT OF THE LESKOVAC TEXTILE INDUSTRY

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Abstract. The first Serbian astrophysicist and the second person, heading the Belgrade Observatory Djordje Stanojević, was also one of the pioneers of the industrialization in Serbia. Here is described his role in the founding of the First Leskovac joint-stock company for hemp and flax processing.

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COLLISIONS WITH CHARGED PARTICLES AND SPECTRAL LINE SHAPES IN ASTROPHYSICAL PLASMAS – RESEARCH ON BELGRADE ASTRONOMICAL OBSERVATORY 2002-2005

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Abstract Activities on the project "Influence of collisional processes on the astrophysical plasma spectra", supported by the Ministry of Science and Environment protection of Serbia from 1st January 2002 up to 31st December 2005 are reviewed, and selected bibliography of the project participants, including other scientific results, is presented.

1. INTRODUCTION

The project “Influence of collisions with charged particles on astrophysical plasma spectral line shapes” was financialy supported by Ministry of Science and Environment protection of Republic of Serbia under the contract number GA-1195, starting with 2002 up to 2005. The contract 146001 for the project under the same name is signed also for the 2006-2010 period. The objective of this contribution is to present the results obtained up to now. Since our main scientific activity was realized through this project, our aim is to inform Belarussian colleagues on our achievments and directions of future activities in order to stimulate the development of Serbian – Belarussian collaboration within this research field.

2. RESEARCH ON THE INFLUENCE OF COLLISIONAL PROCESSES ON THE ASTROPHYSICAL PLASMA SPECTRA ON BELGRADE ASTRONOMICAL OBSERVATORY

Investigations made within the frame of the Project concern plasma in astrophysics, laboratory and technology and the corresponding modelling, determination and research of atomic and molecular processes, optical properties and spectra, with a particular accent on the role of collisional processes. The

particular attention has been paid to the investigation of spectral line profiles, broadened by collisions with charged particles (Stark effect). Such investigations are of interest for the diagnostics and modelling of stellar plasma, plasma in laboratory and technological plasma.

Semiclasical perturbation and Modified semiempirical methods were used, tested and investigated. Stark broadening parameters, line width and shift, were determined for a large number of spectral lines of Ag I, Ar I, Cd I, Ga I, Ge I, Kr I, Ne I, F II, In II, Ne II, Ti II, Be III, Cd III, Co III, Cu III, F III, S III, Si III, Zn III, and Si IV. The results obtained were applied for the investigation of the influence of Stark broadening of spectral lines in stellar atmospheres.

Particularly was investigated the role of Stark broadening at chemically peculiar A type (Ap) stars, as for example Stark broadening of the neutral chromium spectral lines in the spectrum of chromium rich star Beta CrB and of neutral silicon spectral lines in the roAp 10 Aql star atmosphere. Ab initio calculations of Stark broadening parameters of Ne V spectral lines, observed by cosmical Rendgen telescope "Chandra" was made by using the SUPERSTRUCTURE code and the semiclassical perturbation Stark broadening theory. The Modified semiempirical theory was adapted to use more accurate collision strengths from literature, instead of semiempirical Gaunt factor. The adapted theory was applied and tested on ionized oxygen spectral lines.

The large optical flare was observed on AT Microscopii, and modelled using PHOENIX code for the modelling of stellar atmospheres.

The influence of the (n - n') mixing in Rydberg H*(n) atom - H(1s) collisions in Solar atmosphere was investigated, as well as the influence of symmetrical chemi-ionization and chemi-recombination processes in low temperature atmospheric layers of helium rich DB white dwarfs. Moreover, the influence of these processes on hydrogen Rydberg energy level populations in atmospheres of M type red dwarfs, was investigated with PHOENIX code.

Transition probabilities for Kr II, Ne II, Kr III were also investigated. The influence of Stark broadening of Cd II spectral laser lines, on the hollow cathode discharge laser working mode was considered.

The influence of the radiation pressure on micron-size individual dust grains was experimentally investigated, as well as rotation and alignment of the analogs of interstellar dust grains.

By modelling with PHOENIX, lithium in GJ117 atmosphere was considered.

One of the objectives of the Project is development of database BELDATA. Participants of the Project published 43 papers in leading international journals, from which 29 are part of the Project and 14 are connected with other research fields. In total, Project participants published 261 bibliographic items, and 156 are related to the Project while 107 are not.

3. COLLABORATION AND ORGANIZATION OF CONFERENCES

Participants of the project collaborate with colleagues in Bulgaria, Russia, France, Greece, Ukraine, Tunisia, Spain, Hungary, United Kingdom, Germany, Holland and USA.

In order to stimulate collaboration, and professional discussion of results obtained, particular efforts were made in organization of conferences. Participants of the Project have not only take part in organization of 17 scientific conferences as members of Scientific Committees, but five of them organized directly, giving in such a way their contribution to the development of scientific collaboration. Conferences organized by the participants of the Project are: **1.** DEVELOPMENT OF ASTRONOMY AMONG SERBS II, Belgrade 5-7. IV **2002; 2.** IV SERBIAN CONFERENCE ON SPECTRAL LINE SHAPES, Arandjelovac, 10-15. X 2003**; 3.** IV SERBIAN-BULGARIAN ASTRONOMICAL CONFERENCE, Belgrade, 21-24. IV 2004**; 4.** DEVELOPMENT OF ASTRONOMY AMONG SERBS III, Belgrade 25-28. IV 2004**. 5.** 5th SERBIAN CONFERENCE ON SPECTRAL LINE SHAPES IN ASTROPHYSICS, Vršac 6 - 10 June 2005**.**

4. PARTICIPANTS

From 2002 to 2004, 10 researchers were working on this project, and in 2005 seven, all from Belgrade Astronomical Observatory. The coordinator of the project during all period (1st January 2002 - 31st December 2005) was M. S. Dimitrijević, and the participants are: Edi Bon (not in 2005), Miodrag Dačić, Milan S. Dimitrijević, Darko Jevremović, Predrag Jovanović (not in 2005), Nenad Milovanović, Luka Č. Popović, Zoran Simić, Dragana Tankosić, and Zorica Cvetković (not in 2005).

During four years, ten participants were engaged for 227 research months, i.e. 18.9 years. The average age was around 40 years (or year of birth 1963.5).

5. CONCLUSION

Review of our activities during the 2002-2005 period and the corresponding bibliography of the project participants, is an illustration of our results and and might be helpful and inspirative for ideas on the collaboration development with our colleagues. In order to show all our interests and demonstrate possibilities for possible collaboration, all bibliographic items in international journals, and not only references related to the project, are included.

APPENDIX

With an asterisk are denoted papers which are not a part of the considered project.

1. PAPERS IN THE LEADING INTERNATIONAL JOURNALS

1. M. S. Dimitrijević, S. Sahal-Bréchot: STARK BROADENING OF In II SPECTRAL LINES, Physica Scripta **65**, (2002), 83-95.
2. S. Djeniže, V. Milosavljević, M. S. Dimitrijević: STARK SHIFTS AND TRANSITION PROBABILITIES IN THE Ne II SPECTRUM, Astron. Astrophys. **382**, (2002), 359-367.
3. M. S. Dimitrijević, Lj. Skuljan, S. Djeniže: STARK BROADENING OF THE Ar I SPECTRAL LINES 763.51, 738.39 AND 696.54 nm, Physica Scripta **66**, (2002), 77-81.
4. *M. S. Dimitrijević: MILUTIN MILANKOVIĆ (1879-1958) AND HIS CONTRIBUTION TO EUROPEAN ASTRONOMY, Astronomische Nachrichten **323**, (2002), 570-573.
5. S. Djeniže, M. S. Dimitrijević, A. Srećković, S. Bukvić: STARK SHIFTS AND TRANSITION PROBABILITIES IN Si III AND Si IV SPECTRA, Astron. Astrophys. **396**, (2002), 331-336.
6. D. Garcia-Alvarez, D. Jevremović, J. G. Doyle, C. J. Butler, OBSERVATIONS AND MODELLING OF A LARGE OPTICAL FLARE ON AT MICROSCOPII, Astronomy and Astrophys ics **383**, (2002), 548-557.
7. *L. Č. Popović, E. G. Mediavilla, A. Kubičela, P. Jovanović: BALMER LINES EMISSION REGION IN NGC 3516: KINEMATICAL AND PHYSICAL PROPERTIES, Astronomy and Astrophysics **390**, (2002), 473-480.
8. *E. Bon, M. M. Ćirković, I. Milosavljević: A NEW PROPOSITION FOR REDATING THE MITHRAIC TAUROCTONY SCENE, Astronomische Nachrichten **323**, (2002), 579-580.
9. *C. Abajas, E. Mediasvilla, L. Č. Popović, A. Oscoz: THE INFLUENCE OF GRAVITATIONAL MICROLENSING ON THE BROAD EMISSION LINES OF QUASARS, Astrophysical Journal **576**, (2002), 640-652.
10. D. Tankosić, L. Č. Popović, M. S. Dimitrijević: THE ELECTRON-IMPACT BROADENING PARAMETERS FOR Co III SPECTRAL LINES, Astron. Astrophys. **399**, (2003), 795-797.
11. M. S. Dimitrijević, M. Dačić, Z. Cvetković, S. Sahal-Bréchot: STARK BROADENING OF MULTICHARGED IONS OF ASTROPHYSICAL INTEREST. XXIII Be III, Astron. Astrophys. **400,** (2003), 791-793.
12. A. Srećković, M. S. Dimitrijević, S. Djeniže, S. Bukvić: STARK BROADENING PARAMETERS IN THE S III SPECTRUM, Astron. Astrophys. **400,** (2003), 1155-1159.

13.A. A. Mihajlov, D. Jevremović, P. Hauschildt, M. S. Dimitrijević, Lj. M. Ignjatović, F. Alard: INFLUENCE OF CHEMI-IONIZATION AND CHEMI-RECOMBINATION PROCESSES ON THE POPULATION OF HYDROGEN RYDBERG STATES IN ATMOSPHERES OF LATE TYPE DWARFS, Astron. Astrophys. **403**, (2003), 787-791.
14.M. S. Dimitrijević, T. Ryabchikova, L. Č. Popović, D. Shulyak, V. Tsymbal: ON THE INFLUENCE OF STARK BROADENING ON Si I LINES IN STELLAR ATMOSPHERES, Astron. Astrophys. **404**, (2003), 1099-1106.
15.A. A. Mihajlov, Lj. M. Ignjatović, M. S. Dimitrijević, Z. Djurić: SYMMETRICAL CHEMI-IONIZATION AND CHEMI-RECOMBINATION PROCESSES IN LOW-TEMPERATURE LAYERS OF HELIUM-RICH DB WHITE DWARF ATMOSPHERES, Astrophys. J. Suppl. Series **147**, (2003), 369-377.
16.V. Milosavljević, S. Djeniže, M. S. Dimitrijević: EXPERIMENTAL AND CALCULATED STARK WIDTHS WITHIN THE Kr I SPECTRUM, Phys. Rev. E **68**, (2003), 016402-1-8.
17.M. S. Dimitrijević, P. Jovanović, Z. Simić: STARK BROADENING OF NEUTRAL GERMANIUM SPECTRAL LINES, Astron. Astrophys. **410**, (2003), 735-739.
18.M. S. Dimitrijević, S. Sahal-Bréchot: STARK BROADENING OF Ag I SPECTRAL LINES, Atomic Data and Nuclear Data Tables **85**, (2003), 269-290.
19.S. Djeniže, V. Milosavljević, M. S. Dimitrijević: TRANSITION PROBABILITIES IN Kr II AND Kr III SPECTRA, European Physical Journal D **27**, (2003), 209-213.
20.*L. Č. Popović, E.G. Mediavilla, P. Jovanović, J. A. Muñoz: THE INFLUENCE OF MICROLENSING ON THE SHAPE OF THE AGN FE K LINE, Astronomy and Astrophysics **398**, (2003), 975-982.
21.*L. Č. Popović: 2003, BALMER LINES AS DIAGNOSTICS OF PHYSICAL CONDITIONS IN ACTIVE GALACTIC NUCLEI BROAD EMISSION LINE REGIONS, Astrophysical Journal 599, (2003), 140-146.
22.*L. Č. Popović, E. Mediavilla, E. Bon, N. Stanić, A. Kubičela: THE LINE EMISSION REGION IN III ZW 2: KINEMATICS AND VARIABILITY, Astrophysical Journal **599**, (2003), 185-192.
23.N. Milovanović, M. S. Dimitrijević, L. Č. Popović, Z. Simić,: IMPORTANCE OF COLLISIONS WITH CHARGED PARTICLES FOR STELLAR UV LINE SHAPES: Cd III, Astronomy and Astrophysics **417**, (2004), 375-380.
24.M. M. Abbas, P. D. Craven, J. F. Spann, W. K. Witherow, E. A. West, D. L. Gallagher, M. L. Adrian, G. J. Fishman, D. Tankosić, A. LeClair, R. Sheldon, R., E. D. Thomas: RADIATION PRESSURE MEASUREMENTS ON MICRON-SIZE INDIVIDUAL DUST GRAINS, Journal of Geophysical Research: Space Physics, **108**, (2003) SSH 2-1.
25.N. Milovanović, M. S. Dimitrijević, L. Č. Popović, Z. Simić,: IMPORTANCE OF COLLISIONS WITH CHARGED PARTICLES FOR STELLAR UV LINE SHAPES: Cd III, Astronomy and Astrophysics **417**, (2004), 375-380.
26.M. S. Dimitrijević, M. Dačić, Z. Cvetković, Z. Simić: STARK BROADENING OF Ga I SPECTRAL LINES, Astronomy and Astrophysics **425**, (2004), 1147-1152.

27.A. Srećković, S. Bukvić, S. Djeniže, M. S. Dimitrijević: STARK BROADENING PARAMETERS IN SINGLY AND DOUBLY IONIZED FLUORINE SPECTRA, Astronomy and Astrophysics **420**, (2004), 769-774.
28.V. Milosavljević, S. Djeniže, M. S. Dimitrijević: ELECTRON AND ION CONTRIBUTIONS TO THE Ne I SPECTRAL LINE BROADENING, Journal of Physics B: Atomic, Molecular and Optical Physics **37**, (2004), 2713-2724.
29.L. Csillag, M. S. Dimitrijević: ON THE STARK BROADENING OF THE 537.8 nm AND 441.6 nm Cd^+ LINES EXCITED IN A HOLLOW CATHODE LASER DISCHARGE, Applied Physics B: Lasers and Optics **78**, (2004), 221-223.
30.N. Ben Nessib, M. S. Dimitrijević, S. Sahal-Bréchot: STARK BROADENING OF THE FOUR TIME IONIZED SILICON SPECTRAL LINES, Astronomy and Astrophysics **423**, (2004), 397-400.
31.M. M. Abbas, P. D. Craven, J. F. Spann, D. Tankosić, A. Le Clair, D. L. Gallagher, E. A. West, J. C. Weingartner, W. K. Witherow, A. G. G. M. Tielens: LABORATORY EXPERIMENTS ON ROTATION AND ALIGNMENT OF THE ANALOGS OF INTERSTELLAR DUST GRAINS BY RADIATION, Astrophysical Journal **614**, (2004), 781-795.
32.*D. Olević, Z. Cvetković: ORBITS OF 10 INTERFEROMETRIC BINARY SYSTEMS CALCULATED BY USING THE IMPROVED KOVAL'SKIJ METHOD, Astronomy and Astrophysics **415**, (2004), 259-264.
33.*F. Zakharov, L. Č. Popović, P. Jovanović: ON THE CONTRIBUTION OF MICROLENSING TO X-RAY VARIABILITY OF HIGH-REDSHIFTED QSOS, Astronomy and Astrophysics **420**, (2004) 881-888.
34.*L. Christensen, S. F. Sanchez, K. Jahnke, T. Becker, L. Wisotzki, A. Kelz, L. Č. Popović, M. M. Roth: INTEGRAL FIELD SPECTROSCOPY OF EXTENDED Ly EMISSION FROM THE DLA GALAXY IN Q 2233+31, Astronomy and Astrophysics **417**, (2004) 487-497
35.*L. Č. Popović, E. Mediavilla, E. Bon, D. Ilić: CONTRIBUTION OF THE DISK EMISSION TO THE BROAD EMISSION LINES IN AGNS: TWO-COMPONENT MODEL, Astronomy and Astrophysics **423**, (2004) 909-918.
36.*L. Č. Popović, E. G. Mediavilla, E. Bon, D. Ilić, G. Richter: H II EMISSION LINE REGION IN LEDA 212995, A SMALL NEIGHBORING GALAXY OF Mrk 1040, Astronomische Nachrichten **325**, (2004) 376-379.
37.M. S. Dimitrijević, T. Ryabchikova, L. Č. Popović, D. Shulyak, S. Kan: ON THE INFLUENCE OF STARK BROADENING ON Cr I LINES IN STELLAR ATMOSPHERES, Astronomy and Astrophysics **435**, (2005), 1191-1198
38.W. F. Mahmoudi, N. Ben Nessib, M. S. Dimitrijević: MODIFIED SEMIEMPIRICAL ELECTRON WIDTH CALCULATIONS OF SINGLY-IONIZED OXYGEN SPECTRAL LINES, Astronomy and Astrophysics **434**, (2005), 773-778.
39.A. A. Mihajlov, Lj. Ignjatović, M. S. Dimitrijević: PROCESSES OF (n - n')-MIXING IN COLLISIONS OF RYDBERG H*(n) ATOMS WITH H(1s) IN THE SOLAR ATMOSPHERE Astronomy and Astrophysics **437**, (2005), 1023-1027.

40.Z. Simić, M. S. Dimitrijević, N. Milovanović, S. Sahal-Bréchot: STARK BROADENING OF Cd I SPECTRAL LINES, Astronomy and Astrophysics **441**, (2005), 391-393.
41.D. J. Christian, M. Mathioudakis, D. Jevremović, P. H. Hauschildt, E. Baron: ^{6}Li IN THE ATMOSPHERE OF GJ 117, Astrophysical Journal **632**, (2005), L127-L130.
42.*D. Olević, Z. Cvetković: ORBITS OF SIX BINARY STARS, Revista Mexicana de Astronomia y Astrofisica, **41**, (2005), 17-24.
43.*L. Č. Popović, G. Chartas: THE INFLUENCE OF GRAVITATIONAL LENSING ON THE SPECTRA OF LENSED QUASI-STELLAR OBJECTS, Monthly Notices of the Royal Astronomical Society **357,** (2005), 135-144.

2. PAPERS IN THE INTERNATIONAL JOURNALS

1.*M. S. Dimitrijević, E. Theodossiou: THE CALENDAR OF THE GREEK OR-TODOX CHURCH, Astron. Astrophys. Transactions **21**, (2002), 145-147.
2. M. С. Димитриевич: ШТАРКОВСКОЕ УШИРЕНИЕ СПЕКТРАЛЬНЫХ ЛИНИЙ Ne II И Ne III, Ж. Прикл. Спектроск. **70**, (2003), 439-443.
3 M. S. Dimitrijević: STARK BROADENING IN ASTROPHYSICS (APPLICATIONS OF BELGRADE SCHOOL RESULTS AND COLLABORATION WITH FORMER SOVIET REPUBLICS), Astronomy and Astrophysics Transactions **22**, (2003), 389-412.
4. A. A. Mihajlov, D. Jevremović, Lj. M. Ignjatović, P. Hauschildt, M. S. Dimitrijević: THE INFLUENCE OF CHEMICAL IONIZATION AND CHEMICAL RECOMBINATION PROCESSES ON THE PLASMA PARAMETERS IN LOW-TEMPERATURE LAYERS OF STELLAR ATMOSPHERES, Astronomy and Astrophysics Transactions **22**, (2003), 513-517.
5. M. S. Dimitrijević: STARK BROADENING OF Ne II AND Ne III SPECTRAL LINES, Journal of Applied Spectroscopy **70**, (2003), 493-497.
6. V. Milosavljević, M. S. Dimitrijević, S. Djeniže: MEASURED AND CALCULATED STARK BROADENING PARAMETERS FOR SEVERAL Ar I SPECTRAL LINES, High Temperature Material Processes **7**, (2003), 525-533.
7. M. S. Dimitrijević, S. Sahal-Bréchot: STARK BROADENING OF SPECTRAL LINE SHAPES (ON THE FRENCH-SERBIAN COLLABORATION), High Temperature Material Processes, An International Journal, **7**, (2003), 313-318.
8.*L. Č. Popović, P. Jovanović, E. G. Mediavilla, J. A. Muñoz: Influence OF MICROLENSING ON THE ACTIVE GALACTIC NUCLEUS Fe Kα LINE, Astron. Astrophys. Trans. **22**, (2003), 719-725.
9. Z. Simić, M. S. Dimitrijević, L. Č. Popović, M. Dačić: STARK BROADENING OF F III LINES IN LABORATORY AND STELLAR PLASMA, Ж. Прикл. Спектроск. **72**, (2005), 412-415.
10.Z. Simić, M. S. Dimitrijević, L. Č. Popović, M. Dačić: STARK BROADENING OF F III LINES IN LABORATORY AND STELLAR PLASMA, Journal of Applied Spectroscopy **72**, (2005), 443-446.

11.*E. Danezis, E. Theodossiou, I. Gonidakis, M. S. Dimitrijević: „UN-TANGIBLE WORLD“ AND MODERN PHYSICS European Journal for Science and Theology **1** (2005), 29-35.
12.M. Christova, M. S. Dimitrijević, S. Sahal-Bréchot: STARK BROADENING OF Ar I SPECTRAL LINES EMITTED IN SURFACE WAVE SUSTAINED DISCHARGES, Memorie della Societa Astronomica Italiana Supplementi **7**, (2005), 238-241.
13.B. Zmerli, N. Ben Nessib, M. S. Dimitrijević: TEMPERATURE DEPENDENCE OF NON HYDROGENIC ATOM-LINES STARK WIDTHS, Memorie della Societa Astronomica Italiana Supplementi **7**, (2005), 242-243.
14.E. Danezis, D. Nikolaidis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, E. Theodossiou, A. Antoniou: A NEW MODELING APPROACH FOR DACs AND SACs REGIONS IN THE ATMOSPHERES OF HOT EMISSION STARS, Memorie della Societa Astronomica Italiana Supplementi **7**, (2005), 107-113.
15.H. Elabidi, N. Ben Nessib, M. S. Dimitrijević: ELECTRON IMPACT BROADENING OF MULTICHARGED NEON SPECTRAL LINES, Memorie della Societa Astronomica Italiana Supplementi **7**, (2005), 213-216.
16.E. Lyratzi, E. Danezis, D. Nikolaidis, L. Č. Popović, M. S. Dimitrijević, E. Theodossiou, A. Antoniou: A NEW APPROACH FOR THE STRUCTURE OF H ̇ REGIONS IN 120 Be-TYPE STARS, Memorie della Societa Astronomica Italiana Supplementi **7**, (2005), 114-121.
17.M. S. Dimitrijević, T. Ryabchikova, L. Č. Popović, D. Shulyak, S. Kan: ON THE INFLUENCE OF STARK BROADENING OF Cr I LINES IN THE Cr-RICH Ap STAR CrB ATMOSPHERE, Memorie della Societa Astronomica Italiana Supplementi **7**, (2005), 126-127.
18.A. A. Mihajlov, Lj. Ignjatović, M. S. Dimitrijević: PROCESSES OF ATOM – ATOM (n - n') - MIXING INFLUENCE ON HYDROGEN ATOM RYDBERG STATES POPULATIONS IN STELLAR ATMOSPHERES, Memorie della Societa Astronomica Italiana Supplementi **7**, (2005), 151-157.
19.W. F. Mahmoudi, N. Ben Nessib, M. S. Dimitrijević, S. Sahal-Bréchot: CONTRIBUTION TO THE SEMI – CLASSICAL AND MODIFIED SEMI – EMPIRICAL IMPACT STARK BROADENING CALCULATIONS OF SINGLY IONIZED CARBON AND OXYGEN SPECTRAL LINES, Memorie della Societa Astronomica Italiana Supplementi **7**, (2005), 217-220.
20.Z. Simić, L. Č. Popović, M. S. Dimitrijević, M. D. Dačić: STARK BROADENING PARAMETERS FOR Cu III AND Zn III SPECTRAL LINES, Memorie della Societa Astronomica Italiana Supplementi **7**, (2005), 236-237.
21.N. Milovanović: THE STARK BROADENING EFFECT IN HOT STAR ATMOSPHERES: Ti II, Memorie della Societa Astronomica Italiana Supplementi **7**, (2005), 132-135.
22.Z. Simić: INFLUENCE OF IMPACTS WITH CHARGED PARTICLES ON Cd I AND F III SPECTRAL LINES IN STELLAR PLASMA, Memorie della Societa Astronomica Italiana Supplementi **7**, (2005), 122-125.

23.M. A. Jarzembski, D. V. Tankosić: DISCHARGE OF NEGATIVELY CHARGED MICROMETER SIZE PARTICLES IN AN ELECTRODYNAMIC BALANCE DUE TO RADIOACTIVITY, Journal of Aerosol Science **36**, (2005) 1023-1035.

24.*P. Jovanović: MICROLENSING EFFECT ON Fe Kα LINE AND X-RAY CONTINUUM IN THE CASE OF THREE GRAVITATIONALLY LENSED QUASARS: MG J0414+0534, QSO 2237+0305 AND H1413+117, Memorie della Societa Astronomica Italiana Supplement **7**, (2005) 56-59.

25.*C. Abajas, E. Mediavilla, J. A. Muñoz, L. Č. Popović: GRAVITATIONAL MICROLENSING EFFECTS ON THE BROAD EMISSION LINES OF QUASARS, Memorie della Societa Astronomica Italiana Supplement **7,** (2005), 48-55.

26.*I. Chilingarian, Ph. Prugniel, L. Č. Popović: THE HISTORY AND DYNAMICS OF THE STELLAR POPULATION IN THE CENTRAL KPC OF ACTIVE GALAXIES, Memorie della Societa Astronomica Italiana Supplement **7**, (2005), 42-43.

27.*D. Ilić, E. Bon, L. Č. Popović: KINEMATICS OF THE BLR AND NLR IN AGN Mrk 817, Memorie della Societa Astronomica Italiana Supplement **7**, (2005) 30-33.

28.*E. Bon: THE DISK CONTRIBUTION TO THE SHAPE OF THE BALMER BROAD EMISSION LINES IN AGNs, Memorie della Societa Astronomica Italiana Supplement **7**, (2005) 34-37.

29.*D. Ilić, L. Č. Popović, V. Borka: THE UV SPECTRAL PROPERTIES OF RADIO LOUD AND RADIO QUIET QSOs: THE RATIO OF NV/Lyα AND CIV1550/Lyα, Memorie della Societa Astronomica Italiana **7,** (2005), 51-52.

30.*L. Č. Popović: CONNECTION BETWEEN THE X-RAY, UV AND OPTICAL EMISSION LINE REGIONS OF AGN, Memorie della Societa Astronomica Italiana **7**, (2005) 43-46.

3. INVITED LECTURES AT INTERNATIONAL CONFERENCES PUBLISHED IN BOOKS OF INTERNATIONAL PUBLISHERS

1. M. S. Dimitrijević, L. Č. Popović, N. Milovanović, S. Simić, Z. Simić, P. Jovanović: APPLICATIONS OF THE MODIFIED SEMIEMPIRICAL METHOD FOR STELLAR PLASMA INVESTIGATIONS, 21th Summer School and International Symposium on the Physics of Ionized Gases, 21th SPIG, The Physics of ionized Gases, Invited Lectures, Topical Invited Lectures and Progress Reports, eds. N. Bibić, T. Grozdanov, M. K. Radović, M. S. Jovanović, Vinča Institute of Nuclear Sciences, Belgrade (2003), 413-424.
2. L. Č. Popović, M. S. Dimitrijević, E. Mediavilla, E. Danezis, E. Lyratzi, E. Bon, D. Ilić, P. Jovanović, E. Theodossiou, M. Dačić: SOME SPECTROSCOPIC METHODS FOR ASTROPHYSICAL PLASMA RESEARCH, in: "The Physics of Ionized Gases", 22nd Summer School and International Symposium on the Physics of Ionized Gases, Invited Lerctures, Topical Invited Lectures and Progress Reports,

eds. Lj. Hadžievski, T. Grozdanov, N. Bibić, American Institute of Physics Conference Proceedings **740**, (2004), 497-508.

3. *S. Simić, L. Č. Popović: SPECTRAL DEPENDENCE OF THE GRB LIGHT CURVE PULSE, in: "The Physics of Ionized Gases", 22nd Summer School and International Symposium on the Physics of Ionized Gases, Invited Lerctures, Topical Invited Lectures and Progress Reports, eds. Lj. Hadžievski, T. Grozdanov, N. Bibić, American Institute of Physics Conference Proceedings **740**, (2004).
4. *L. Č. Popović: PHYSICAL AND KINEMATICAL PROPERTIES IN CENTRAL PART OF ACTIVE GALAXIES: FROM NARROW TO BROAD EMISSION LINES, Proceedings of the 17th International Conference on Spectral Line Shapes, June 21-25, 2004 – Paris, France, ed. E. Dalimier, Editions FRONTIER GROUP – 2004, 257-264

4. INVITED LECTURES AT INTERNATIONAL CONFERENCES

1. M. S. Dimitrijević: SOLAR PLASMA AND STARK BROADENING INVESTIGATIONS, Proceedings of the Regional meeting on Solar physics: Solar researches in the South-Eastern European countries: Present and perspectives, 24-28 April 2001, Bucharest, Romania, Observations Solaires (2002), 133-137.
2. M. S. Dimitrijević, L. Č. Popović, M. Dačić, Z. Cvetković: APPROXIMATE METHODS FOR STARK BROADENING CALCULATIONS FOR ASTROPHYSICALLY IMPORTANT SPECTRAL LINES, Proc. 3rd Bulgarian-Serbian Astronomical Meeting, May 13-15, 2002, Gjolechitsa, Bulgaria, eds. G. Ivanov, M. S. Dimitrijević, P. Jovanović, Publ. Astron. Obs. Belgrade **73**, 13-26.
3. L. Č. Popović, P. Jovanović, E. Bon, M. S. Dimitrijević: GRAVITATIONAL MICROLENSES IN ACTIVE GALACTIC NUCLEI, Proc. 3rd Bulgarian-Serbian Astronomical Meeting, May 13-15, 2002, Gjolechitsa, Bulgaria, eds. G. Ivanov, M. S. Dimitrijević, P. Jovanović, Publ. Astron. Obs. Belgrade **73**, 49-65.
4. M. S. Dimitrijević, L. Csillag: 2004, ON THE STARK BROADENING OF THE Kr II 469.4 nm, Ar II 476.5 nm AND Ar II 480.6 nm LINES, Proceedings of the V symposium of Belarus, Serbia and Montenegro on Physics and Diagnostics of Laboratory and Astrophysical Plasmas (PDP-V'2004), September 20-23, Minsk, eds. V. S. Burakov, A. F. Chernyavskii, National Academy of Sciences of Belarus, Institute of Molecular and Atomic Physics, Minsk 2004, 40-43.
5. M. S. Dimitrijević: 2005, FULLERENES AND ASTRONOMY, Proceedings of the IV Serbian-Bulgarian Astronomical Conference, Belgrade 21-24 April 2004, eds. M. S. Dimitrijević, V. Golev, L. Č. Popović, M. Tsvetkov, Publications of the Astronomical Society "Ruđer Bošković", **5,** 51-58.

5. THESES

1. Zoran Simić: 2004, УТИЦАЈ СУДАРА СА НАЕЛЕКТРИСАНИМ ЧЕСТИЦАМА НА СПЕКТРАЛНЕ ЛИНИЈЕ Cd I И F III У ЗВЕЗДАНОЈ ПЛАЗМИ (Influence of collisions with charged particles on Cd I and F III spectral lines in stellar plasma), MSc Thesis, Faculty of Mathematics, Belgrade.

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DJORDJE STANOJEVIĆ IN WORKS OF JULES JANSSEN

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Abstract. Jules Janssen (Paris 1824 - Meudon 1907) is well known as the founder of the "Observatoire d'Astronomie Physique de Paris (sis à Meudon)". He was also teacher and coworker of Djordje Stanojević, who was the first Serbian astrophysicist, rector of the Belgrade University and the second person on the head of Belgrade Astronomical Observatory, the first builder of hydro power plants in Serbia, the author of the first color photography in Serbia and the book with colored photographies ("Srbija u slikama" - Serbia in photos), pioneer of electrification and industrialization of our country. His articles in the journal of the French Academy of Sciences (Comptes Rendus de l'Académie des Sciences) are in the Serbian Astronomy the first modern scientific papers. They are presented and commented in Academy by Jules Janssen, who also mentions Stanojević in his works in various contexts. In this contribution, the presence of Djordje Stanojević in works of Jules Janssen, and his comments on Stanojević's work in Comptes Rendus are analyzed. Also, the work and life of Jules Janssen are presented.

1. INTRODUCTION

Djordje Stanojević (07. April 1858, Negotin, Serbia - 24. December 1921, Paris, France), the first Serbian astrophysicist, rector of the Belgrade University and the second person on the head of Belgrade Astronomical Observatory, the first builder of hydro power plants and the author of the first color photography in Serbia, pioneer of electrification and industrialization of our country (Dimitrijević 1997ab, 2002, Dimitrijević and Petrović 1999), learned solar physics and made his first steps in European science in Meudon Observatory, in Paris, working with the founder of this astronomical institution, Jules Janssen. This famous French astrophysicist presented also to the French Academy of Science all astronomical articles of Djordje Stanojević, published in its journal *Comptes Rendus Hebdomadaires de l'Académie des Sciences*. We note that these are the first scientific papers in the modern sense in Serbian Astrophysics (Dimitrijević 1997a).

In this work, we will present life and work of Jules Janssen and his relations with Djordje Stanojević.

2. LIFE AND WORK OF JULES JANSSEN

Jules Janssen (Fig. 1) was born in Paris on 22nd February 1824. His father was a clarinettist and his mother was the daughter of an architect (Launay and Hingley



Figure 1: Left: Jules Janssen from "L'illustration", 1873, when he was elected in French Academy of Sciences. Right: Jules Janssen (sitting in the middle) in Japan 1874 for the Venus transit observation. His "photographic revolver" is on the left side of the photo. From Launay and Hingley (2005).

2005, Launay 2008). Due to financial problems in family, he started to work as an accountant in the bank before his 17th birthday. He also began to study mathematics and physics. In 1855 he became an assistant teacher in a grammar school in Paris. In 1857 he was sent to Peru to determine the course of the magnetic equator. On his return to France he obtained a job for the industrialists of Le Creusot, where he studied the absorption of radiant heat in the mediums of the eye. He obtained with this research the doctorate of science in 1860. In 1861 he constructed an ophtalmoscope (Launay 2004) but also he started the research on the solar spectrum, as one of the first in France who started to study spectral analysis and its astronomical applications. He found that some spectral lines are particularly prominent at sunrise and sunset. Assuming that they are due to the water vapor of the earth's atmosphere he named them "telluric lines" which stayed in the science up today. In order to investigate this hypothesis he studied the absorption spectrum of the water vapor, what enabled him to announce in 1867 the presence of water vapor in the atmosphere of Mars.

Next year, he observed the total solar eclipse of 18 August 1868 at Guntoor, India. Here he realized that the spectrum of solar prominences may be observed without eclipse using the spectroscope which enables observations in monochromatic photospheric lines. This method was proposed independently by Lockyer. In honor of this discovery, the French Academy of Sciences coined a medal with portraits of both scientists. So, in 1869 he describes the principle of the spectrohelioscope enabling to obtain monochromatiques images of the Sun.

In December 1870, when Janssen was in Paris besieged by Prussians, during the Franco-Prussian war, a total eclipse was announced to be visible in Algeria. In order to observe it, he left the besieged Paris during the night in a baloon. He could not observe the event due to clouds but during the flight he invented an aeronautic compass.

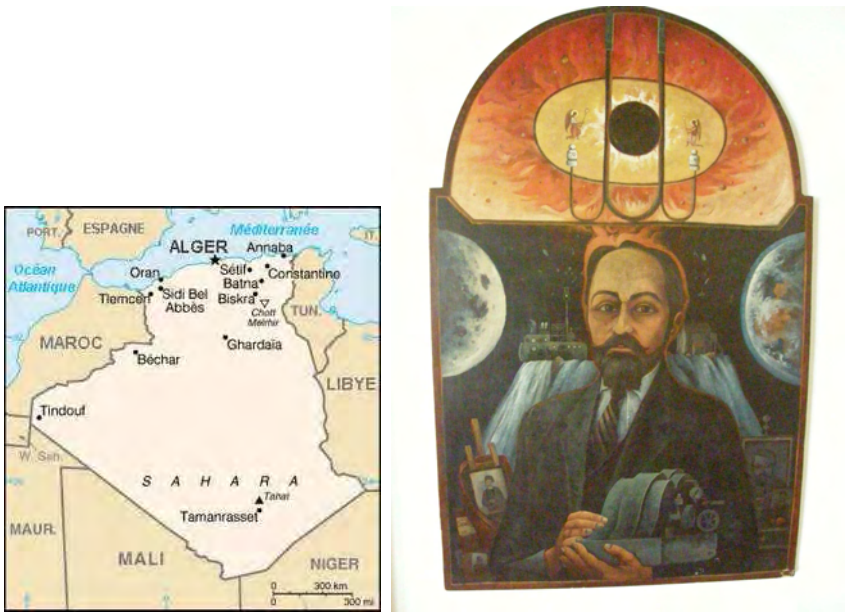

Figure 2: Left: Map of Algeria with Biskra. Right: Portrait of Djordje Stanojević by Milić of Mačva in Memorial room of Stanojević in Negotin (photo Jan Vondrak).

On the 10th of February 1873, he was elected to be a fellow of the French Academy of Sciences. His portrait in the Fig. 1 (left) was published on this occasion.

He is very important as well for the history of photography. Not only due to his astronomical photographies and first photos in the monochromatic light, but also due to his "photographic revolver", precursor of the movie camera, invented to obtain a number of photographies in quick succession of the Transit of Venus, which he observed in Japan in 1874 (Fig. 1, right).

In 1875, he founded the "Observatoire d'Astronomie Physique de Paris", in Meudon, devoted to the astrophysics, as a difference from Paris Observatory, traditionally devoted to positional astronomy and navigation.

On the International Meridian Conference in Washington, for the determination of the starting meridian, he was the leader of the French delegation, proposing a neutral meridian which would cross the Ocean instead of the Greenwich one.

From 1885 to 1890 he carried on spectroscopic investigations in Meudon and experiments on the absorption laws of the oxygen spectra at Mont Blanc. In 1893 he established on Mont Blanc an Observatory for such a research.

In 1889 he was the chairman of the International congress of the photography and celestial photography (Launay 2004) and in 1907, seven months before his death, he was the chairman (Launay 2004) of the Conference of the International Union for Solar Research, held at Meudon.

Janssen died at the age of 83, in Meudon Observatory on the 23rd of December 1907, the day of the winter solstice. His statue (Fig. 4, right) at the Meudon Terrace, besides the Observatory, was unveiled by Camille Flammarion in 1920.



Figure 3: Tower near Biskra in Algeria, used as observatory by Janssen and Stanojević in 1890. Photographied by Jan Vondrak in the Memorial room of Djordje Stanojević in Negotin.

3. DJORDJE STANOJEVIĆ AND JULES JANSSEN

From 1883 to 1887 Djordje Stanojević, as a bursar of Military Ministry, was on studies and specialization at the most known astronomical and meteorological institutions in Europe, but majority of time he spent in Meudon Observatory working with Jules Janssen. When Janssen in 1885 started spectroscopic investigations in Meudon, Stanojević was with him. In a number of papers from that period (Janssen 1885, 1886, 1890b) Janssen acknowledges the help of Stanojević in his research. In Janssen (1885) is written: " Je ne veux pas terminer sans dire combien j'ai été secondé dans ces études, avec zéle et capacité, par M. Stanoïevitch, attaché en ce moment á l'observatoire comme éléve serbe" (I do not want to finish without saying how much I was supported in this study, with devotion and capacity, by M. Stanoïevitch, attached at this moment to the Observatory as an serbian student.). In Janssen (1886) is stated at the end: "M. Stanoïévitch a continué á màssister dans ces études" (M. Stanoïévitch continued to assist me in these studies.)

The first astrophysical scientific papers in the modern sense published by a serbian astrophysicist (Dimitrijević 1997a) in the journal of French Academy of Sciences (*Comptes Rendus de l'Académie des Sciences* - Stanoiewitch 1886, 1887, 1888) were presented to Academy by Janssen, always with an acknowledgement to him, and in Stanoiewitch (1986, 1988) with comments of Janssen.

When Serbian Academy of Sciences refused to publish his work on Solar Photospheric network, he wrote a paper (Stanojević 1888), presenting arguments against this decision and underlying that Janssen, whose results were criticized by Stanojević



Figure 4: Left: Djordje Stanojević in the oasis Biskra in Algeria in 1890 (photographied by Jan Vondrak in the Memorial room of Djordje Stanojević in Negotin). Right: The monument to Jules Janssen in Meudon Observatory and M. S. Dimitrijević (photo by Paskal Sotirovski).

in the brief note published by French Academy (Stanoiewitch 1886), and who was against the given conclusions, presented this note to Academy and recommended its publication.

In 1887, on the special recommendation of Janssen, the Serbian government sent Stanojević to Russia, to observe the total solar eclipse of the 19th of August 1887. The report of Stanojević, together with the big comment of Janssen is published in Stanoiewitch (1888). This expedition was also commented in Janssen (1887ab).

Janssen invited Stanojević to join him in the expedition in Biskra (see Fig. 2, Left) in Algeria to study solar spectrum near horizon in order to investigate the influence of terrestrial atmosphere on solar spectrum, in particular telluric lines. The expedition continued during four months and a half in the end of 1889 and the beginning of 1890. This expedition is described in detail in Janssen (1890a). It is interesting that the participation of Stanojević is only acknowledged by the sentence:

"Dans ce travail, j'ai été successivement aidé par MM. Stanoiévitch et Gabriel Gaupillat". (In this work I was alternatively helped by MM. Stanoiévitch and Gabriel Gaupillat". The word "succesivement" indicates that maybe Stanojević was not in Biskra the whole duration of the expedition.

In 1907, Stanojević attended the Third Conference of the International Union for Co-operation in Solar Research, held at Meudon, May 20-23, 1907 (*** 1908) chaired by Janssen (Launay 2004) seven month before his death.

Jules Janssen, due to his collaboration with Djordje Stanojević, and his role in the publication of the first modern serbian astrophysical scientific papers, has an important role in the history of not only European and French, but also Serbian astronomy.

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I am grateful to Dr Francoise Launay, for article, poster and discussion concerning Jules Janssen.

References

***: 1908, List of Delegates, Third Conference of the International Union for Co-operation in Solar Research held at Meudon, May 20-23, 1907, Transactions of the International Union for Co-operation in Solar Research, Vol. II, University Press, Manchester.

Dimitrijević, M. S.: 1997a, "Djordje Stanojević prvi srpski astrofizičar" (Djordje Stanojević the first Serbian Astrophysicists), in Development of Astronomy among Serbs, eds. M. S. Dimitrijević, J. Milogradov-Turin, L. Č. Popović, *Publ. Astron. Obs. Belgrade*, **56**, 119.

Dimitrijević, M. S.: 1997b, "Djordje Stanojević čovek koji je Leskovcu dao svetlost" (Djordje Stanojević the man who gave the light to Leskovac), *Naše Stvaranje*, **XLV**, (4), 65.

Dimitrijević, M. S.: 2002, "O doprinosu astronoma Djordja Stanojevića razvoju tekstilne industrije Leskovca" (On the contribution of the astronomer Djordje Stanojević to the development of the textile industry of Leskovac), in Development of Astronomy among Serbs II, ed. M. S. Dimitrijević, *Publ. Astron. Obs. Belgrade*, **72**, 57.

Dimitrijević, M. S., Petrović, T.: 1999, "Djordje Stanojević, fizičar, astrofizičar i inženjer" (Djordje Stanojević, Physicist, Astrophysicist and Engineer), Zbornik predavanja sa republičkog seminara o nastavi fizike, Society of Physicists of Serbia, Belgrade, p. 16.

Janssen, J.: 1885, Analyse spectrale des éléments de l'atmosphère terrestre, *Comptes Rendus des Séances de l'Académie des Sciences*, **CI**, (44), 649.

Janssen, J.: 1886, Sur les spectres d'absorption de l'oxygène, *Comptes Rendus des Séances de l'Académie des Sciences*, **CII**, 857.

Janssen, J.: 1887a, Note sur les travaux récents exécutés a l'Observatoire de Meudon, *Comptes Rendus des Séances de l'Académie des Sciences*, **CV**, 325.

Janssen, J.: 1887b, Note sur l'éclipse du 19 août 1887, *Comptes Rendus des Séances de l'Académie des Sciences*, **CV**, 365.

Janssen, J.: 1890a, Note sur des travaux récents exécutés en Algérie, *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, **CX**, 1067.

Janssen, J.: 1890b, Le spectre de l'atmosphère terrestre, *L'Astronomie*, **IX**, (9).

Launay, F.: 2004, Jules Janssen, Poster, Observatoire se Paris.

Launay, F.: 2008, Un globe-trotter de la physique céleste : L'astronome Jules Janssen, Vuibert, Paris.

Launay, F., Hingley, P.: 2005, "Jules Janssen's "Revolver photographique" and its British derivative, "The Janssen slid", *Journal for the History of Astronomy*, **36**, 59.

Stanoiewitch, G. M.: 1886, Sur l'origine du résau photospherique solaire, *Comptes Rendus des Séances de l'Académie des Sciences*, **CII**, (15), 853.

Stanoiewitch, G. M.: 1887, Sur la photographie directe de l'état barométrique de l'atmosphere solaire, *Comptes Rendus des Séances de l'Académie des Sciences*, **CIV**, (19), 1263.

Stanoiewitch, G. M.: 1888, L'éclipse totale du Soleil du 19 août 1887. observée en Russie (Pétrowsk), *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, **CVI**, 43.

Stanojević, Dj.: 1888, Sunčeve fotosferske mreže pred Kraljevsko-srpskom Akademijom prirodnih nauka (Solar photospheric networks before Royal Serbian Academy of Sciences), Beograd.

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ACTIVITIES OF THE GROUP FOR ASTROPHYSICAL SPECTROSCOPY 2005-2008

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Abstract. Results of activities of the fellows of the Group for Astrophysical Spectroscopy in the period 2005-2008 (between two conferences of Serbian astronomers) are reported.

1. GROUP FOR ASTROPHYSICAL SPECTROSCOPY 2005-2008

Fellows of the Group for Astrophysical Spectroscopy (GAS) are participants of projects "Influence of collisions with charged particles on astrophysical plasma spectra", "Spectroscopy of extragalactic objects" and "Serbian Virtual Observatory", working together on the spectroscopy of cosmical plasmas in different celestial objects like Active Galactic Nuclei and stellar atmospheres. The projects are supported by Ministry of Science and Technological Development of Serbia, first two as projects from fundamental sciences, and third as a technological project. Within the 2005-2008 period fellows of the Group published 41 papers in the international journals on the Science Citation Index (SCI) list (38 within the projects subjects and five monographic books). In other international journals 14 papers were published, while 13 papers were published in the national journals, such as "Serbian Astronomical Journal". Additionally, 16 invited lectures were published as well as 92 papers in conference proceedings and 87 abstracts, in total 268 bibliographic items.

We have also international collaboration with France, Greece, Italy, Russia, Germany, Tunisia, Spain, USA, Italy, Mexico, United Kingdom and Bulgaria and within the considered period we had almost one hundred visits of foreign scientists and students.

In the considered period we have investigated the following: physics and kinematics of the central part of AGN (in the X-ray, UV and optical part, and their connection with the radio emission); spectroscopy of lensed quasars and influence of microlensing effects on quasar spectra; connection between stellar population and activity in galaxies; gamma ray burst (as violent processes in the Universe); Stark broadening in astrophysical plasmas; collisional processes in cosmic plasmas and their influence on spectral characteristics. Also, papers devoted to the history and philosophy of astronomy were published.

The main observational activities were: - Performed radio observation with VLBI network; - Performed spectroscopical observation (in optical band) with the 6 m telescope Special Astrophysical Observatory (Nizhniy Arkhiz, Russia) and 2m telescope at Rozhen Observatory (Bulgaria).

Within the period 2005-2008, within the frame of the GAS activity (the activity of the three mentioned projects) 5 PhD and 4 MSc theses were defended. Here we give their lists, as well as lists of monographs, papers published in the journals from SCI list and conferences organized by GAS.

2. DEFENDED PhD THESES

1. Predrag Jovanović, 2005, THE INFLUENCE OF GRAVITATIONAL MICROLENSING ON THE X-RAY RADIATION OF THE ACCRETION DISK IN ACTIVE GALAXIES, Faculty of Mathematics, University of Belgrade (Mentor Luka Č. Popović).

2. Magdalena Christova, 2007, DIAGNOSTICS OF THE DISCHARGE IN THE FIELD OF SURFACE WAVES, USING THE EMITTED SPECTRAL LINES, University of Sofia, Sofia (Mentor Milan S. Dimitrijević).

3. Saša Simić, 2008, VARIATION OF LIGHT CURVES OF GAMMA BURSTS: MODIFICATION OF THE MODEL OF SHOCK WAVES, Faculty of Sciences, University of Kragujevac (Mentor Luka Č. Popović).

4. Zoran Simić, 2008, INFLUENCE OF THE COLLISIONS WITH CHARGED PARTICLES ON PROFILES OF SPECTRAL LINES OF HEAVY METALS IN SPECTRA OF A-TYPE STARS AND WHITE DWARFS, Faculty of Mathematics, University of Belgrade (Mentor Milan S. Dimitrijević).

5. Dragana Ilić, 2008, PLASMA DIAGNOSTICS IN THE BROAD LINE REGION OF ACTIVE GALAXIES USING EMISSION LINES (Mentor Luka Č. Popović).

3. DEFENDED MSc THESES

1. Dragana Ilić, 2005, KINEMATICAL AND PHYSICAL PROPERTIES OF THE ACTIVE GALAXY Mrk 817, Faculty of Mathematics, University of Belgrade (Mentor Luka Č. Popović).

2. Giovanni La Mura, 2005, BALMER LINES INTENSITIES AS AN INDICATOR OF PHYSICAL PROCESSES IN THE BLR, Diploma thesis at Università degli Studii di Padova, Facoltà di Scienze, Padova (Mentor Luka Č. Popović).

3. Jelena Kovačević, 2008, EMISSION Fe II, [O III] and C IV REGIONS IN ACTIVE GALACTIC NUCLEI, Faculty of Mathematics, University of Belgrade (Mentor Luka Č. Popović).

4. Nataša Gavrilović, 2008, ASSYMMETRY OF EMISSION LINES AT ACTIVE GALAXIES: THE CASE OF Mrk 533 AND Mrk 110, Faculty of Mathematics, University of Belgrade (Mentor Luka Č. Popović).

4. MONOGRAPHS

1. Milan S. Dimitrijević: SRPSKI ASTRONOMI U INDEKSU NAUČNIH CITATA U XX VEKU, SERBIAN ASTRONOMERS IN SCIENCE CITATION INDEX IN THE XX CENTURY, INSPIRATIO, No. 2, Zadužbina Andrejević, Belgrade, 2005.

2. Predrag Jovanović: UTICAJ GRAVITACIONIH SOČIVA NA SPEKTRE KVAZARA (Influence of gravitational lenses on quasar's spectra), DISSERTATIO No. 228, Zadužbina Andrejević, Belgrade, 2005.

3. Zoran Simić: ŠTARKOVO ŠIRENJE SPEKTRALNIH LINIJA Cd I I F III (Stark broadening of the Cd I and F III spectral lines), ACADEMIA 142, Zadužbina Andrejević, Belgrade, 2005.

4. Dragana Ilić: AKTIVNA GALAKSIJA Mrk 817: OSOBINE EMISIONE OBLASTI (Active galaxy Mrk 817: Properties of the emission region), ACADEMIA 173, Zadužbina Andrejević, Belgrade, 2006.

5. Andjelka Kovačević: O ODREDJIVANJU MASA ASTEROIDA (On the determination of asteroid masses), Zadužbina Andrejević, Belgrade, 2008.

5. PUBLICATIONS IN INTERNATIONAL JOURNALS FROM SCI LIST 2005-2008

1. M. S. Dimitrijević, T. Ryabchikova, L. Č. Popović, D. Shulyak, S. Kan: ON THE INFLUENCE OF STARK BROADENING ON Cr I LINES IN STELLAR ATMOSPHERES, Astronomy and Astrophysics 435, (2005), 1191-1198.

2. W. F. Mahmoudi, N. Ben Nessib, M. S. Dimitrijević: MODIFIED SEMIEMPIRICAL ELECTRON WIDTH CALCULATIONS OF SINGLY- IONIZED OXYGEN SPECTRAL LINES, Astronomy and Astrophysics 434, (2005), 773-778.

3. A. A. Mihajlov, Lj. Ignjatović, M. S. Dimitrijević: PROCESSES OF (n - n')-MIXING IN COLLISIONS OF RYDBERG H*(n) ATOMS WITH H(1s) IN THE SOLAR ATMOSPHERE Astronomy and Astrophysics 437, (2005), 1023-1027.

4. Z. Simić, M. S. Dimitrijević, N. Milovanović, S. Sahal-Bréchot: STARK BROADENING OF Cd I SPECTRAL LINES, Astronomy and Astrophysics 441, (2005), 391-393.

5. D. J. Christian, M. Mathioudakis, D. Jevremović, P. H. Hauschildt, E. Baron: ^{6}Li IN THE ATMOSPHERE OF GJ 117, Astrophysical Journal 632, (2005), L127-L130.

6. L. Č. Popović, G. Chartas: THE INFLUENCE OF GRAVITATIONAL LENSING ON THE SPECTRA OF LENSED QUASI-STELLAR OBJECTS, Monthly Notices of the Royal Astronomical Society, 357 (2005), 135-144.

7. M. A. Jarzembski, D. V. Tankosić: DISCHARGE OF NEGATIVELY CHARGED MICROMETER SIZE PARTICLES IN AN ELECTRODYNAMIC BALANCE DUE TO RADIOACTIVITY, Journal of Aerosol Science 36, (2005) 1023-1035.

8. M. M. Abbas, D. Tankosić, P. D. Craven, J. F. Spann, A. Leclair, E. A. West, J. C. Weingartner, A. G. G. M. Tielens, J. A. Nuth, R. P. Camata, P. A. Gerakines: PHOTOELECTRIC EMISSION MEASUREMENTS ON THE ANALOGS OF INDIVIDUAL COSMIC DUST GRAINS, Astrophysical Journal 645 (2006), 324-336.

9. L. Č. Popović, P. Jovanović, E. Mediavilla, A. F. Zakharov, C. Abajas, J. A. Muñoz, G. Chartas: A STUDY OF THE CORRELATION BETWEEN THE AMPLIFICATION OF THE FeK ALPHA LINE AND THE X-RAY CONTINUUM OF QUASARS DUE TO MICROLENSING, Astrophysical Journal, 637 (2), (2006), 620-630.

10. L. Č. Popović, L. Č. Jovanović, T. Petrović, V. N. Shalyapin: AMPLIFICATION AND VARIABILITY OF THE AGN X-RAY EMISSION DUE TO MICROLENSING, Astronomische Nachrichten, 327 (10), (2006), 981-984.

11. E. Bon, L. Č. Popović, D. Ilić, E. Mediavilla: STRATIFICATION IN THE BROAD LINE REGION OF AGN: THE TWO-COMPONENT MODEL, New Astronomy Reviews, 50 (9-10), (2006), 716-719.

12. D. Ilić, L. Č. Popović, E. Bon, E. G. Mediavilla, V. H. Chavushyan: COMPLEX EMISSION LINE REGION OF Mrk 817, Monthly Notices of the Royal Astronomical Society, 371 (4), (2006), 1610-1616.

13. P. Jovanović: INFLUENCE OF GRAVITATIONAL MICROLENSING ON X-RAY RADIATION FROM ACCRETION DISKS OF ACTIVE GALAXIES, Publications of the Astronomical Society of the Pacific, 118 (842), (2006), 656-657.

14. H. Elabidi, N. Ben Nessib, M. S. Dimitrijević: ELECTRON IMPACT BROADENING OF MULTICHARGED ION LINES OF ASTROPHYSICAL INTEREST: Ne VII, Ne VIII, AND Si XI, New Astronomy 12 (2006), 64-70.

15. Z. Simić,. M. S. Dimitrijević, L. Č. Popović, M. D. Dačić: STARK BROADENING PARAMETERS FOR Cu III, Zn III AND Se III LINES IN LABORATORY AND STELLAR PLASMA, New Astronomy 12 (2006), 187-191.

16. A. A. Smirnova, N. Gavrilović, A. V. Moiseev, L. Č. Po pović, V. L. Afanasiev, P. Jovanović, M. Dačić: THE GAS KINEMATICS IN THE Mrk 533 NUCLEUS AND CIRCUMNUCLEAR REGION: A GASEOUS OUTFLOW, Monthly Notices of the Royal Astronomical Society, 377 (2), (2007), 480-490.

17. E. Lyratzi, E. Danezis, L. Č. Popović, M. S. Dimitrijević, D. Nikolaidis, A. Antoniou: THE COMPLEX STRUCTURE OF THE Mg II λ 2795.523, 2802.698 A

REGIONS OF 64 Be STARS, Publications of the Astronomical Society of Japan, 59, (2007), 357-371.

18. E. Danezis, D. Nikolaidis, E. Lyratzi, L. Č. Popović, M. S. Dimitrijević, A. Antoniou, E. Theodossiou: A NEW MODEL FOR THE STRUCTURE OF THE DACs AND SACs REGIONS IN THE Oe AND Be STELLAR ATMOSPHERES, Publications of the Astronomical Society of Japan 59, (2007), 827-834.

19. A. N. Klyucharev, N. N. Bezuglov, A. A. Matveev, A. A. Mihajlov, Lj. M. Ignjatović, M. S. Dimitrijević: RATE COEFFICIENTS FOR THE CHEMI-IONIZATION PROCESSES IN SODIUM- AND OTHER ALKALI-METAL GEO-COSMICAL PLASMAS, New Astronomy Review, 51 (2007), 547-562.

20. S. Simić, L. Č. Popović, M. I. Andersen, L. Christensen: MECHANISM OF LIGHT CURVE VARIABILITY IN THE GAMMA RAY BURSTS, Astrophysics and Space Science, 309 (1-4), (2007), 173-177.

21. G. L. La Mura, L. Č. Popović, S. Ciroi, P. Rafanelli, D. Ilić: DETAILED ANALYSIS OF BALMER LINES IN A SELECTED SAMPLE OF 90 BROAD LINE AGN, Astrophysical Journal, 671, (2007) 104-117.

22. M. S. Dimitrijević, L. Č. Popović, J, Kovačević, M. Dačić, D. Ilić: THE FLUX RATIO OF THE [O III]$\lambda\lambda$ 5007, 4959 $\AA$ LINES IN AGN: COMPARISON WITH THEORETICAL CALCULATIONS, Monthly Notices of The Royal Astronomical Society, 374 (3), (2007) 1181-1184.

23. M. S. Dimitrijević, T. Ryabchikova, Z. Simić, L. Č. Popović, M. Dačić: THE INFLUENCE OF STARK BROADENING ON CrII SPECTRAL LINE SHAPES IN STELLAR ATMOSPHERES, Astronomy and Astrophysics, 469 (2), (2007) 681-686.

24. M. M. Abbas, D. Tankosić, P. D. Craven, J. F. Spann, A. Leclair, E. A. West: LUNAR DUST CHARGING BY PHOTOELECTRIC EMISSION, Planetary and Space Science 55, (2007), 953-965.

25. M. S. Dimitrijević, M. Christova, S. Sahal-Bréchot: STARK BROADENING OF VISIBLE Ar I SPECTRAL LINES, Physica Scripta, 75, (2007) 809-819.

26. A. Dotter, B. Chaboyer, D. Jevremović, E. Baron, J. W. Ferguson, A. Sarajedini, J. Anderson: THE ACS SURVEY OF GALACTIC GLOBULAR CLUSTERS. II. STELLAR EVOLUTION TRACKS, ISOCHRONES, LUMINOSITY FUNCTIONS, AND SYNTHETIC HORIZONTAL-BRANCH MODELS, Astronomical Journal, 134, (2007), 376-390.

27. A. Dotter, B. Chaboyer, J. W. Ferguson, H. Lee, G. Worthey, D. Jevremović, E. Baron: STELLAR POPULATION MODELS AND INDIVIDUAL ELEMENT ABUNDANCES. I. SENSITIVITY OF STELLAR EVOLUTION MODELS, Astrophysical Journal, 666, (2007), 403-412.

28. L. Č. Popović, M. S. Dimitrijević, Z. Simić, M. Dačić, A. Kovačević, S. Sahal-Bréchot: STARK BROADENING AND HFS OF Mn II, New Astronomy, 13, (2008), 85-92.

29. R. Hamdi, N. Ben Nessib, N. Milovanović, L. Č. Popović, M. S. Dimitrijević, S. Sahal-Bréchot: ATOMIC DATA AND ELECTRON-IMPACT BROADENING EFFECT IN DO WHITE DWARF ATMOSPHERES: Si VI, Monthly Notices of the Royal Astronomical Society, 387, (2008), 871-882.

30. B. Zmerli, N. Ben Nessib, M. S. Dimitrijević, TEMPERATURE DEPENDENCE OF ATOMIC SPECTRAL LINE WIDTHS IN A PLASMA, European Journal of Physics D 48, (2008), 389-395.

31. D. J. Christian, M. Mathioudakis, D. Jevremović: ^{6}Li IN THE ATMOSPHERE OF GJ 117 REVISITED, Astrophysical Journal, 686 (1), (2008), 542-547.

32. A. Dotter, B. Chaboyer, D. Jevremović, V. Kostov, E. Baron, J. W. Ferguson: THE DARTHMOUT STELLAR EVOLUTION DATABASE, Astrophysical Journal Supplement Series, 178 (1), (2008), 89-101.

33. D. Casebeer, E. Baron, K. Leighly, D. Jevremovic, D. Branch: SELF-CONSISTENT NLTE-SPECTRA SYNTHESIS MODEL OF FeLoBAL QSOs, Astrophysical Journal, 676 (2), (2008), 857-867.

34. L. Č. Popović, A. I. Shapovalova, V. H. Chavushyan, D. Ilić, A. N. Burenkov, A. Mercado, N. G. Bochkarev: PROBING THE PHYSICAL PROPERTIES OF THE NGC 5548 BROAD LINE REGION USING BALMER LINES, Publications of the Astronomical Society of Japan, 60 (1), (2008), 1-9.

35. P. Jovanović, A. F. Zakharov, L. Č. Popović, T. Petrović: MICROLENSING OF THE X-RAY, UV AND OPTICAL EMISSION REGIONS OF QUASARS: SIMULATIONS OF THE TIME-SCALES AND AMPLITUDE VARIATIONS OF MICROLENSING EVENTS, Monthly Notices of the Royal Astronomical Society, 386 (1), (2008), 397-406.

36. P. Jovanović, L. Č. Popović: OBSERVATIONAL EFFECTS OF STRONG GRAVITY IN VICINITY OF SUPERMASSIVE BLACK HOLES, Fortschrift für Physik (Progress in Physics), 55 (2008), 1-5.

37. A. I. Shapovalova, L. Č. Popović, S. Collin, A. N. Burenkov, V. H. Chavushyan, N. G. Bochkarev, E. Bentez, D. Dultzin, A. Kovačević, N. Borisov, L. Carrasco, J. León-Tavares, A. Mercado, J. R. Valdes, V. V. Vlasyuk, V. E. Zhdanova: LONG-TERM VARIABILITY OF THE OPTICAL SPECTRA OF NGC 4151. I. LIGHT CURVES AND FLUX CORRELATIONS, Astronomy and Astrophysics, 486 (1), (2008), 99-111.

38. S. Simić, L. Č. Popović: INVESTIGATION OF ELEMENTAL ABUNDANCE IN THE SURROUNDINGS OF GRB AFTERGLOWS, International Journal of Modern Physics D, 17, (2008), 1377-1382.

6. MISCELLANEOUS

1. A. Kovačević: DETERMINATION OF THE MASS OF (4) VESTA BASED ON NEW CLOSE APPROACHES, Astronomy and Astrophysics 430, (2005), 319-325.

2. A. Kovačević, M. Kuzmanoski: A NEW DETERMINATION OF THE MASS OF (1) CERES, Earth, Moon and Planets 100, (2005), 117-123.

3. A. Kovačević: GRAVITATIONAL EFFECTS OF MINOR PLANETS AND THEIR MASS DETERMINATION, Publications of the Astronomical Society of Pacific 119, (2007), 134.

4. M. S. Dimitrijević, E. Th. Theodossiou, P. Z. Mantarakis: MILUTIN MILANKOVIĆ AND THE REFORM OF THE JULIAN CALENDAR IN 1923, Journal of Astronomical History and Heritage 11 (2008), 50-54.

7. CONFERENCES ORGANIZED BY THE GROUP FOR ASTROPHYSICAL SPECTROSCOPY 2005-2008

1. V SERBIAN CONFERENCE ON SPECTRAL LINE SHAPES IN ASTROPHYSICS, Vršac, 6 - 10 June 2005 (Co-Chairs of the Scientific Organizing Committee (SOC) L. Č. Popović, M. S. Dimitrijević, member D. Jevremović, Chair of the Local Organizing Committee (LOC) M. S. Dimitrijević).

2. DEVELOPMENT OF ASTRONOMY AMONG SERBS IV, Belgrade 22-26 April 2006 (Chair of the SOC, M. S. Dimitrijević).

3. V BULGARIAN-SERBIAN CONFERENCE ON ASTRONOMY AND SPACE SCIENCE, Sofia, 9-12 May 2006 (Organizers and editors of Proceedings M. K. Tsvetkov, L. G. Filipov, M. S. Dimitrijević, L. Č. Popović).

4. VI SERBIAN - BELARUSSIAN SYMPOSIUM ON PHYSICS AND DIAGNOSTICS OF LABORATORY AND ASTROPHYSICAL PLASMAS (PDP-VI'2006), Belgrade, 22 - 25. August 2006 (Co-Chairs of the SOC, M. Ćuk, M. S. Dimitrijević, V. S. Burakov, A. F. Chernyavski, Scientific Secretary L. Č. Popović).

5. VI SERBIAN CONFERENCE ON SPECTRAL LINE SHAPES IN ASTROPHYSICS, Sremski Karlovci, 11-15 June 2007. (Co-Chairs of the SOC L. Č. Popović, M. S. Dimitrijević, Chairman of the LOC L. Č. Popović, Co-Vice Chairs D. Ilić, N. Milovanović).

6. THE FIRST SUMMER SCHOOL IN ASTRONOMY AND GEOPHYSICS, Belgrade, 6-10 August 2007 (Co-Chairs of the SOC M. S. Dimitrijević, N. Pejović, Scientific secretary A. Kovačević).

7. DEVELOPMENT OF ASTRONOMY AMONG SERBS V, Belgrade 18-22 April 2008 (Chair of the SOC, M. S. Dimitrijević).

8. VI SERBIAN-BULGARIAN ASTRONOMICAL CONFERENCE, Belgrade, 7-11 May 2008 (Co-Chairs of the SOC M. S. Dimitrijević, M. K. Tsvetkov, Co-Vice Chairs of the SOC, L. Č. Popović, V. Golev, Chair of the LOC A. Kovačević).

9. 24th SUMMER SCHOOL AND INTERNATIONAL SYMPOSIUM ON THE PHYSICS OF IONIZED GASES, Novi Sad, 25-29 August 2008 (Co-Chairs of the LOC L. Č. Popović, M. S. Dimitrijević, Secretary of the LOC D. Ilić).

10. VII BELARUSSIAN-SERBIAN SYMPOSIUM ON PHYSICS AND DIAGNOSTICS OF LABORATORY AND ASTROPHYSICAL PLASMAS (PDP-VII'2008), Minsk, 22-26 September 2008 (Co-Vice Chairs of the Programme Organizing Committee, V. I. Arkhipenko, M. S. Dimitrijević).

11. THE SECOND SUMMER SCHOOL IN ASTRONOMY, Belgrade, 29 September - 1 October 2008 (Co-Chairs of the SOC M. S. Dimitrijević, T. Prodanović, L. Č. Popović, Chair of the LOC A. Kovačević).

12. XV NATIONAL CONFERENCE OF ASTRONOMERS OF SERBIA, Belgrade, 2-5 October 2008 (Chair of the LOC D. Ilić).

13. DJORDJE STANOJEVIĆ - LIFE AND WORK (150 YEARS FROM HIS BIRTH), Novi Sad, 10-11 October 2008 (Organizers V. Marić, M. S. Dimitrijević).

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EUROPEAN VIRTUAL ATOMIC AND MOLECULAR DATA CENTER – VAMDC

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Abstract. Reliable atomic and molecular data are of great importance for different applications in astrophysics, atmospheric physics, fusion, environmental sciences, combustion chemistry, and in industrial applications from plasmas and lasers to lighting. Currently, very important resources of such data are highly fragmented, presented in different, non-standardized ways, available through a variety of highly specialized and often poorly documented interfaces, so that the full exploitation of all their scientific worth is limited, hindering research in many topics like e.g. the characterization of extrasolar planets, understanding the chemistry of our local solar system and of the wider universe, the study of the terrestrial atmosphere and quantification of climate change; the development of the fusion rersearch, etc.

The Virtual Atomic and Molecular Data Centre (http://www.vamdc.eu, VAMDC) is an European Union funded FP7 project aiming to build a secure, documented, flexible and interoperable e-science environment-based interface to existing atomic and molecular data. It will also provide a forum for training potential users and dissemination of expertise worldwide. Partners in the Consortium of the Project are: 1) Centre National de Recherche Scientifique - CNRS (Paris, Reims, Grenoble, Bordeaux, Dijon, Toulouse); 2) The Chancellor, Masters and Scholars of the University of Cambridge – CMSUC; 3) University College London – UCL; 4) Open University – OU; (Milton Keynes, England); 5) Universitaet Wien - UNIVIE; 6) Uppsala Universitet – UU; 7) Universitaet zu Koeln – KOLN; 8) Istituto Nazionale di Astrofisica – INAF (Catania, Cagliari); 9) Queen's University Belfast – QUB; 10) Astronomska Opservatorija - AOB (Belgrade, Serbia); 11) Institute of Spectroscopy RAS – ISRAN (Troitsk, Russia); 12) Russian Federal Nuclear Center - All-Russian Institute of Technical Physics - RFNC-VNIITF (Snezhinsk, Chelyabinsk Region, Russia; 13) Institute of Atmospheric Optics - IAO (Tomsk, Russia); 14) Corporacion Parque tecnologico de Merida – IVIC (Merida, Venezuela); 15) Institute for Astronomy RAS - INASAN (Moscow, Russia).

This review describes the VAMDC project and its objectives.

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USING THE GR MODEL TO STUDY THE AGN SPECTRA

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Abstract. According to the GR model, the Broad Absorption Line Region (BALR), lie in a disk around the quasar and is composed of a number of successive independent absorbing density regions that have different apparent rotational and radial velocities. By fitting the observed absorption lines with GR model, we can calculate some basic kinematical parameters of BALR, such as the random, rotational and radial velocities. Here, fitting with the GR model the C IV resonance lines in the spectra of several HiBAL QSOs, taken with HST, we calculate the values of the kinematical parameters of the respective density regions. Moreover, using the obtained parameters from the best fit, we discuss the general characteristics of the regions which create the studied C IV lines.

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STARK BROADENING PARAMETERS FOR WHITE DWARF ATMOSPHERES RESEARCH

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Abstract. Stark broadening parameters of C II lines were determined within 3d-nf series using semiclassical perturbation method. The atomic energy levels needed for calculations were taken from TOPBASE as well as the oscillator strengths, which were additionally calculated using the method of Bates and Damgaard. The both results were compared and only insignificant differences were found. Calculations were performed for plasma conditions relevant for atmospheres of DQ white dwarfs and for a new type of white dwarfs, with surface composed mostly of carbon, discovered in 2007 by Dufour et al. The aim of this work is to provide accurate C II Stark broadening data, which are crucial for this type of white dwarf atmosphere modellisation. Obtained results will be included in STARK-B database (http://stark-b.obspm.fr/), entering in the FP7 project of European Virtual Atomic and Molecular Data Center VAMDC aiming at building an interoperable e-Infrastructure for the exchange of atomic and molecular data (http://www.vamdc.org/).

1. INTRODUCTION

Stark broadening is dominant pressure broadening mechanism in white dwarf atmospheres and it was found that for such stars it is dominant in practically all relevant atmospheric layers (see e.g. Simić et al. 2009, Popović et al. 1999, Tankosić et al. 2003, Hamdi et al. 2008). Consequently, data on spectral line widths broadened by this mechanism are in particular important for analysis, synthesis and interpretation of white dwarf spectra, for radiative transfer considerations, abundance determination, and for the investigation, diagnostics and modelling of plasma of such stars.

If traces of carbon, either as neutral carbon lines or molecular C_2 Swan bands are present in white dwarf spectra, they are collectively known as DQ stars. In hotter DQ stars C II spectral lines are also present. For example Thejll et al. (1990) for the modelling of the spectrum of the carbon rich DQ white dwarf G35-26 (Gr 469, WD 0203+207), used data on the Stark broadening of C II lines.

A new type of white dwarfs has recently been discovered by Dufour et al. (2007, 2008). The surface composition of these stars is mostly composed of carbon. There is hardly neither hydrogen nor helium in the atmosphere. In order to understand the origin and evolution of this new type of stars, the determination of gravity is essential, and it is necessary to develop a new generation of accurate models. In fact, the inclusion of accurate spectral line broadening is crucial for this type of white dwarf atmosphere modellisation. At these temperatures and pressures of interest (effective temperatures within 19,000-23,000 K, electron density within 10^{15} cm^{-3} - $10^{18}cm^{-3}$, the dominant ion is C II. There is a contribution of C III for the most profound layers or for very hot models but it can be neglected. The

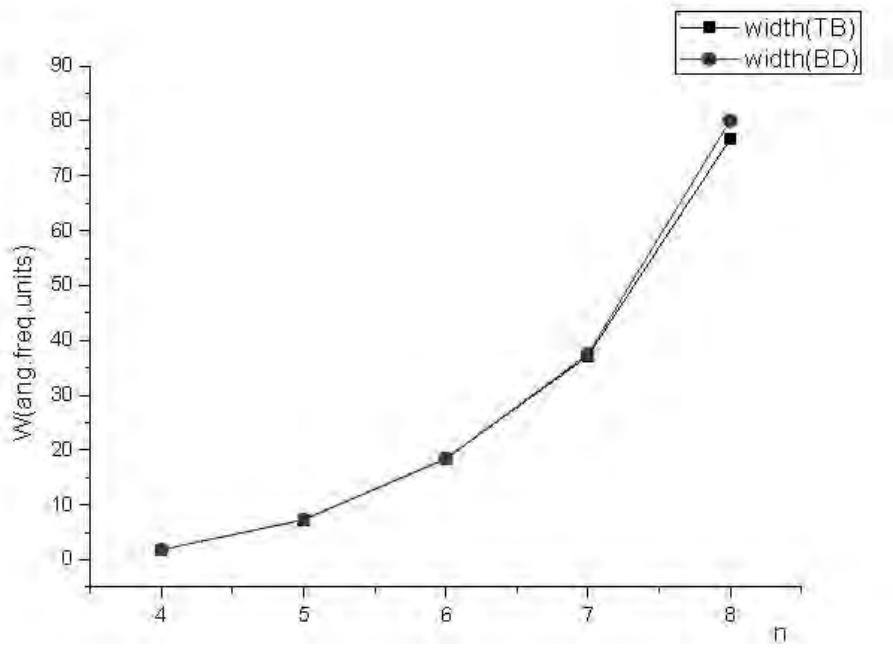

Figure 1: Electron-impact full half-widths (in angular frequency units) for C II 3d-nf lines as a function of n for T = 10000 K. The electron density is 10^{14} cm^{-3}. For the calculation of widths denoted as TB needed energies and oscillator strengths were taken from TOPBASE. The widths denoted as BD were calculated using TOPBASE for the energy of atomic levels and oscillator strengths were calculated using the method of Bates and Damgaard.

Table 1. C II Stark widths and shifts for 3d-nf series for an electronic density of $N_e=10^{14}$ cm^{-3}. In the first column, we give transitions, wavelengths for the transitions in Å and C values which, when divided with W, give an estimate for the maximum perturber density for which the line may be treated as isolated. Asterisks denote cases where the impact approximation is not valid.

Transition	T[K]	W_e[Å]	d_e [Å]	$W_{C\ II}$ [Å]	$d_{C\ II}$ [Å]
2s2 4f-2s2 3d	5000.	0.220E-02	-0.434E-04	0.138E-03	-0.103E-03
	10000.	0.175E-02	-0.212E-04	0.168E-03	-0.123E-03
4299.9 Å	20000.	0.142E-02	-0.121E-04	0.192E-03	-0.144E-03
C= 0.15E+17	30000.	0.130E-02	-0.108E-04	0.209E-03	-0.154E-03
	50000.	0.119E-02	-0.122E-04	0.236E-03	-0.178E-03
	80000.	0.110E-02	-0.649E-05	0.241E-03	-0.184E-03
2s2 5f-2s2 3d	5000.	0.386E-02	0.151E-03	0.366E-03	0.325E-03
	10000.	0.349E-02	0.194E-03	0.463E-03	0.381E-03
3009.9 Å	20000.	0.316E-02	0.138E-03	0.491E-03	0.419E-03
C= 0.10E+16	30000.	0.296E-02	0.112E-03	0.563E-03	0.464E-03
	50000.	0.273E-02	0.110E-03	0.670E-03	0.497E-03
	80000.	0.251E-02	0.960E-04	0.775E-03	0.563E-03
2s2 6f-2s2 3d	5000.	0.693E-02	0.532E-03	0.962E-03	0.804E-03
	10000.	0.651E-02	0.502E-03	0.108E-02	0.942E-03
2588.1 Å	20000.	0.605E-02	0.350E-03	0.123E-02	0.114E-02
C= 0.46E+15	30000.	0.574E-02	0.314E-03	0.128E-02	0.114E-02
	50000.	0.530E-02	0.285E-03	0.139E-02	0.116E-02
	80000.	0.487E-02	0.202E-03	0.171E-02	0.145E-02
2s2 7f-2s2 3d	5000.	0.118E-01	0.146E-02*	0.205E-02*	0.178E-02
	10000.	0.112E-01	0.116E-02*	0.239E-02*	0.196E-02
2386.5 Å	20000.	0.104E-01	0.868E-03	0.252E-02	0.243E-02
C= 0.25E+15	30000.	0.990E-02	0.771E-03	0.259E-02	0.228E-02
	50000.	0.919E-02	0.612E-03	0.338E-02	0.274E-02
	80000.	0.846E-02	0.420E-03	0.330E-02	0.285E-02
2s2 8f-2s2 3d	5000.	0.221E-01	0.922E-02	*	*
	10000.	0.210E-01	0.720E-02	*	*
2271.8 Å	20000.	0.195E-01	0.547E-02*	0.593E-02	0.553E-02
C= 0.16E+15	30000.	0.183E-01	0.465E-02*	0.779E-02	0.595E-02
	50000.	0.168E-01	0.362E-02*	0.678E-02	0.623E-02
	80000.	0.153E-01	0.278E-02*	0.913E-02	0.555E-02

predominant cause of broadening of CII lines is Stark broadening, i.e. broadening by electron-impact and ion interactions.

The aim of this work is to provide accurate C II Stark broadening data, which are crucial for this type of white dwarf atmosphere modellisation.

2. RESULTS AND DISCUSSION

Using semiclassical perturbation approach (Sahal-Bréchot, 1969ab), we have obtained ab initio Stark broadening parameters for 148 C II multiplets. All details of the calculations as well as analysis of obtained results and comparison with existing experimental and theoretical results will be given in Larbi-Terzi et al. (2010). As an example of obtained results, here are given C II Stark widths (FWHM) and shifts for 3d-nf series for an electronic density of $N_e=10^{14}$ cm^{-3}. In order to see the applicability of the method of Bates and Damgaard for the calculation of C II Stark widths, in Fig. 1 are compared within 3d-nf series Stark widths obtained with oscillator strengths taken from TOPBASE (http://cdsweb.u-strasbg.fr/topbase/topbase.html) with those with oscillator strengths calculated using the method of Bates and Damgaard. One can see that the differences are insignificant.

Obtained results will be included in STARK-B database containing Stark broadening parameters obtained theoretically within the semiclassical perturbation approach (http://stark-b.obspm.fr/), entering in the FP7 project of European Virtual Atomic and Molecular Data Center VAMDC aiming at building an interoperable e-Infrastructure for the exchange of atomic and molecular data (http://www.vamdc.org/).

References

Dufour, P., Fontaine, G., Liebert, J., Schmidt, G. D., Behara, N.: 2008, *Astrophys. J*., **683**, 978.

Dufour, P., Liebert, J., Fontaine. G., and Behara, N.: 2007, *Nature*, **450**, 522.

Hamdi, R., Ben Nessib, N., Milovanović , N., Popović , L. Č., Dimitrijević, M. S., Sahal-Bréchot, S., 2008, *MNRAS*, **387**, 871.

Larbi-Terzi, N., Sahal-Bréchot , S., Ben Nessib, N., Dimitrijević, M. S.: 2010, *MNRAS*, to be submitted.

Popović, L. Č., Dimitrijević, M. S., Tankosić, D.: 1999, *Astron. Astrophys. Suppl. Series*, **139**, 617.

Sahal-Bréchot, S.: 1969a, *Astron. Astrophys*., **1**, 91.

Sahal-Bréchot, S.: 1969b, *Astron. Astrophys*., **2**, 322.

Simić, Z., Dimitrijević, M. S., Kovačević, A.: 2009, *New Astron. Rev*., **53**, 246.

Tankosić, D., Popović, L. Č., Dimitrijević, M.S.: 2003, *Astron. Astrophys*., **399**, 795.

Thejll, P., Shipman, H. L., MacDonald, J., MacFarland, W. M.:1990, *Astrophys. J*., **361**, 197.

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ELECTRICAL CONDUCTIVITY OF PLASMAS IN DB WHITE DWARF ATMOSPHERES

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Abstract. The calculation of the static electrical conductivity of non-ideal, dense, partially ionized helium plasma was carried over a wide range of plasma parameters: temperatures 10^4 K < T < 10^5 K and mass density 10^6 g/cm^3 < ρ < 2 g/cm^3 . Calculations of electrical conductivity of plasma for the considered range of plasma parameters are of interest for DB white dwarf atmospheres with effective temperatures $1\cdot10^4$ K < T_{eff} < $3\cdot10^4$ K. Electrical conductivity of plasma was calculated by using the modified random phase approximation and semiclassical method, adapted for the case of dense, partially ionized plasma.

1. INTRODUCTION

The data on electrical conductivity of plasma of stars with a magnetic field or moving in the magnetic field of the other component in a binary system could be of significant interest, since they are useful for the study of thermal evolution of such objects (cooling, nuclear burning of accreted matter) and the investigation of their magnetic fields. Moreover, electrical conductivity was particularly investigated for solar plasma, since it is of interest for the consideration of various processes in the observed atmospheric layers, like the relation between magnetic field and convection, the question of magnetic field dissipation and the energy released by such processes. Given the analogous role electrical conductivity plays in other stars as well, it is of interest to investigate its significance, to adapt the methods for research into stellar plasma conditions and to provide the needed data.

An additional interest for data on electrical conductivity in white dwarf atmospheres may be stimulated by the search for extra-solar planets. Namely Jianke, Ferrario and Wickramasinghe have shown in 1998, that a planetary core in orbit around a white dwarf may reveal its presence through its interaction with the magnetosphere of the white dwarf. Such an interaction will generate electrical currents that will directly heat the atmosphere near its magnetic poles. They emphasize that this heating may be detected within the optical wavelength range as Hα emission.

For investigation and modeling of such electrical currents, the data on electrical conductivity in white dwarf atmospheres will be useful.

We calculated here the static electrical conductivity of non-ideal, dense, partially ionized helium plasma within a wide range of temperatures and mass densities, of interest for the DB white dwarf atmospheres with effective temperatures between 10000 K and 30000 K. Electrical conductivity of plasma was calculated by using the modified random phase approximation (RPA) and semiclassical method, adapted for the case of dense, partially ionized plasma,

$$\sigma_0 = \frac{4e}{3m}\int_0^\infty E\omega(E)\frac{1}{\left[\frac{1}{t_{ee;ei}(E)}+\nu_{ea}(E)\right]}\frac{df_{FD}(E)}{dE}dE\,, \tag{1}$$

where m and e are the mass and the modulus of charge of the electron, ω(E) is the density of the single electron states in the energy space, $f_{FD}(E)$ is the Fermi-Dirac distribution function and $t_{ee;ei}(E) = t^{RPA}_{ee;ei}$ or $t_{ee;ei}(E) = t^{SC}_{ee;ei}$ is effective electron relaxation time given in Srećković et al. (2010). Finaly the electron-atom collision frequency ν_{ea}, in equation for σ_0, is given here by the known expression $\nu_{ea} = N_a \upsilon Q_{ea}^{tr}$ wher where N_a is the He(1s2) atom density, $v(E)=(2E/m)^{1/2}$- relative electron-atom velocity, and Q_{ea}^{tr} momentum transfer cross section calculated, following the previous papers Ignjatović & Mihajlov (1997) and Srećković et al. (2010) , using the potential U(r) (defined in Eq.2 and table 1).

$$U(r) = \begin{cases} U_0 = -\dfrac{Z}{r} + \dfrac{q}{r+r_0} + \dfrac{Z-q}{r_0}, & 0 < r < r_i \\ U_m = ar^2 + br + c, & r_i < r < r_f \\ U_{as} = -\dfrac{\alpha}{2(r^2+h^2)^2}, & r_f < r < \infty \end{cases} \tag{2}$$

Table 1. The parameter values of the model potential U(r) in atomic units.

Z	q	a	b	c	α	h	r_i	r_f	r_0
2	0.7	-0.59597652	2.2545472	-2.19405731	1.384	0.01	0.73	1.75	0.9

2. THE RESULTS

The developed method was then applied to calculation of plasma electrical conductivity for the models of DB white dwarf atmospheres presented in Fig.1. The results of the calculations are shown in Fig.3. First, let us note a regular behavior of the static electrical conductivity which one should expect considering the characteristics of DB white dwarf atmospheres.

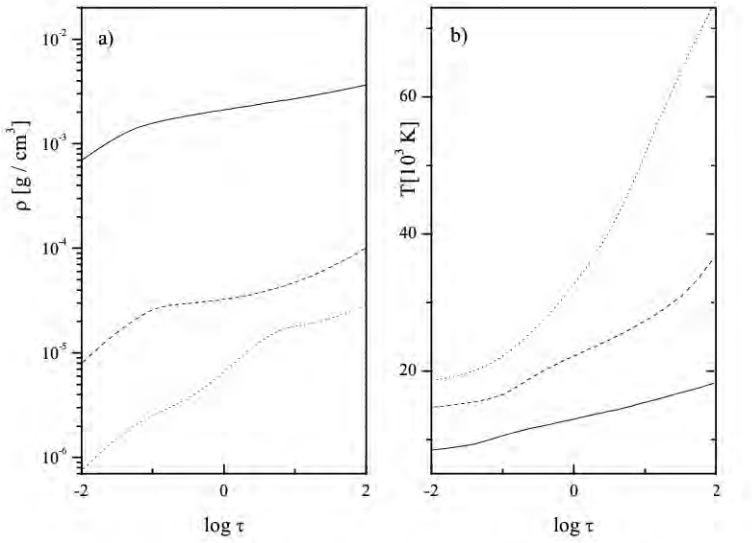

Figure 1: DB white dwarf atmosphere models with log g=8 and T_{eff}=12000K (full curve), T_{eff}=20000K (dashed curve) and T_{eff} =30000K (dotted curve) from Koester (1980): (a) The mass densities; (b) The temperatures, as functions of Rosseland opacity τ.

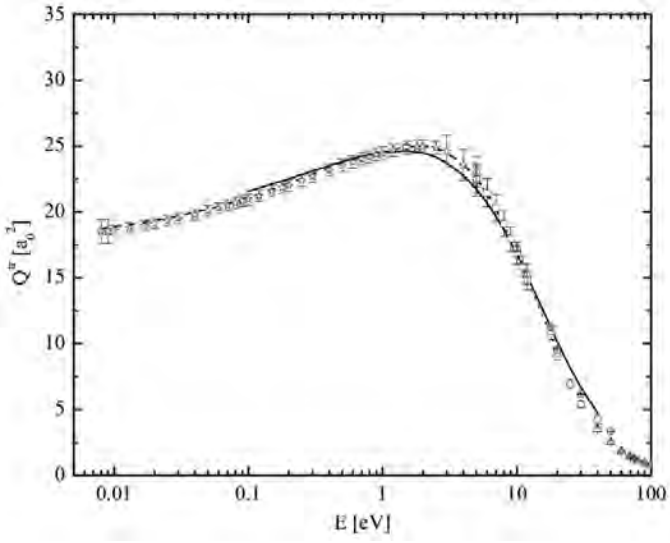

Figure 2: Momentum transfer cross section Q_{tr} as a function of energy E. Calculated data (full curve) for helium together with results of other authors see Srećković et al. (2010).

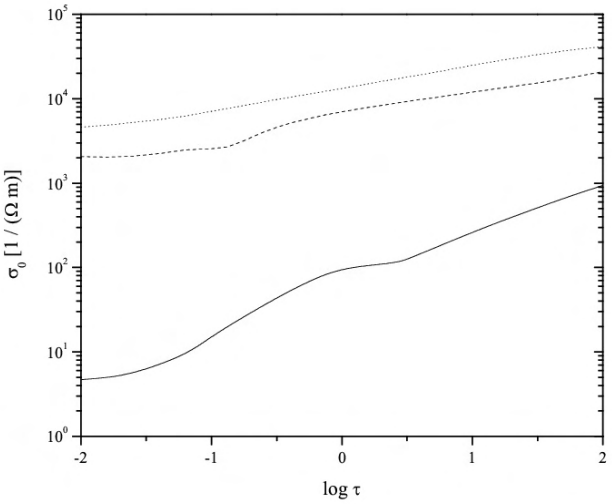

Figure 3: Static electrical conductivity σ_0 as a function of the logarithm of Rosseland opacity τ for DB white dwarf atmosphere models with log g=8 and T_{eff}=12000K (full curve), T_{eff}=20000K (dashed curve) and T_{eff}=30000K (dotted curve).

The method developed in this paper represents a powerful tool for research into white dwarfs with different atmospheric compositions (DA, DC etc.), and for the investigation of some other stars (M type red dwarfs, Sun etc.). Finally, the presented method provides a basis for the development of methods to describe the other transport characteristics which are important for the study of all the mentioned astrophysical objects, such as the electronic thermo-conductivity in the star atmosphere layers with large electron density, electrical conductivity in the presence of strong magnetic fields and high frequency electrical conductivity.

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References

Ignjatović, Lj. M., Mihajlov, A. A.: 1997, *Contrib. Plasma Phys.*, **37,** 39.
Koester, D.: 1980, *A&AS.*, **39**, 401.
Srećković, V. A., Ignjatović, Lj. M., Mihajlov, A. A., Dimitrijević, M. S.: 2010, *MNRAS.*, **doi:** 10.1111/j.1365-2966.2010.16702.x.