UDC 521–525
YU ISSN 0373–3734

BULLETIN

DE

L'OBSERVATOIRE ASTRONOMIQUE DE BELGRADE

№ 139

OMNIA IN NUMERO ET MENSURA · 1887 ·

BEOGRAD
1988

BULLETIN

DE

L'OBSERVATOIRE ASTRONOMIQUE DE BELGRADE

FOUNDED IN 1936

Published by Astronomical Observatory, Volgina 7,
11050 Belgrade, Yugoslavia

Director of the Astronomical Observatory: M. Mitrović

The publication of this issue is financially supported by the Republic Community of Sciences of Serbia

Printed by

Zavod za grafičku delatnost Instituta za vodoprivredu „Jaroslav Cerni"
Beograd – Bulevar vojvode Mišića 43/III; Tel.: 651–067

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Nº 139

Bull. Obs. Astron. Belgrade, Nº 139 (1988) UDC 523.44

ASTEROID MEAN ORBITAL ELEMENTS

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(Received: May 26. 1988)

SUMMARY: Procedure of elimination of the asteroid short-periodic perturbations and derivation of the mean orbital elements by means of the theory of Yuasa (1973) is described in detail. The initial Hamiltonian and first order generating function are completed with terms coming from the indirect part of the disturbing function, expressed, in turn, with respect to a fixed plane. A table of mean elements for the first 25 numbered asteroids is given as an example for the results. List of the mean elements of all numbered asteroids in a computer readable form, as well FORTRAN77 program for their derivation, are available on request.

1. INTRODUCTION

Apart from some very particular cases, asteroid short-periodic perturbations, being typically of the order of perturbing mass, were usually considered as small enough to be safely neglected in studying the asteroid motions. Hence, they were seldom accurately calculated and explicitly eliminated in practice. Kozai (1979) and Williams and Hierath (1987), while deriving the parameters for their family classifications, applied some sorts of short-periodic perturbations elimination procedures based on the harmonic analysis and on the analytic removal of the most important terms, respetively, but they both didn't publish the results, nor examined them for accuracy. Asteroid mean elements (those obtained when the short-periodic perturbations are removed from the instantaneous, osculating elements), have never been taken care of in a systematic way, so that for the wast majority of numbered asteroids these elements are not available even at present.

On the other hand, as demonstrated in some recent studies (Carpino et al., 1986; Knežević et al., 1988), asteroid short-periodic perturbations are important not, as previously believed, only for the asteroids located in the vicinity of the mean motion resonances, or for those having high eccentricities and/or inclinations, but also for the dynamically "common" asteroids. This is particularly true if one seeks to derive highly accurate proper elements, necessary for the reliable classification of asteroids into families. Furthermore, studies of characteristics of asteroid long-term motions are more straightforwardly and clearly carried out, if the disturbing short-periodic noise was previously removed, etc. Hence, it might be useful to dispose of the list of mean elements of as much as possible asteroids, derived by means of a suitable procedure, and with the good accuracy.

The analytic theory of asteroid secular perturbations by Yuasa (1973) was used in the present paper to derive the asteroid mean elements. In the frame of this theory, short-periodic terms in the disturbing function of up to the fourth degree in eccentricity and inclination are taken into account, Jupiter and Saturn are considered as perturbing bodies, and the mean elements are obtained by means of the Hori's (1966) canonical transformation method. The procedure is discussed and explained in detail, and the results are presented in the form of the table, containing, as for an example, the mean elements of the first 25 numbered asteroids. The complete list of the mean elements for all the numbered asteroids, as well as the FORTRAN-77 computer programs for their determination are available on request.

2. THEORY

As already mentioned, theory of Yuasa is based on the method of canonical transformations of the equations of asteroid motion. In the following, we shall explain some important details in connection with the transformation performed to eliminate the short-periodic terms only, since we are not interested here in other transformations, necessary to eliminate the long-periodic perturbations and get the solutions.

Equations of motion of an asteroid in the canonical form are given as follows:

$$\frac{dL}{dt} = \frac{\partial F}{\partial l}\,;\quad \frac{dl}{dt} = -\frac{\partial F}{\partial L}\,;\quad \frac{dG}{dt} = \frac{\partial F}{\partial g}\,;\quad \frac{dg}{dt} = -\frac{\partial F}{\partial G}$$
$$\frac{dH}{dt} = \frac{\partial F}{\partial h}\,;\quad \frac{dh}{dt} = -\frac{\partial F}{\partial H}\,;\quad \frac{dK}{dt} = \frac{\partial F}{\partial k}\,;\quad \frac{dk}{dt} = -\frac{\partial F}{\partial K} \qquad (1)$$

where F represents the Hamiltonian of the transformation:

$$F = F_0 + F_1 \qquad (2)$$

F_0 describing here the unperturbed motion, and F_1 being the common disturbing function. L, G, H, K, l, g, h, k are the so called Delaunay's canonical variables, related to the elliptic elements through:

$$L = (\tilde{\mu} a)^{1/2}\ ;\quad l = M$$
$$G = L\,(1 - e^2)^{1/2}\ ;\quad g = \omega$$
$$H = G \cos I\ ;\quad h = \Omega \qquad (3)$$

where:

$$\tilde{\mu} = G_0\ (m_\odot + m) \qquad (4)$$

and G_0 denotes Gaussian constant. Variable K is the momentum conjugate to time k (=t).

The unperturbed Hamiltonian can now be written as:

$$F_0 = \frac{\tilde{\mu}^2}{2L^2} - K \qquad (5)$$

Regarding the disturbing function F_1, in order to take easily into account perturbations by several planets, Yuasa modified the well-known development of LeVerrier (1855) by expressing it with respect to the invariable plane (LeVerrier's development takes as a reference plane the orbital plane of the disturbing planet). Note that the obtained expression holds, in fact, for any fixed plane, providing the elements with respect to that particular plane are used in the calculation.

Formulae for transformation of the LeVerrier's development are given in Yuasa's paper by equations (6) – (15), and the function obtained in this way by equation (16). Since, however, these are huge expressions, we are not going to reproduce them here. Let's just state, instead, that all of them have been carefully checked, and no errors have been found.

Yet, there is a point pertaining to the disturbing function as given by Yuasa, that has to be clarified. Equation (16), since given with respect to the invariable plane, contains only terms coming from the development of the principal part of the disturbing function. If, therefore, one wants to work in the simpler and more comfortable way, using the common, heliocentric, ecliptical system, fixed for some standard epoch, it is necessary to add to the Yuasa's equation (16) the corresponding indirect part. That's exactly what was done in the present paper, and the development of the indirect part of the disturbing function, modified by means of the same Yuasa's transformation formulae, has been obtained as:

$$F_{1\,ind} = \sum_j m'_j \frac{\alpha}{a'}$$
$$\cdot\ \Big(\{-1 + \frac{1}{2}e^2 + \frac{1}{2}e'^2 + \frac{1}{4}\sin^2 I + \frac{1}{4}\sin^2 I'\}\cos[\lambda' - \lambda]$$
$$-\ \{\frac{1}{4}\sin I \sin I' + \sin\frac{I}{2}\sin\frac{I'}{2}\}\cos[\lambda' - \lambda + h - h']$$
$$-\ \{\frac{1}{4}\sin I \sin I' - \sin\frac{I}{2}\sin\frac{I'}{2}\}\cos[\lambda' - \lambda - h + h']$$
$$-\ e e' \cos[2\lambda' - 2\lambda - \tilde{\omega}' + \tilde{\omega}]$$
$$+\ \{\frac{3}{2}e - \frac{3}{4}e e'^2 - \frac{3}{8}e\,[\sin^2 I + \sin^2 I']\}\cos[\lambda' - \tilde{\omega}]$$
$$+\ \frac{3}{2}e\ \{\frac{1}{4}\sin I \sin I' + \sin\frac{I}{2}\sin\frac{I'}{2}\}\cos[\lambda' - \tilde{\omega} + h - h']$$

$$+\frac{3}{2}e\ \left\{\frac{1}{4}\sin I\sin I' - \sin\frac{I}{2}\sin\frac{I'}{2}\right\}\cos[\lambda' - \tilde{\omega} - h + h']$$

$$+\left\{-\frac{1}{2}e + \frac{1}{4}ee'^2 + \frac{3}{8}e^3 + \frac{1}{8}e(\sin^2 I + \sin^2 I')\right\}\cdot$$

$$\cdot\cos[\lambda' - 2\lambda + \tilde{\omega}]$$

$$-\frac{1}{2}e\ \left\{\frac{1}{4}\sin I\sin I' + \sin\frac{I}{2}\sin\frac{I'}{2}\right\}\cdot$$

$$\cdot\cos[\lambda' - 2\lambda + \tilde{\omega} + h - h']$$

$$-\frac{1}{2}e\ \left\{\frac{1}{4}\sin I\sin I' - \sin\frac{I}{2}\sin\frac{I'}{2}\right\}\cdot$$

$$\cdot\cos[\lambda' - 2\lambda + \tilde{\omega} - h + h']$$

$$+\left\{-2e' + e^2e' + \frac{3}{2}e'^3 + \frac{1}{2}e'(\sin^2 I + \sin^2 I')\right\}\cdot$$

$$\cdot\cos[2\lambda' - \lambda - \tilde{\omega}']$$

$$-2e'\ \left\{\frac{1}{4}\sin I\sin I' + \sin\frac{I}{2}\sin\frac{I'}{2}\right\}\cdot$$

$$\cdot\cos[2\lambda' - \lambda - \tilde{\omega}' + h - h']$$

$$-2e'\ \left\{\frac{1}{4}\sin I\sin I' - \sin\frac{I}{2}\sin\frac{I'}{2}\right\}\cdot$$

$$\cdot\cos[2\lambda' - \lambda - \tilde{\omega}' - h + h']$$

$$-\frac{3}{4}e^2e'\cos[2\lambda' - 3\lambda - \tilde{\omega}' + 2\tilde{\omega}]$$

$$+\frac{3}{16}ee'^2\cos[\lambda' - 2\tilde{\omega}' + \tilde{\omega}]$$

$$-\frac{27}{16}ee'^2\cos[3\lambda' - 2\lambda - 2\tilde{\omega}' + \tilde{\omega}]$$

$$+\frac{3}{8}e\sin^2 I\cos[\lambda' + \tilde{\omega} - 2h]$$

$$+\frac{3}{8}e\sin^2 I'\cos[\lambda' + \tilde{\omega} - 2h']$$

$$-\frac{3}{4}e\sin I\sin I'\cos[\lambda' + \omega - h - h']$$

$$-\frac{1}{8}e^2\cos[\lambda' + \lambda - 2\tilde{\omega}]$$

$$-\frac{3}{8}e^2\cos[\lambda' - 3\lambda + 2\tilde{\omega}]$$

$$+3ee'\cos[2\lambda' - \tilde{\omega}' - \tilde{\omega}]$$

$$-\frac{1}{8}e'^2\cos[\lambda' + \lambda - 2\tilde{\omega}']$$

$$+\frac{27}{8}e'^2\cos[3\lambda' - \lambda - 2\tilde{\omega}']$$

$$-\frac{1}{4}\sin^2 I\cos[\lambda' + \lambda - 2h]$$

$$-\frac{1}{4}\sin^2 I'\cos[\lambda' + \lambda - 2h']$$

$$+\frac{1}{2}\sin I\sin I'\cos[\lambda' + \lambda - h - h']$$

$$-\frac{1}{24}e^3\cos[\lambda' + 2\lambda - 3\tilde{\omega}]$$

$$-\frac{1}{3}e^3\cos[\lambda' - 4\lambda + 3\tilde{\omega}]$$

$$-\frac{1}{4}e^2e'\cos[2\lambda' + \lambda - \tilde{\omega}' - 2\tilde{\omega}]$$

$$-\frac{1}{16}ee'^2\cos[\lambda' + 2\lambda - 2\tilde{\omega}' - \tilde{\omega}]$$

$$+\frac{81}{16}ee'^2\cos[3\lambda' - 2\tilde{\omega}' - \tilde{\omega}]$$

$$-\frac{1}{6}e'^3\cos[2\lambda' + \lambda - 3\tilde{\omega}']$$

$$-\frac{16}{3}e'^3\cos[4\lambda' - \lambda - 3\tilde{\omega}']$$

$$-\frac{1}{8}e\sin^2 I\cos[\lambda' + 2\lambda - \tilde{\omega} - 2h]$$

$$-\frac{1}{8}e\sin^2 I'\cos[\lambda' + 2\lambda - \tilde{\omega} - 2h']$$

$$+\frac{1}{4}e\sin I\sin I'\cos[\lambda' + 2\lambda - \tilde{\omega} - h - h']$$

$$-\frac{1}{2}e'\sin^2 I\cos[2\lambda' + \lambda - \tilde{\omega}' - 2h]$$

$$-\frac{1}{2}e'\sin^2 I'\cos[2\lambda' + \lambda - \tilde{\omega}' - 2h']$$

$$+e'\sin I\sin I'\cos[2\lambda' + \lambda - \tilde{\omega}' - h - h']\Big) \qquad (6)$$

Primed quantities refer here to the perturbing planet, subscript j being omitted for simplicity, α is the ratio of the semimajor axes of the perturbed and perturbing bodies, while $\lambda = 1 + g + h$ is the longitude of perihelion.

The complete Hamiltonian is, consequently, given as a sum of the terms from Yuasa's equation (16), and of those from the above equation (6). In total, it contains 123 terms.

Once the initial Hamiltonian is available, it becomes a straightforward thing to write down a scheme for elimination of the short-periodic perturbations according to the Hori's canonical transformation method. Denoting the generating function of the transformation by S, and the transformed Hamiltonian, not containing the fast variables, by F^*, one developes them in powers of the disturbing mass:

$$S = S_1 + S_2 + \ldots$$

$$F^* = F_0^* + F_1^* + F_2^* + \ldots \tag{7}$$

where each S_k and F_k^* contains a factor $m'^{\,k}_j$. It can be easily demonstrated that:

$$F_0^* = F_0$$

$$F_1^* = F_{1,s}$$

$$F_2^* = \frac{1}{2}\{F_1 + F_1^*, S_1\}_s$$

$$S_1 = \int (F_1 - F_{1,s})\, dt \tag{8}$$

Subscript s refers here to the secular terms, and { , } stands for the Poisson brackets.

If one neglects minor short-periodic terms of the second order with respect to disturbing mass (adopting thus $S \cong S_1$), it is almost trivial, by using the definition (8), to derive the expression for the generating function. Representing here the result just by the very first terms coming from the principal and indirect part of the Hamiltonian, one has:

$$\begin{aligned} S_1 = \sum_j m'_j \Big(\sum_i \Big\{ \frac{1}{i(n'-n)} \Big[& (1)^{(i)} \Big(1 - i^2 \sin^2\frac{I}{2}\sin^2\frac{I'}{2}\Big) + \\ & + (2)^{(i)} \Big(\frac{e}{2}\Big)^2 + (3)^{(i)} \Big(\frac{e'}{2}\Big)^2 + (4)^{(i)} \Big(\frac{e}{2}\Big)^4 + \\ & + (5)^{(i)} \Big(\frac{e}{2}\Big)^2 \Big(\frac{e'}{2}\Big)^2 + (6)^{(i)} \Big(\frac{e'}{2}\Big)^4 + (11)^{(i)} \Big(\frac{1}{4}\sin^2 I + \\ & + \frac{1}{4}\sin^2 I' + \frac{1}{16}\sin^4 I + \frac{1}{16}\sin^4 I' - \frac{1}{8}\sin^2 I \sin^2 I'\Big) + \\ & + (12)^{(i)} \Big(\frac{e}{2}\Big)^2 \Big(\frac{1}{4}\sin^2 I + \frac{1}{4}\sin^2 I'\Big) + (13)^{(i)}\Big(\frac{1}{4}\sin^2 I + \\ & + \frac{1}{4}\sin^2 I'\Big) + (17)^{(i)} \Big(\frac{1}{16}\sin^4 I + \frac{1}{16}\sin^4 I' + \\ & + \frac{1}{4}\sin^2 I \sin^2 I'\Big) \Big] \sin(i\lambda' - i\lambda)_{i \neq 0} + \cdots \Big\} + \\ & + \frac{\alpha}{a'} \Big[\frac{1}{n'-n}\Big(-1 + \frac{1}{2}e^2 + \frac{1}{2}e'^2 + \frac{1}{4}\sin^2 I + \\ & + \frac{1}{4}\sin^2 I'\Big) \sin(\lambda' - \lambda) + \cdots \Big] \Big) \end{aligned} \tag{9}$$

The mean values of the Delaunay's variables are now obtained from (c. f. Milani, 1988):

$$L^* = L - \frac{\partial S_1}{\partial l}$$

$$G^* = G - \frac{\partial S_1}{\partial g} \; ; \qquad g^* = g + \frac{\partial S_1}{\partial G}$$

$$H^* = H - \frac{\partial S_1}{\partial h} \; ; \qquad h^* = h + \frac{\partial S_1}{\partial H} \tag{10}$$

Since S_1 is expressed as function of the elliptical elements, the derivatives over the Delaunay's variables are determined from:

$$\frac{\partial}{\partial L} = 2\Big(\frac{a}{\tilde{\mu}}\Big)^{1/2} \frac{\partial}{\partial a} + \frac{1 - e^2}{(\tilde{\mu} a)^{1/2} e} \frac{\partial}{\partial e}$$

$$\frac{\partial}{\partial G} = - \frac{(1 - e^2)^{1/2}}{(\tilde{\mu} a)^{1/2} e} \frac{\partial}{\partial e} + \frac{1}{\operatorname{tg} I \, [\tilde{\mu} a (1 - e^2)]^{1/2}} \frac{\partial}{\partial I}$$

$$\frac{\partial}{\partial H} = - \frac{1}{\sin I \, [\tilde{\mu} a (1 - e^2)]^{1/2}} \frac{\partial}{\partial I} \tag{11}$$

Representing again the obtained partial derivatives of the generating function over the Delaunay's variables just by the very first terms of the principal and indirect part (only the derivatives over l and G are actually shown), one easily finds the explicit expressions for corrections to the osculating elements, appearing in (10):

$$\begin{aligned} \frac{\partial S_1}{\partial l} = \sum_j m'_j \Big(\sum_i \Big\{ \frac{-1}{(n'-n)} \Big[& (1)^{(i)} \Big(1 - i^2 \sin^2\frac{I}{2}\sin^2\frac{I'}{2}\Big) + \\ & + (2)^{(i)} \Big(\frac{e}{2}\Big)^2 + (3)^{(i)} \Big(\frac{e'}{2}\Big)^2 + (4)^{(i)} \Big(\frac{e}{2}\Big)^4 + \\ & + (5)^{(i)} \Big(\frac{e}{2}\Big)^2 \Big(\frac{e'}{2}\Big)^2 + (6)^{(i)} \Big(\frac{e'}{2}\Big)^4 + (11)^{(i)} \Big(\frac{1}{4}\sin^2 I + \\ & + \frac{1}{4}\sin^2 I' + \frac{1}{16}\sin^4 I + \frac{1}{16}\sin^4 I' - \frac{1}{8}\sin^2 I \sin^2 I'\Big) + \\ & + (12)^{(i)} \Big(\frac{e}{2}\Big)^2 \Big(\frac{1}{4}\sin^2 I + \frac{1}{4}\sin^2 I'\Big) + (13)^{(i)}\Big(\frac{1}{4}\sin^2 I + \\ & + \frac{1}{4}\sin^2 I'\Big) + (17)^{(i)} \Big(\frac{1}{16}\sin^4 I + \frac{1}{16}\sin^4 I' + \\ & + \frac{1}{4}\sin^2 I \sin^2 I'\Big) \Big] \cos[i\lambda' - i\lambda]_{i \neq 0} + \cdots \Big\} + \\ & + \frac{\alpha}{a'} \Big[\frac{-1}{n'-n}\Big(-1 + \frac{1}{2}e^2 + \frac{1}{2}e'^2 + \frac{1}{4}\sin^2 I + \\ & + \frac{1}{4}\sin^2 I'\Big) \cos[\lambda' - \lambda] + \cdots \Big] \Big) \end{aligned} \tag{12}$$

$$
\begin{aligned}
\frac{\partial S_1}{\partial G} = & -\frac{(1-e^2)^{1/2}}{(\tilde{\mu} a)^{1/2}\, e}\left[\sum_j m'_j \left(\sum_i \left\{\frac{1}{i(n'-n)}\cdot\right.\right.\right. \\
& [(2)^{(i)}\left(\frac{e}{2}\right) + (4)^{(i)}\left(\frac{e^3}{4}\right) + (5)^{(i)}\left(\frac{e}{2}\right)\left(\frac{e'}{2}\right)^2 + \\
& + (12)^{(i)}\left(\frac{e}{2}\right)\left(\frac{1}{4}\sin^2 I + \frac{1}{4}\sin^2 I'\right)] \\
& \sin\,[i\lambda' - i\lambda\,]_{i\neq 0} + \cdots\} + \frac{\alpha}{a'}\,\frac{1}{n'-n}\, e\sin\,[\lambda' - \lambda\,] \\
& \left.\left. + \cdots\right)\right] + \frac{1}{\mathrm{tg}\, I\,[\tilde{\mu} a(1-e^2)\,]^{1/2}}\left\{\sum_j m'_j\right. \\
& \left[\sum_i \left(\frac{1}{i(n'-n)}\right.\right.\ \{-(1)^{(i)} i^2 \cdot \sin^2\frac{I'}{2}\sin\frac{I}{2}\cos\frac{I}{2} + \\
& + \sin I\cos I\,[(11)^{(i)}\left(\frac{1}{2} + \frac{1}{4}\sin^2 I - \frac{1}{4}\sin^2 I'\right) + \\
& (12)^{(i)}\,\frac{1}{2}\left(\frac{e}{2}\right)^2 + (13)^{(i)}\,\frac{1}{2}\left(\frac{e'}{2}\right)^2 + (17)^{(i)}\left(\frac{1}{4}\sin^2 I +\right. \\
& \left.\left. + \frac{1}{2}\sin^2 I'\right)]\,\}\sin\,[i\lambda' - i\lambda]_{i\neq 0} + \cdots\right) + \frac{\alpha}{a'}\,\frac{1}{n'-n}\cdot \\
& \left.\left.\frac{1}{2}\sin I\cos I\sin\,[\lambda' - \lambda\,] + \cdots\right]\right\} \qquad (13)
\end{aligned}
$$

Mean elements are finally obtained by inversion of the equations (3).

3. RESULTS

Mean elements for the first 25 numbered asteroids, derived by means of the above described analytical procedure, are shown in Table I together with their osculating counterparts, given for a comparison. Osculating elements are taken from the file supplied by Minor Planet Center (B. G. Marsden), and they refer to the epoch 1987 July 24.0 (JD 2447000.5), and to the ecliptic and equinox 1950.0. Considered are perturbations by Jupiter and Saturn only, and their corresponding osculating elements are taken from Leningrad Ephemerides of Minor Planets for 1987.

Generally speaking, the results behave in the expected manner. By comparing the obtained mean elements with their osculating counterparts, one can easily find that, for example, the amount of the perturbation increases with the distance from the Sun, it is especially large for nearly commensurable objects, etc. The accuracy of these data was investigated by Knežević et al. (1988), who found that the analytical theory of Yuasa, when applied in the completed form, successfully removes the short-periodic perturbations and supplies the asteroid mean elements of very good accuracy. Another proof of this finding is given by the fact that the accuracy of the mean semimajor axis in particular, preserves its high level even for the asteroids of rather high eccentricities and inclinations (Knežević and Jovanović, 1988); hence, one may assume the same for other elements, too.

Bearing in mind that the present theory can be further improved without difficulty, by taking into account other perturbing planets, or by extending the disturbing function development to even higher degree(s), one can state in conclusion that, obviously, by means of the theory of Yuasa we have got an efficient tool for the fast and reliable calculation of the asteroid mean elements, so that their systematic determination should no longer present any problem.

ACKNOWLEDGEMENT

I am grateful to A. Milani for his valuable comments upon the previous version of the paper.

This work bas been supported by Republic Association for Science of Serbia through the project "Physics and Motions of Celestial Bodies and Artificial Satellites".

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Table 1. Osculating and mean elements for the first 25 numbered asteroids.

No	M	ω	Ω	i	e	a
1	114°.84110	72°.25577	80°.03877	10°.60638	.0783549	2.7660676
		71.73760	80.01724	10.59639	.0778597	2.7670930
2	102.76624	309.82937	172.64279	34.80152	.2339951	2.7719664
		309.16670	172.68300	34.84613	.2330977	2.7705520
3	294.39008	246.86321	169.87984	13.00436	.2582769	2.6678762
		247.30630	169.85040	12.99269	.2568815	2.6694030
4	185.64865	150.44170	103.37263	7.14094	.0905112	2.3606659
		151.24110	103.33670	7.13889	.0892928	2.3615130
5	36.88734	356.52589	141.14627	5.36082	.1909920	2.5754824
		356.49000	141.17870	5.35484	.1888872	2.5762670
6	300.27227	238.68057	138.38891	14.78631	.2021706	2.4245143
		238.61680	138.45600	14.76649	.2025089	2.4252830
7	278.20581	144.91414	259.34766	5.51301	.2296491	2.3855029
		144.80890	259.36170	5.51367	.2301391	2.3861080
8	294.69208	285.00949	110.50440	5.89020	.1566114	2.2009840
		285.05870	110.51680	5.88898	.1564878	2.2013990
9	57.32261	4.97883	68.48567	5.58332	.1216851	2.3866299
		5.42157	68.49013	5.58125	.1224882	2.3864260
10	250.70300	316.45437	283.06773	3.83863	.1198966	3.1353905
		320.91200	282.78890	3.83453	.1124366	3.1422410
11	184.53125	193.66409	125.07888	4.62502	.0999911	2.4521990
		192.71670	125.03930	4.63361	.1009577	2.4522370
12	168.38924	68.82732	235.13563	8.37942	.2201410	2.3335028
		68.57369	235.15050	8.37280	.2198887	2.3342610
13	302.48598	80.72353	42.75550	16.51924	.0861999	2.5759917
		80.14167	42.82306	16.51707	.0864410	2.5763200
14	298.58538	95.12505	86.21560	9.11268	.1655777	2.5862488
		95.70988	86.11636	9.12068	.1644507	2.5875810
15	144.73628	97.30863	292.91836	11.75886	.1850393	2.6447013
		97.72799	292.86760	11.74672	.1867459	2.6436780
16	161.30818	227.25911	149.88171	3.09454	.1338453	2.9243840
		227.33110	149.84470	3.09557	.1368757	2.9221640
17	238.52567	135.87582	125.04751	5.59031	.1374942	2.4686126
		137.11110	124.77820	5.60514	.1334673	2.4710220
18	220.63284	227.43704	150.06173	10.13874	.2180635	2.2959543
		227.41020	150.08400	10.13663	.2181022	2.2956270
19	81.49723	181.77813	210.94094	1.57407	.1583294	2.4416627
		181.72100	210.80100	1.56915	.1577805	2.4419880
20	301.44506	254.95503	206.03632	.70660	.1442781	2.4095547
		255.37330	206.05440	.70592	.1438634	2.4086110
21	216.84311	249.48964	80.45079	3.06900	.1610753	2.4363134
		249.34230	80.39392	3.07008	.1625770	2.4352300
22	54.33417	355.12145	65.81391	13.69670	.0979513	2.9101048
		356.74690	65.89480	13.71607	.1005690	2.9098340
23	172.59796	59.38933	66.69464	10.15417	.2310936	2.6277960
		58.76463	66.77198	10.14327	.2324008	2.6278530
24	87.16484	110.65614	35.70144	.75825	.1342630	3.1290823
		106.82640	35.85755	.75821	.1276394	3.1342890
25	337.68327	90.46470	213.70485	21.58911	.2540143	2.4009142
		90.10225	213.76820	21.59468	.2548405	2.4003510

Bull. Obs. Astron. Beograde, N° 139 (1988)

UDC 524.3 (083.8)

ACCURACY OF THE CORRECTIONS DETERMINED FOR FK4 STARS

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(Received: March 10, 1988)

SUMMARY: The results of observations of fundamental stars in series (zones) at he corresponding MC position are presented. The errors are $\epsilon_\alpha \cos\delta = \pm 0^s022$, $\epsilon_{n+m} \cdot \cos\delta = \pm 0^s005$ in the right ascension; $\epsilon_\delta = \pm 0.32$, $\epsilon_{M_0} = \pm 0.08$ in the declination.

1. INTRODUCTION

Differential method observations of two observing programmes

1. Double–Star Programme
2. Programme comprising Observations of Stars situated in the Vicinity of Radio Sources

were carried out with the Meridian Circle in Belgrade between 1981 (1982) and 1987. Since the differential method requires observations of a certain number of fundamental stars, we also observed during the realisation of the two programmes 732 FK4 stars and the total number of observations was 4335. In the case of the Double–Star Programme the measurements were done in zones of 20° within the declination range between −30° and +60°. In the case of the other one the measurements were done over the whole sky. The average duration of observing a series was 4 hours and the total number of the series was 242. Each one contained FK4 stars, between 25% and 30% of the total number of stars, with at least three northern stars of large declinations. The pressure and the temperature of the barometer were always measured at the beginning and at the end of each observational series, whereas the temperature of the air in the pavilion was measured avery 10–15 minutes at two places (north and sourth of the instrument). The length of the time interval between two successive temperature measurements depended on the time distribution of stars within an observational series. The collimation error was generally measured in the middle of a series, though there were some cases of measuring it at the end of a series, whereas the horizontal flexure was always, strictly, measured after finishing a series. The inclination of the instrument was determined twice a month for both positions of the circle on the basis of the readings of the mercury mirror. The Küstner series were regularly observed twice a month-once at CE and once at CW-in order to control the instrument and to determine the flexure. The value of the flexure obtained from the Küstner series observations was compared to thet obtained from the laboratory measurements.

2. REDUCTIONS

The reductions of the observational material were carried out in the right ascension by use of the Bessel formula

$$\alpha_i = T_i + r\sec\delta_i + (u+m)_{m.v} + n_{m.v}\tan\delta_i$$

where is

$$r = c + a\cos\varphi + \frac{\omega}{2}\ ;\ n = \frac{(\alpha_j - T_j) - (\alpha_i' - T_i')}{\tan\delta_j - \tan\delta_i}$$

$$(n+m)_{i,j} = \alpha_{j,i} - T_{j,i} - n\tan\delta_{j,i}\ ,$$

where are

T_i – mean value obtained from 10 contacts;
c – collimation error; a – diurnal aberration constant;
φ – geographic latitude of the MC in Belgrade;
$\frac{\omega}{2}$. – correction for contact width and lost motion of the micrometer

In the declination it is done by use

$$M_i = M + R_\delta m + \Delta\lambda + \rho + f\sin z,$$

where is

$$M_0 = \delta_i \pm M_i \qquad \delta_i' = M_{m.v} \pm M_i$$

M_i – corrected reading of the circle for i-th star;
M – mean value obtained from four microscope-micrometers;
$\Delta\lambda$ – correction of the circle division;
ρ – refraction;
z – zenith distance of a star;
M_0 – equatorial point;
δ_i – declinations of fundamental stars;
$M_{m.v}$ – mean value of the equatorial point obtained from fundamental stars.

The results obtained from the measurements in zones (series) coresponding to certain positions of the circle are presented in Table I and Table II.

The columns of Table I contain: col. 1 – serial number; col. 2 – obesrvational zone; col. 3 – position of the instrument; col. 4 – N_G' (number of upper culminations); col. 5 and 8 – N_α, N_δ (number of fundamental stars within an observational series); col. 6 and

TABLE I

Values obtained from Fundamental–Star Measurements for the Double–Star Catalogue

No	ZONE	CIRCLE	N_G	N_α	ϵ_α	ϵ_{u+m}	N_δ	ϵ_δ	ϵ_{M_0}	B	t_B	t_v
1	20–40	E	–	–	–	–	13	±0.″34	±0.″10	749.7	19.1	-1.8
2	40–60	E	3	14	±0.ˢ027	±0.ˢ007	14	34	9	742.8	20.0	7.3
3	0–20	E	2	5	31	14	5	41	18	747.6	20.2	9.5
4	-20– 0	E	–	–	–	–	19	39	9	739.6	19.0	12.6
5	0–20	E	–	–	–	–	25	37	7	745.5	20.2	13.1
6	20–40	E	–	–	–	–	23	34	7	745.4	20.9	14.7
7	40–60	E	–	–	–	–	14	39	10	745.8	21.2	16.3
8	20–40	E	3	22	23	5	25	38	8	745.6	20.5	15.8
9	0–20	E	2	20	28	6	20	34	8	743.1	21.1	15.1
10	-20– 0	E	4	32	28	5	36	36	6	742.6	21.1	13.2
11	40–60	E	3	10	23	7	11	33	10	737.0	20.2	9.4
12	40–60	E	2	10	26	8	11	35	11	745.0	17.2	6.7
13	-20– 0	W	2	24	28	6	26	35	7	738.8	19.7	12.0
14	20–40	W	4	26	30	6	26	34	7	746.2	21.0	16.3
15	40–60	W	3	23	19	4	24	36	7	747.4	20.6	17.3
16	0–20	W	3	13	36	10	13	40	11	746.1	23.2	21.9
17	-20– 0	W	3	31	28	5	31	38	7	743.6	24.1	21.6
18	-20– 0	E	3	30	31	6	30	40	7	740.6	25.1	24.8
19	0–20	E	4	15	21	5	15	30	8	739.2	26.0	24.0
20	20–40	E	3	18	27	6	18	43	10	743.0	24.0	18.4
21	40–60	E	3	20	28	6	21	35	8	742.8	23.1	20.2
22	-20– 0	W	3	24	25	5	24	34	7	743.6	23.0	16.7
23	-20– 0	E	3	17	25	6	19	40	9	743.8	23.0	19.8
24	0–20	E	4	15	27	7	15	34	9	742.3	22.9	17.0
25	20–40	E	2	14	25	7	14	32	9	742.1	22.8	20.9
26	0–20	W	2	11	40	12	11	32	10	748.3	25.8	27.1
27	20–40	W	2	11	37	11	11	31	9	748.1	26.0	22.6
28	40–60	W	3	8	32	11	8	37	13	745.3	25.1	21.8
29	-20– 0	W	2	15	35	9	15	41	10	743.1	25.3	21.7
30	40–60	E	2	11	25	8	11	43	13	742.5	21.9	18.2
31	20–40	E	1	14	24	6	14	38	10	737.3	21.8	21.6
32	0–20	E	5	15	30	8	15	33	9	745.4	22.0	22.6
33	-20– 0	E	4	20	26	6	20	36	8	741.6	22.2	24.2
34	20–40	E	2	14	24	6	14	36	10	746.4	21.1	18.7
35	40–60	E	4	20	24	5	21	35	8	748.2	20.1	16.2
36	20–40	W	2	14	24	6	14	33	9	744.2	19.0	12.7
37	40–60	W	2	16	26	6	16	40	10	746.2	19.8	11.1
38	20–40	W	4	21	22	5	21	31	7	742.2	17.0	1.4
39	0–20	W	4	14	30	8	14	36	10	745.3	17.1	3.8
40	40–60	W	2	13	19	5	13	27	8	741.9	18.1	8.7
41	-20– 0	W	2	18	30	7	18	36	8	740.5	19.1	8.9
42	-20– 0	E	4	38	21	3	38	28	5	747.1	20.0	11.1
43	0–20	E	2	23	24	5	23	37	8	743.8	20.0	14.7
44	20–40	E	2	18	18	4	18	29	7	743.0	18.3	17.2
45	40–60	E	3	22	24	5	22	37	8	743.3	21.0	18.8
46	0–20	E	3	13	22	6	13	29	8	748.3	22.1	20.9
47	20–40	E	4	16	20	5	16	25	6	743.6	23.2	17.2
48	40–60	W	5	20	18	4	20	35	8	741.5	23.1	21.5
49	-20– 0	W	–	–	–	–	24	29	6	746.3	23.0	20.4
50	0–20	W	3	12	25	7	12	32	9	740.6	21.2	20.4
51	-20– 0	W	3	22	25	5	–	–	–	741.6	22.0	22.5
52	20–40	W	3	13	23	6	13	32	9	746.3	25.0	24.6
53	40–60	W	4	10	18	6	10	38	12	743.1	25.8	25.1
54	0–20	E	1	7	19	7	7	31	12	743.0	22.5	19.2
55	40–60	E	2	6	14	6	6	40	16	742.0	23.1	22.0
56	0–20	E	3	9	20	7	9	26	9	746.2	23.1	20.6
57	20–40	E	3	9	24	8	9	32	11	747.5	21.9	21.2
58	-20– 0	E	4	15	24	6	15	34	9	747.8	22.0	20.5
59	-20– 0	W	4	14	20	5	14	31	8	744.6	22.0	19.7
60	0–20	W	4	12	24	7	12	29	8	744.4	21.2	21.2
61	20–40	W	3	9	22	7	9	28	9	743.0	21.1	18.8
62	40–60	W	3	14	17	4	14	31	8	741.4	18.4	14.4

Table 1 (Continued)

No	ZONE	CIRCLE	N_N	N_α	ϵ_α	ϵ_{u+m}	N_δ	ϵ_δ	ϵ_{Mo}	B	t_B	t_v
63	0–20	W	5	13	±0.ˢ018	±0.ˢ005	13	±0.″30	±0.″08	744.8	21.2	14.9
64	40–60	W	3	14	19	5	14	31	8	744.5	21.8	15.9
65	0–20	W	5	18	19	4	18	31	7	751.8	19.1	9.3
66	-20– 0	W	4	21	21	5	21	33	7	752.2	18.2	8.3
67	0–20	E	6	19	20	5	19	23	5	746.2	19.1	11.0
68	-20– 0	E	4	22	19	4	22	26	6	744.0	20.2	11.2
69	40–60	E	2	20	20	5	20	27	6	749.6	18.1	6.0
70	0–20	E	4	9	17	6	15	29	8	744.1	22.9	12.3
71	20–40	E	1	9	22	7	9	22	7	749.1	18.2	4.2
72	0–20	E	2	10	21	7	–	–	–	740.4	19.2	13.8
73	40–60	E	3	14	22	6	14	32	9	744.2	20.5	18.8
74	0–20	E	2	8	23	8	8	26	9	735.7	19.1	16.0
75	-20– 0	E	2	26	19	4	26	29	6	739.9	20.2	19.2
76	20–40	W	3	19	21	5	19	30	7	740.8	23.2	21.4
77	0–20	W	4	20	22	5	20	27	6	741.2	24.1	21.3
78	40–60	W	4	26	21	4	26	26	5	744.7	21.6	19.5
79	-20– 0	W	1	19	20	5	19	25	6	745.6	22.1	21.5
80	40–60	E	3	11	19	6	11	27	8	744.1	24.0	21.1
81	-20– 0	E	2	21	22	5	21	26	6	743.8	25.0	23.2
82	-20– 0	E	1	15	22	6	15	28	7	748.0	24.0	18.6
83	-20– 0	W	0	8	21	7	8	28	10	743.9	24.0	20.8
84	0–20	W	3	12	16	5	12	25	7	742.5	23.9	21.6
85	20–40	W	2	18	23	5	18	31	7	747.1	20.2	16.8
86	0–20	W	3	19	26	6	19	22	5	741.0	20.9	19.2
87	-20– 0	W	3	21	22	5	21	25	5	749.9	19.0	14.9
88	40–60	E	1	20	16	4	20	26	6	746.7	19.0	16.1
89	20–40	E	0	12	20	6	12	28	8	750.0	19.0	16.8
90	0–20	E	2	14	25	7	14	30	8	747.8	19.1	16.9
91	-20– 0	E	3	11	16	5	11	30	9	747.7	20.1	21.2
92	40–60	W	3	12	25	7	12	30	9	744.2	20.3	18.2
93	20–40	W	3	17	26	6	17	31	7	743.7	20.0	2.4
94	40–60	W	3	16	25	6	16	25	6	740.5	20.6	2.0
95	0–20	W	1	16	22	5	16	23	6	744.8	19.1	-0.1
96	-20– 0	W	2	20	19	4	20	31	7	743.4	21.2	13.9
97	40–60	W	5	16	20	5	16	36	9	737.6	18.2	12.4
98	-20– 0	W	2	21	20	4	22	27	6	736.4	21.0	17.0
99	-20– 0	E	1	6	24	10	6	31	13	740.0	19.6	11.8
100	-20– 0	E	2	20	22	5	20	28	6	737.8	20.3	19.3
101	-20– 0	E	4	14	21	6	14	32	9	748.7	19.1	15.9
102	40–60	E	4	17	18	4	17	28	7	744.8	20.1	19.7
103	0–20	E	4	15	21	5	15	30	8	745.5	20.4	17.2
104	20–40	E	2	11	19	6	11	27	8	739.0	21.2	21.1
105	0–20	W	1	10	18	6	10	32	10	738.6	23.0	22.3
106	0–20	W	1	10	22	7	15	34	9	744.2	20.1	18.5
107	0–20	W	4	15	21	6	15	28	7	744.6	21.2	21.1
108	20–40	W	1	18	22	5	18	24	6	744.6	21.6	23.6
109	20–40	E	4	28	17	3	28	34	6	740.2	23.1	24.5
110	0–20	E	2	19	17	4	18	32	8	738.8	19.4	17.8
111	20–40	E	4	24	24	5	24	31	6	744.4	17.0	13.5
112	40–60	E	2	14	21	6	14	32	9	748.3	17.8	13.7
113	-20– 0	E	2	26	22	4	26	30	6	746.2	18.0	16.1
114	40–60	W	2	18	19	4	18	32	8	745.2	19.0	16.4
115	-20– 0	W	2	26	21	4	26	31	6	746.1	17.8	10.1
116	0–20	W	4	17	18	4	17	30	7	747.1	17.0	1.5
117	20–40	W	3	15	20	5	15	27	7	742.5	17.9	0.0
118	20–40	W	4	22	22	5	22	29	6	748.1	17.6	2.6
119	-20– 0	W	3	20	16	4	20	30	7	745.8	16.7	10.4
120	0–20	W	4	13	21	6	13	32	9	744.1	16.4	-0.5
121	40–60	E	3	23	22	5	23	31	6	747.8	18.4	-1.6
122	0–20	E	2	11	20	6	11	30	9	748.1	17.9	8.1
123	-20– 0	E	2	8	21	7	8	34	12	750.9	18.5	3.0
124	40–60	E	3	19	19	4	19	28	6	743.7	18.0	1.0
125	-20– 0	E	2	23	20	4	23	27	6	742.4	20.9	15.4
126	40–60	E	3	8	23	8	–	–	–	737.6	21.9	18.1
127	20–40	E	3	27	19	4	27	30	6	738.9	19.8	13.9

Table 1 (Continued)

No	ZONE	CIRCLE	N_G	N_α	ϵ_α	ϵ_{u+m}	N_δ	ϵ_δ	ϵ_{Mo}	B	t_B	t_v
128	40–60	W	3	13	±0^{s}016	±0^{s}004	13	±0$''$31	±0$''$09	733.0	20.1	15.5
129	0–20	W	3	23	20	4	23	30	6	741.1	19.1	9.7
130	−20– 0	W	2	12	21	6	12	32	9	741.4	22.2	19.9
131	−20– 0	W	0	12	22	6	12	32	9	740.0	23.0	20.6
132	20–40	W	1	7	20	7	7	33	13	745.3	24.0	22.3
133	20–40	W	2	12	20	6	12	31	9	744.6	21.5	15.9
134	20–40	E	4	18	21	5	18	29	7	747.2	19.1	13.3
135	0–20	E	4	12	21	6	12	30	9	745.8	18.3	11.3
136	40–60	E	2	16	19	5	16	31	8	746.1	19.1	13.4
137	−20– 0	E	2	15	17	4	15	29	7	746.6	21.6	16.0
138	40–60	W	3	24	18	4	24	34	7	751.4	19.4	12.4
139	40–60	E	2	21	20	4	21	28	6	749.9	19.6	16.7
140	0–20	E	1	15	20	5	15	32	8	747.0	20.1	18.4
141	−20– 0	E	4	22	22	5	22	30	6	744.0	20.9	17.1
142	20–40	E	5	28	22	4	28	31	6	746.0	21.0	16.3
143	−20– 0	E	3	21	19	4	21	29	6	753.5	19.1	6.4
144	0–20	E	1	9	22	7	9	29	10	740.8	20.6	6.2
145	20–40	W	4	24	18	4	24	29	6	743.6	19.1	10.3
146	0–20	W	1	4	8	4	4	36	18	744.7	20.0	10.6
147	0–20	W	2	15	23	6	15	30	8	744.3	18.0	10.6
148	40–60	W	2	13	22	6	13	27	7	743.3	18.2	10.2
149	−20– 0	W	4	22	22	5	22	32	7	743.7	18.2	3.9
150	−20– 0	W	4	22	19	4	22	34	7	741.0	17.0	1.1
151	20–40	W	3	18	20	5	18	29	7	733.9	18.0	6.1
152	0–20	W	1	12	20	6	11	28	8	747.7	19.1	4.5
153	20–40	W	–	–	–	–	38	32	5	741.8	20.2	13.8
154	20–40	W	5	23	20	4	23	28	6	741.7	19.0	16.4
155	40–60	W	5	17	21	5	17	38	9	743.1	19.5	18.0
156	−20– 0	W	2	23	22	5	23	33	7	741.7	21.0	20.4
157	20–40	W	1	8	22	8	–	–	–	738.2	21.7	22.9
158	0–20	W	3	17	22	5	17	29	7	740.1	21.0	16.2
159	20–40	W	2	17	22	5	–	–	–	740.6	20.9	16.6
160	−20– 0	E	2	33	20	4	33	33	6	743.3	19.3	15.6
161	40–60	E	6	13	19	5	13	28	8	742.0	20.1	18.3
162	0–20	E	2	15	25	6	15	33	9	748.6	21.9	18.1
163	40–60	E	5	18	20	5	18	27	6	749.6	19.8	7.5
164	20–40	E	4	28	22	4	28	34	7	756.5	16.0	4.1
165	40–60	W	3	9	19	6	9	26	9	754.0	17.0	6.1
166	40–60	W	2	9	21	7	9	27	9	752.1	15.5	−1.1
167	20–40	W	3	14	18	5	14	29	8	750.2	16.1	−0.4
168	−20– 0	W	2	11	22	7	11	39	12	746.6	19.2	−1.3
169	−20– 0	W	1	10	20	6	10	35	11	746.8	19.2	−0.7
170	0–20	W	2	10	18	6	10	32	10	749.9	19.2	0.4
171	−20– 0	E	1	12	18	5	12	29	8	740.2	18.1	5.0
172	−20– 0	E	1	9	22	7	9	34	12	739.3	19.8	11.3
173	20–40	E	4	15	22	6	15	35	9	741.2	19.1	11.0
174	20–40	E	2	13	22	6	–	–	–	743.4	20.6	12.8

TABLE II

Values obtained from Fundamental–Star Measurements for the Catalogue of Stars situated in the Vicinity of Radio Sources

No	CIRCLE	N_G	N_α	ϵ_α	ϵ_{n+m}	N_δ	ϵ_δ	ϵ_{Mo}	B	t_B	t_v
1	W	3	21	±0^{s}027	±0^{s}006	21	±0$''$36	±0$''$08	753.9	19.1	2.5
2	E	3	16	23	6	16	35	9	752.0	19.6	5.3
3	E	3	22	21	5	22	37	8	742.8	20.2	14.7
4	E	5	24	27	5	24	39	8	740.4	18.2	6.6
5	E	1	29	26	5	31	32	6	746.3	22.6	20.9
6	W	6	10	24	8	10	29	9	745.3	24.3	23.1
7	E	7	19	22	5	19	28	6	744.8	23.1	21.5

Table 2 (Continued)

No	CIRCLE	N_G	N_α	ϵ_α	ϵ_{n+m}	N_δ		ϵ_{Mo}	B	t_B	t_v
8	E	5	26	±0ˢ022	±0ˢ004	26	±0.″28	±0.″06	745.4	22.2	19.8
9	W	4	28	19	4	28	33	6	746.0	22.0	21.0
10	W	3	36	22	4	36	28	5	753.2	20.2	12.3
11	E	2	27	20	4	27	33	6	752.2	18.9	10.8
12	E	4	26	21	4	26	31	6	748.0	21.1	8.3
13	E	3	15	22	6	15	27	7	746.1	20.0	17.1
14	E	4	22	22	5	22	27	6	742.0	21.0	20.7
15	W	1	28	21	4	28	31	6	744.6	23.0	21.7
16	W	1	25	22	4	25	26	5	747.0	22.1	14.5
17	E	1	21	19	4	21	30	6	745.8	22.1	18.0
18	E	3	25	21	4	25	25	5	745.5	22.1	20.4
19	E	5	22	19	4	22	28	6	744.9	25.0	23.1
20	W	4	14	17	5	14	32	9	743.9	24.0	19.8
21	W	3	12	16	5	12	25	7	742.5	23.9	20.9
22	E	6	21	24	5	21	31	7	746.8	20.2	15.7
23	E	5	15	25	6	17	29	7	750.0	19.0	16.5
24	E	5	22	26	5	22	33	7	747.8	19.1	17.3
25	W	–	–	–	–	9	36	12	746.0	18.8	13.1
26	W	1	22	26	6	22	27	6	752.8	18.1	1.7
27	W	5	18	22	5	18	31	7	737.2	19.0	9.5
28	W	4	15	20	5	15	33	9	740.9	20.0	11.0
29	W	1	20	21	5	20	33	7	736.0	18.9	15.3
30	E	2	19	22	5	19	26	6	738.6	19.4	15.1
31	E	2	12	25	7	12	23	6	739.7	21.4	21.0
32	W	4	14	18	5	14	26	7	745.3	22.2	22.8
33	W	4	17	19	5	17	31	8	744.8	24.9	27.7
34	W	5	14	21	6	14	35	9	744.6	21.9	21.0
35	W	4	19	24	5	19	32	7	743.0	23.1	19.6
36	E	5	11	16	5	11	28	8	748.0	22.1	19.0
37	E	7	21	21	5	21	29	6	742.8	21.2	20.2
38	W	8	26	18	4	26	33	7	747.0	21.2	13.9
39	E	6	25	24	5	25	33	7	752.1	17.8	12.3
40	E	4	15	20	5	15	26	7	746.0	18.9	15.6
41	W	2	22	25	5	22	30	6	741.8	17.2	10.6
42	W	6	26	22	4	26	26	5	742.8	18.1	11.3
43	W	1	19	18	4	19	32	7	742.1	20.1	7.0
44	E	6	35	19	3	35	29	5	753.0	20.9	4.8
45	E	5	33	20	4	33	33	6	747.0	17.0	4.6
46	E	7	14	23	6	16	33	8	752.3	17.9	2.9
47	W	5	14	23	6	14	32	9	752.0	18.7	2.1
48	W	1	5	21	9	5	35	16	744.0	17.9	5.8
49	E	2	22	20	4	22	29	6	746.5	19.0	2.1
50	E	2	12	19	5	12	31	9	745.8	16.9	2.5
51	W	2	16	20	5	16	32	8	740.0	23.0	20.0
52	W	2	28	22	4	28	33	6	738.4	23.0	19.5
53	E	1	9	15	5	9	29	10	742.1	21.0	21.1
54	E	3	11	20	6	11	32	10	738.0	23.8	23.4
55	W	5	33	21	4	33	30	5	752.6	19.8	12.9
56	E	4	29	20	4	29	29	5	743.3	21.4	15.1
57	E	2	20	20	4	20	26	6	754.0	19.7	4.7
58	W	2	30	18	3	30	32	6	748.9	17.0	10.8
59	W	2	30	22	4	30	29	5	748.6	18.4	10.5
60	W	5	17	16	4	17	34	8	739.8	18.0	7.9
61	W	5	31	22	4	31	32	6	741.9	18.0	12.7
62	W	4	27	21	4	27	28	5	743.7	20.0	18.2
63	W	3	21	18	4	20	36	8	743.8	21.1	16.7
64	E	3	17	27	7	19	32	7	745.5	22.0	20.8
65	E	3	20	20	5	20	38	9	735.1	19.9	15.5
66	W	3	35	20	3	35	34	6	751.3	16.9	7.1
67	W	2	23	18	4	23	32	7	750.8	17.0	6.5
68	W	4	20	20	4	20	29	7	751.6	17.3	5.2
69	W	3	21	18	4	21	30	6	750.5	17.8	7.0
70	E	4	18	23	5	18	29	7	748.7	17.1	4.6
71	E	4	20	19	4	20	30	7	751.1	17.0	6.1
72	E	4	24	24	5	24	34	7	750.8	19.1	11.6

9 – root-mean square errors of determinations of right ascension, i. e. declination; col. 7 and 10 – determination errors (n+m) and M_0; col. 11 – barometer value; col. 12 – barometer temperature; col. 13 – mean value of the air temperature in the pavilion.

The only difference between Table I and Table II is that the later one does not contain the observational zones. The stars situated in the vicinity of radio sources were observed over the whole sky. On the basis of the calculated values presented in Table I and Table II we derive the quantities characterizing the calculated positions of the fundamental stars presented in Tables III–VI.

Tables III and IV contain the following values: col. 1 – observation zones; col. 2 and 7 – number of series observed within the zone; col. 3 and 8 – number of upper culminations within an observational series; col. 4. and 9 – number of fundamental stars within a series; col. 5 and 10 – root-mean square errors of star-position determinations coresponding to clump

TABLE III

Values chracterizing Right–Ascension Observations for Fundamental Stars–Double–Star Programme (DS)

ZONE	n_E	N_G	N_α	ϵ_α	ϵ_{u+m}	n_W	N_G	N_α	ϵ_α	ϵ_{u+m}
$-20^\circ - 0^\circ$	23	3	20	$\pm 0^s.022$	$\pm 0^s.005$	22	2	19	$\pm 0^s.023$	$\pm 0^s.005$
$0^\circ - 20^\circ$	21	3	13	± 0.023	± 0.006	22	3	14	± 0.023	± 0.006
$20^\circ - 40^\circ$	20	3	18	± 0.022	± 0.005	20	3	16	± 0.023	± 0.005
$40^\circ - 60^\circ$	21	3	16	± 0.021	± 0.005	19	3	15	± 0.020	± 0.005

TABLE IV

Values characterizing Declination Observations for Fundamental Stars–DS Programme

ZONE	n_E	N_δ	ϵ_δ	ϵ_{M_0}	n_W	N_δ	ϵ_δ	M_0
$-20^\circ - 0^\circ$	24	20	$\pm 0''.32$	$\pm 0''.07$	22	19	$\pm 0''.32$	$\pm 0''.07$
$0^\circ - 20^\circ$	21	14	± 0.32	± 0.08	22	14	± 0.30	± 0.08
$20^\circ - 40^\circ$	20	18	± 0.33	± 0.08	19	18	± 0.30	± 0.07
$40^\circ - 60^\circ$	21	16	± 0.32	± 0.08	19	15	± 0.32	± 0.08

TABLE V

Values characterizing Obsevations of Fundamental Stars in Right Ascension–Programme of Stars situated in the Vicinity of Radio Source

ZONE	n_E	N_G	N_α	ϵ_α	ϵ_{u+m}	n_W	N_G	N_α	ϵ_α	ϵ_{u+m}
$-10^\circ - 60^\circ$	36	4	21	$\pm 0^s.022$	$\pm 0^s.005$	35	3	22	$\pm 0^s.022$	$\pm 0^s.005$

TABLE VI

Values characterizing Obsevations of Fundamental Stars in Declination – Programme of Stars situated in the Vinicity of Radio Sources

ZONE	n_E	N_δ	ϵ_δ	ϵ_{M_0}	n_W	N_δ	ϵ_δ	ϵ_{M_0}
$-10^\circ - 60^\circ$	36	21	$\pm 0''.30$	$\pm 0''.07$	36	21	$\pm 0''.31$	$\pm 0''.07$

east ant to clump west, respectively; col. 6 and 11 – determination errors (n+m) and M_0 corresponding to clump east and to clump west, respectively.

3. CONCLUSION

On the basis of the observational results presented in Tables III–VI one may conclude that the Meridian Circle of Belgrade Observatory-the errors of the circle--division determination, the value of the screw revolution in the right ascension and declination, the values calculated for refraction, the horizontal flexure, the collimation error–well determined and the instrument, itself, possesses a very high quality. This statement is confirmed by the root-mean-square errors of the positions of the fundamental stars determined in the present paper.

This work been supported by RZNS (Republic Association Community for Science of Serbia) thorugh the project "Physics and Motions of Celestial Bodies and Artificial Satellites".

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APPLICATION OF BROSCHE'S METHOD TO EXAMINATIONS OF COORDINATE DIFFERENCES FOR STARS OF TWO CATALOGUES

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(Received: March 20, 1988)

SUMMARY: A short review concerning the method, it self, is presented, as well as the results obtained from the comparison of the IKŠZ Catalogue with the FK4, N30 and AGK3 ones.

The comparisons of the Derived Catalogue of Latitude Stars (IKŠZ) with the catalogues FK4, N30 and AGK3 are carried out by using Brosche's method (Brosche, 1966). This method takes the dependence of the differences ($\Delta\delta = \delta_{IK\check{S}Z} - \delta_{CAT}$) on both coordinates, α and δ simultaneously. Before the method appeared, the dependence of the systematic part of a difference on the declination f (δ), and f (α) on the right ascension, has been found by averaging the differences within declination zones, i. e. within hour groups, and by applying the formula

$$f(\alpha, \delta) = f(\alpha) + f(\delta)$$

Various authors, among them also Yatskiv (Yatskiv, 1971) have pointed out the arbitrariness in the choice of interval and in the method of smoothing, as wel as the absence of a reliable criterion which makes possible the separation between the systematic and the random components of a star coordinate difference.

The difference field is represented by spherical harmonic functions according to Brosche's method and the order of representation is determined on the basis of the ϑ^2 criterion.

However, one should emphasize that the method can give neither a choice of the criterion as good as possible, nor the estimate of the quality of the terms appearing in the representation through spherical harmonic functions, a priori, but it is of interest to any procedure of determination of the systematic part of the differences in star coordinates contained in catalogues.

The differences of star coordinates contained in two catalogues (i = 1, 2, 3 . . . N), where N is the number of common stars to the catalogues, are denoted as $\Delta\delta_i$. If an observed value depends sistematically only on the star position (α_i, δ_i) on the celestial sphere and has the same mean error and weight, then one cam express it as a sum of spherical function of the form

$$P_{nm}(\delta_i) \sin m\alpha_i \quad \text{and} \quad P_{nm}(\delta_i) \cos m\alpha_i$$

$$\Delta\delta_i = \sum_{n=0}^{p} \sum_{m=0}^{n} (b_{nm} \cos m\alpha_i + b'_{nm} \sin m\alpha_i) P_{nm}(\delta_i) + \epsilon_i$$

where is

p – the largest value appearing in the spherical–function representation;

b_{nm} and b'_{nm} – coefficients;

ϵ_i – residuum of a deviation;

$P_{nm}(\delta)$ – Legendre polinomial.

$$P_{nm}(\delta) = \cos^m\delta \left(\sin^{n-m}\delta - \frac{(n-m)(n-m-1)}{2(2n-1)}\sin^{n-m-2}\delta + \frac{(n-m)(n-m-1)(n-m-2)(n-m-3)}{2\cdot 4\cdot(2n-1)(2n-3)}\sin^{(n-m-4)}\delta + \ldots + \ldots\ldots\right) =$$

$$= \cos^m\delta \left(\sin^k\delta + \sum_{\mu=1}^{[\frac{k}{2}]} \frac{(-1)^\mu \prod_{\nu=0}^{2\mu-1}(k-\nu)}{\prod_{j=1}^{\mu} 2v(2n-2+1)}\right.$$

$$K = n - m$$

$[\frac{k}{2}]$ - the largest integer still possible, equal to, or less than $\frac{k}{2}$. The index n is not limited (n = 1, 2, 3 . . .), whe as m can values only from O to n.

The spherical area represented by harmonic funcions depends mainly on the declinations (δ_i), and right ascensions (α_i) of stars.

To n = m = 0 corresponds $P_{0,0}(\delta_i) = 1$ for m = 0 the corresponding value is

$$P_{nm}(\delta_i)$$

where as the other two functions

$$P_{nm}(\delta_i) \sin m\alpha_i \quad \text{and} \quad P_{nm}(\delta_i) \cos m\alpha_i$$

$m \neq 0$.

Introducing the spherical functions of n–th order $K_{nm}(\alpha_i, \delta_i)$ and a third index **l** we obtain:

$$K_{nml}(\alpha, \delta) = \begin{cases} P_{no}(\delta) & \text{to } m = 0 \\ P_{nm}(\delta) \sin m\alpha & \text{to } m \neq 0 \text{ and } l = 1 \\ P_{nm}(\delta) \cos m\alpha & \text{to } m \neq 0 \text{ and } l = 1 \end{cases}$$

If m = 0 it is assumed $l = 1$, if $m \neq 0$ the corresponding value of l is 0 or 1, depending on the spherical function.

In order to simplify the expression one introduces an abreviating designation

$$j = n^2 + 2m + l - 1$$

and the form of the differences becomes

$$\Delta\delta = \sum_{j=0}^{q} b_j K_j(\alpha_i, \delta_i) + \epsilon$$

The coefficients (b_j) and the residuum amounts of the order of are calculated by using the least-square method.

In order to determine the upper limit „q" of the uniform representation of individual differences of star coordinates in the separation of the systematic part from the random one, the ϑ^2 – criterion based on the comparison of two independent estimates of the disperations δ_1^2 and δ_2^2 of observed values $\Delta\delta_i$, i. e. $\Delta\mu_i$ is used.

The values $\Delta\delta_i$ are considered on the celestial sphere at the points (α_i, δ_i) (where is i = 1, 2, 3, . . . N–N_1 is the number of stars measured) and they possess the following properties:

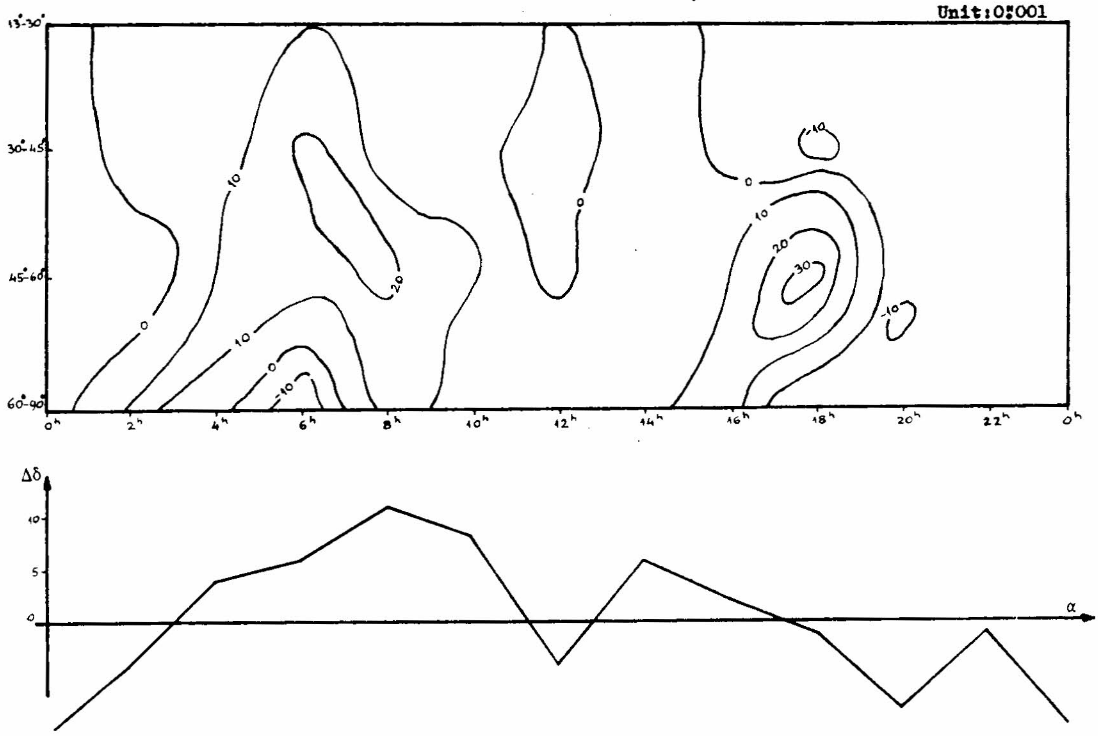
1) they depend systematically on the star positions (α_i, δ_i) on the celestial sphere;
2) they depend systematically on a following variable not coinciding with the position if the first condition is not satisfied;
3) they have the same root-mean square errors which need not be known.

On the basis of the theory presented above a programme for the computer "MINSK 22" is made giving

Systematic differences $\Delta\delta_\alpha = \delta_{IKSZ} - \delta_{FK4}$

Graph.1.

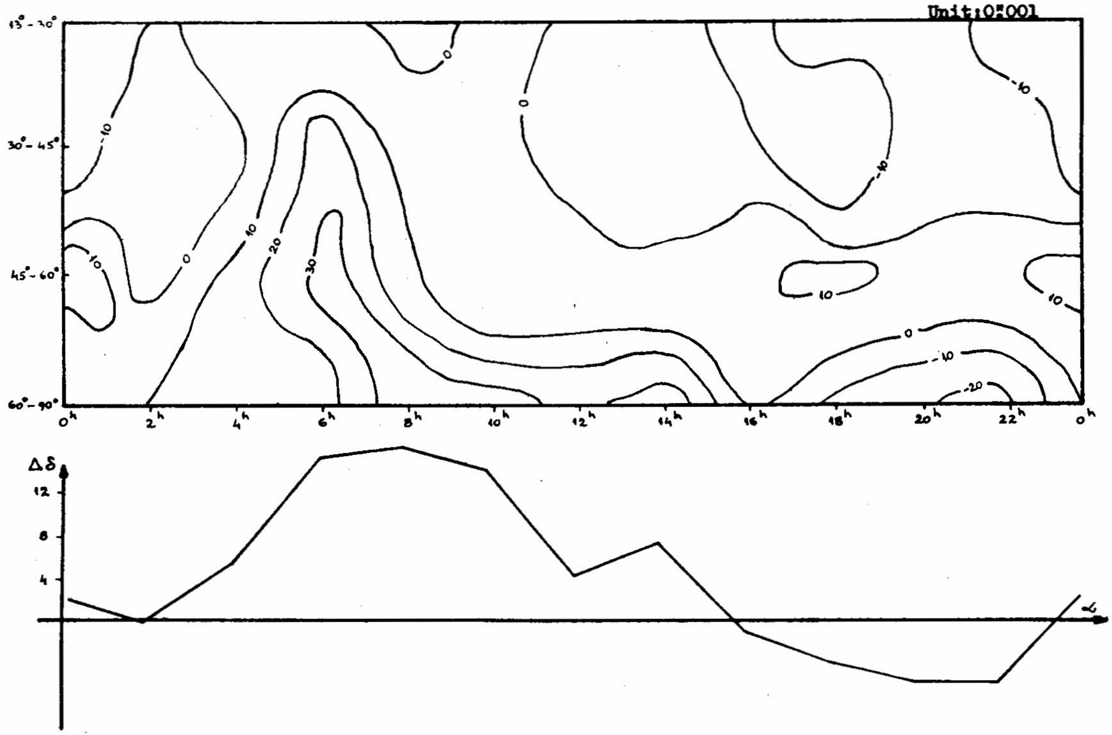
Unit:0.″001



Graph.2.

Systematic differences $\Delta\delta_\alpha = \delta_{inšz} - \delta_{N30}$

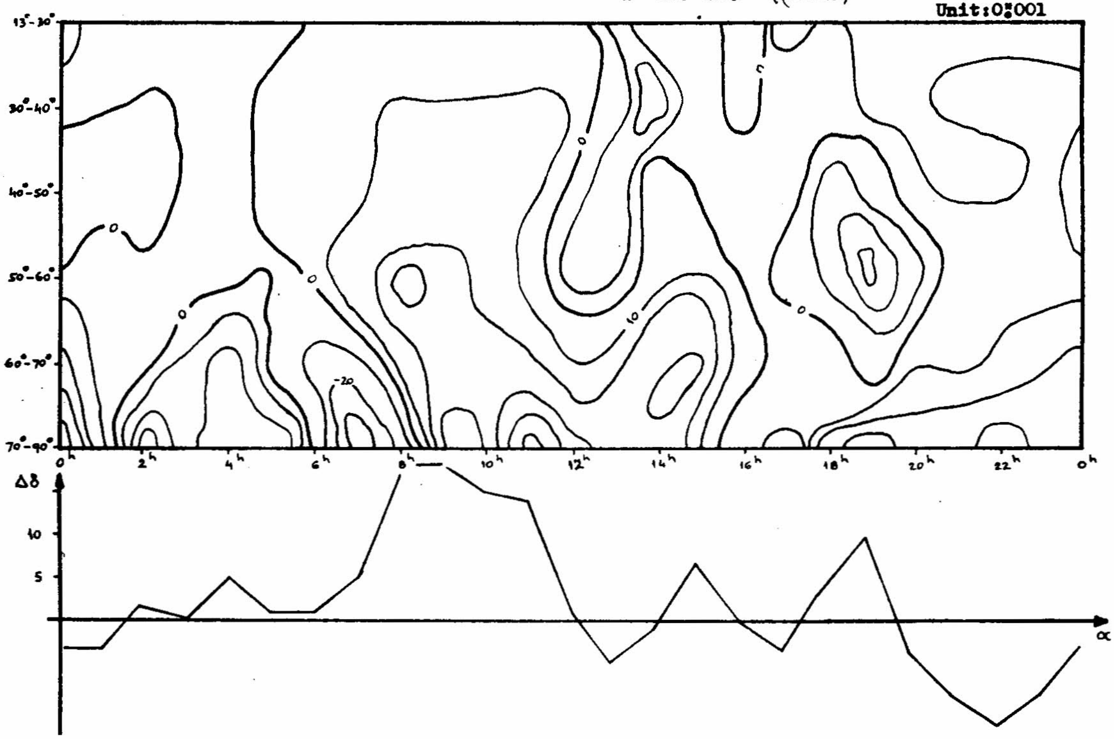
Unit: 0".001



Graph.3.

Systematic differences $\Delta\delta_\alpha = \delta_{inšz} - \delta_{AGK3}$ (α = inšz)

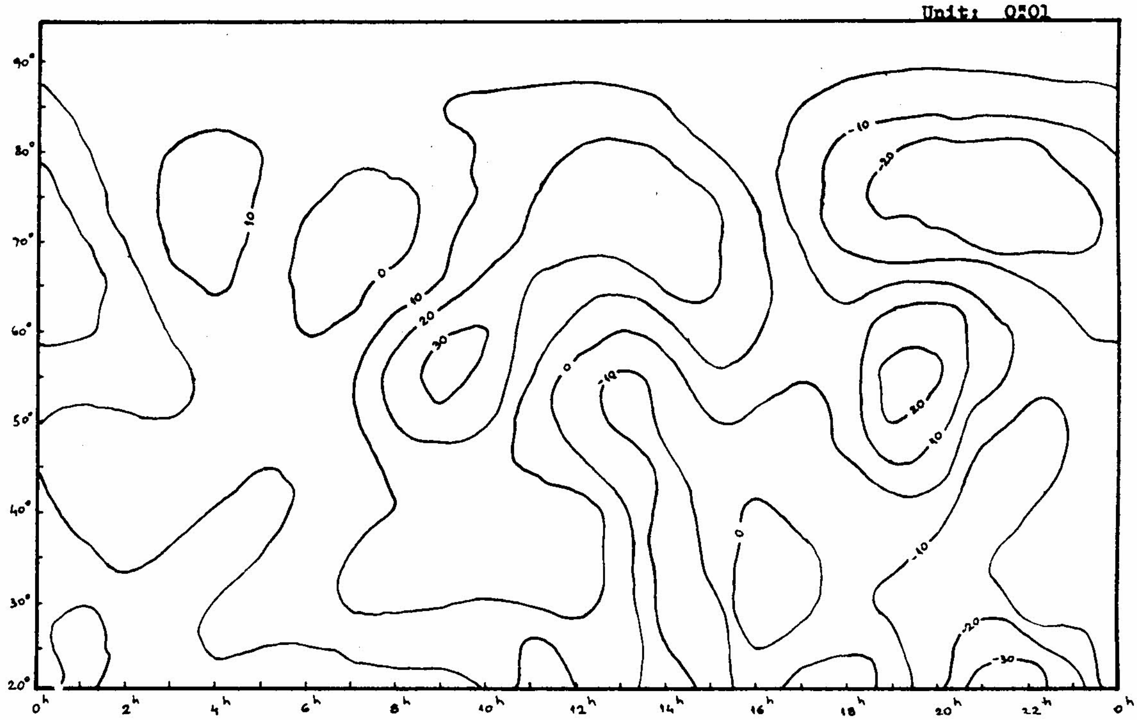
Unit: 0".001



Graph.4.

Systematic differences $\Delta\delta_{\alpha} = \delta_{IKSZ} - \delta_{AGK3}$ (α = AGK3)

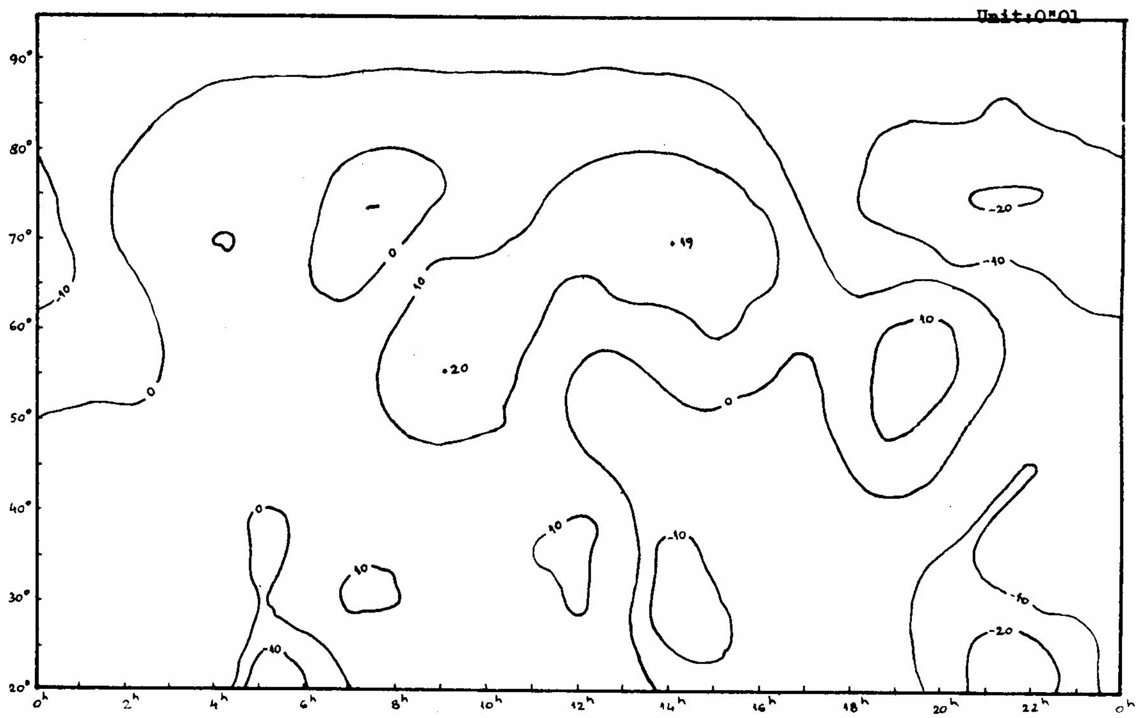
Unit: 0".01



Graph.5.

Systematic differences $\Delta\delta_{\alpha} = \delta_{IKSZ} - \delta_{AGK3}$ (α = IKSZ)

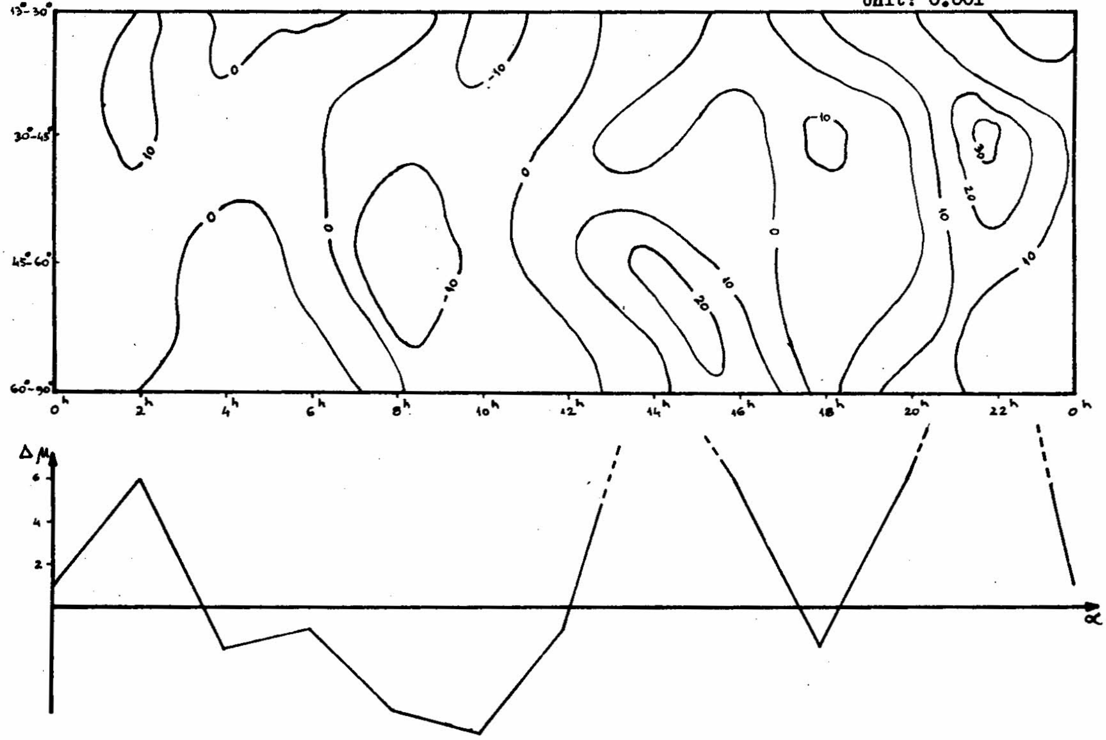
Unit: 0".01



Graph.6

Systematic differences $\Delta\mu_\delta = \mu_{IK62} - \mu_{FK4}$

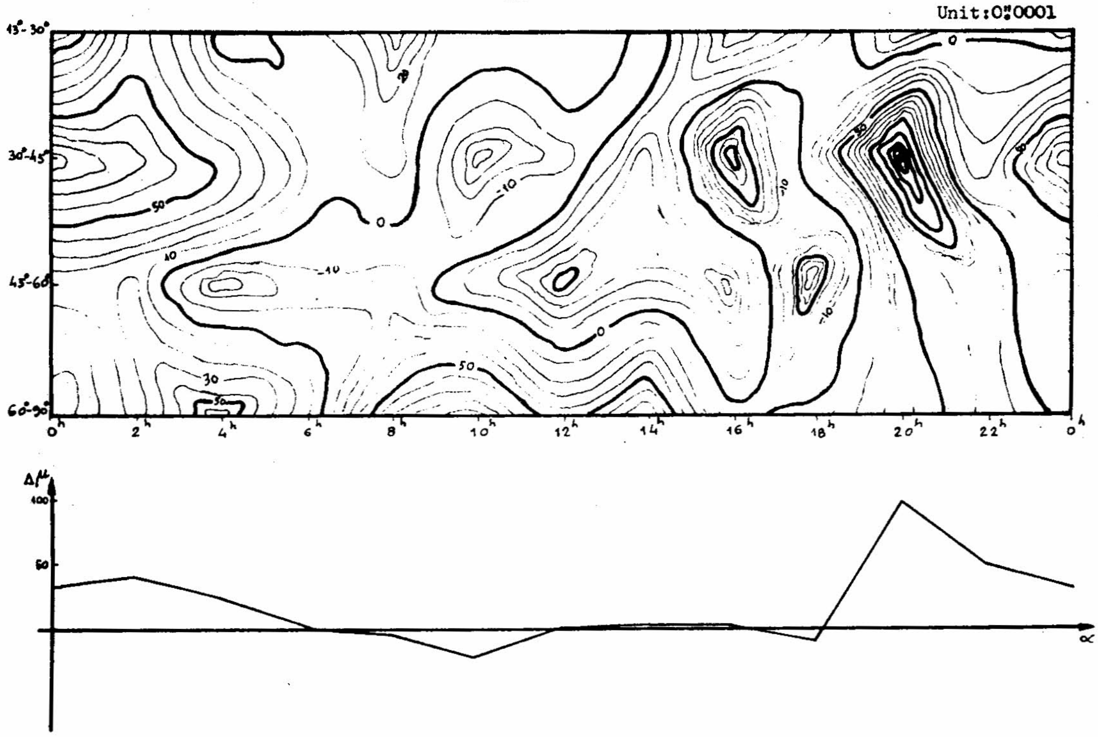
Unit: 0".001



Graph.7.

Systematic differences $\Delta\mu_\delta = \mu_{IK62} - \mu_{N30}$

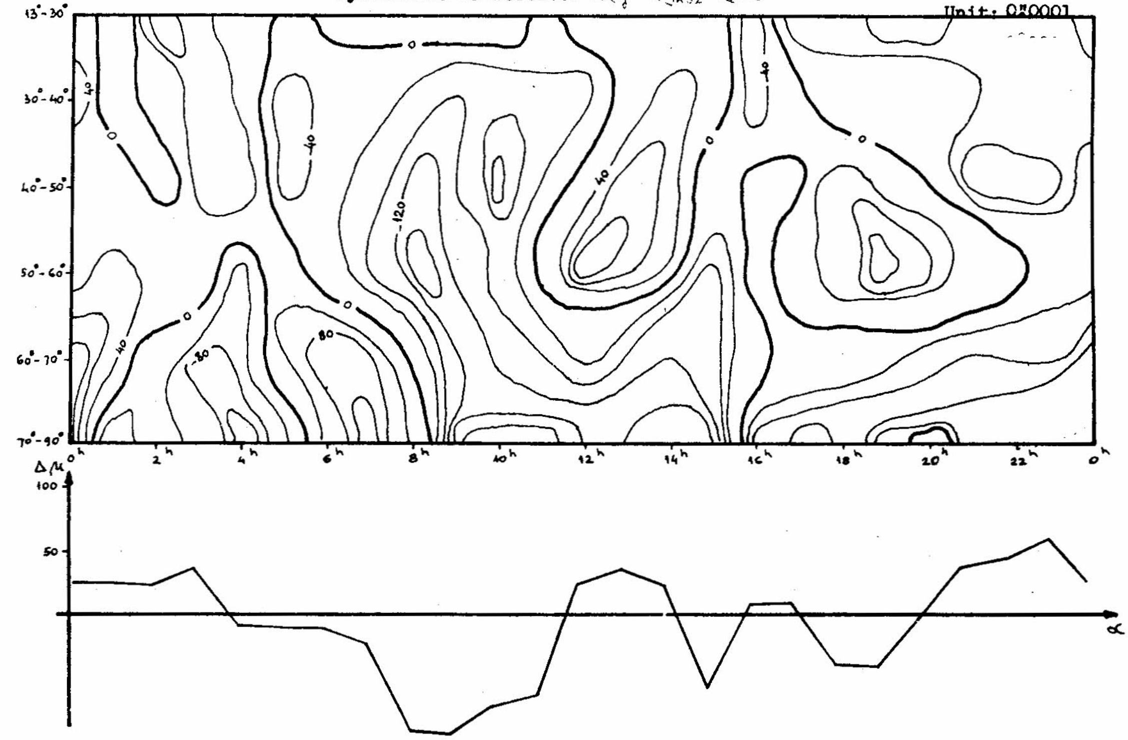
Unit: 0".0001



Graph.8.

Systematic differences $\Delta\mu_{\delta} = \mu_{IKS2} - \mu_{AGK3}$

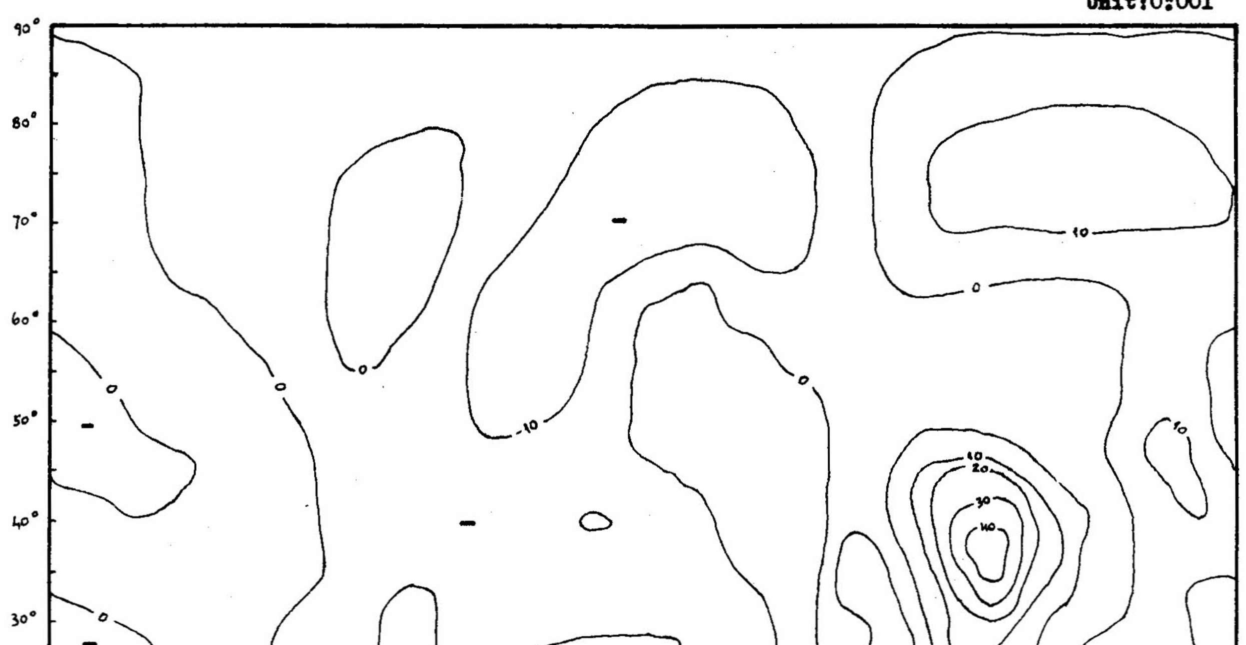
Unit: 0"0001



Graph.9.

Systematic differences $\Delta\mu_{\delta} = \mu_{IKS2} - \mu_{AGK3}$

Unit:0"001



a presentation of the observed difference field $\Delta\delta_i = \delta_{IKŠZ} - \delta_{CAT}$ and $\Delta\mu_i = \mu_{IKŠZ} - \mu_{CAT}$.

The values of Legendre polinoials and of the spherical function of j–th order at the points (α_i, δ_i)–se plots 1–9, the systematic differences of the $\Delta\delta_\alpha$ type-see plots 1–6, the systematic differences of the type $\Delta\mu_\delta$ – see plots 6–9.

On the basis of the results obtained from the comparison of the comparison of the IKŠZ to the catalogues FK4, N30 and AGK3 it is seen that in the declination differences and in those of the proper motions there are opposite signs.

The maximal values in the declinations correspond to the minimal ones in the proper motions along the declination. This circumstance is a reliable indication that the catalogues corresponding to older epoches are not free of systematic errors or the catalogues corresponging to earlier epochs used in the compilation of the IKŠZ affect the latter one by their systematic errors. The small differences between the IKŠZ and the FK4 are due to the proximity of their epochs.

As for the comparison to the AGK3 (with which the IKŠZ has a large number of common sars–3777) we obtain the most probable values, mostly free of systematic errors. Their amounts are not systematically significant but of the order of those obtained from the comparisons to the catalogue N30.

The results of the comparisons for the positions and proper motions of stars in the FK4, N30 and AGK3 in all zones between 13° and 90° and in the time interval between 0^h and 24^h are in favour of the statement that the order of the IKŠZ systematic errors of $\Delta\delta_\alpha$ type is to $\pm0''.02$ and that of $\Delta\mu_\delta$ tupe to $\pm0''.001$.

ACKNOWLEDGEMENTS

This work has been supported by Republik Association for Science of Serbia through the project "Physics and Motions of Celestial Bodies and Artificial Satelites".

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GALACTOCENTRIC ORBIT AND TIDAL RADIUS OF M 22

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(Received: May 13, 1988)

SUMMARY: The globular cluster M 22 (NGC 6656) appears to be in a not very eccentric orbit –e = 0.5 ± 0.2 – especially not highly inclined to the galactic plane –i = 150°± 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.

1. INTRODUCTION

The globular cluster M 22 (NGC 6656) appears to be very metal-poor and very old: [Fe/H] = – 1.9, τ = 14.5 Gyr (Alcaino, Liller, 1983). It is usualy thought that the galactocentric motion of such clusters takes place along very eccentric orbits, highly inclined to the galactic plane, but it seems that the orbits of those metal-poor globulars situated at present in the inner parts of the Galaxy are systematically less eccentric and less inclined to the galactic plane (Ninković, 1983). The latter conclusion was reached by analysing solely one velocity component-that along the line of sight-being usualy the case when the motion of a number of globular clusters is examined. Thefore, it is of interest to verify it in those cases, though very limited in number, when the proper motion of a globular cluster is available. The cases of two distant, metal-poor clusters NGC 5466 (Brosche et al., 1983) and NGC 4147 (Brosche et al., 1985), as well as that of the relatively metal-rich and close to the galactic centre M 71 (Ninković, 1987a), seem to agree well with the present author's conclusion.

2. THEORETICAL BASE

It is assumed to represent the galactic potential by means of an approximative formula instead of using rather complicated functions resulting from a model of the Galaxy. Such a procedure is justified bearing in mind the purpose of the present contribution (see also some of the earlier papers: e. g. Ninković, 1987a) It is assumed that the potential is spherically symmetric, since in such a case there are always four independent, unequivocal, integrals of motion. With regard to the shape of the galactic rotation curve it is assumed that the potential arises form such a density

$$\rho = A\left[\frac{1}{1+\frac{R^2}{R_c^2}} - \frac{1}{1+\frac{R_l^2}{R_c^2}}\right], A, R_c, R_l = \mathrm{const}$$

$$R \leqslant R_l \quad \rho = 0 \quad R > R_l, \tag{1}$$

where R is the distance to the galactic centre. The purpose of introducing the first term within the brackets is to avoid the singularity at the centre and that of introducing the second one to avoid the discontinuity at the boundary. The potential arising from (1) is given by

$$\Pi = 4\pi G\cdot\{AR_c^2[1 + \ln(\frac{R_l^2 + R_c^2}{R^2 + R_c^2})^{1/2} - R_c$$

$$\arctan(R/R_c)/R] - \frac{1}{2}C(R_l^2 - \frac{1}{3}R^2)\}, \tag{2}$$

$$C = \frac{A}{1 + \frac{R_l^2}{R_c^2}}$$

The values of the three constants appearing in (1) and (2) are found by assuming $R_\odot$ = 8.5 kpc (R –distance to the galactic axis of rotation) according to the IAU (Wielen, 1986) and by requiring that the potential at the Sun is equal to 125000 km^2 s^{-2} (the local escape velocity about 500 km s^{-1} according to e. g. Ninković, 1987b, Sandage, Fouts, 1987), that the local circular velocity is equal to 220 km s^{-1} in accordance with the IAU recommendation (Wielen, 1986) and that the local value of the second radial derivative of the potential is about 600 km s^{-2} kpc^{-2} corresponding to an almost flat rotation curve. In such a way one obtains A = 1.04 $M_\odot$ pc^{-3}, R_c = 1.005 kpc, R_l = 51.5 kpc.

3. PROCEDURE

The data about M 22 relevant to a galactocentric orbit determination are taken from Cudworth (1986). At first the phase coordinates in the heliocentric coordinate system x'y'z' are calculated. The directions of the axes are defined as $\vec{e}_{x'}$: l = 0°, b = 0°, $\vec{e}_{y'}$: l = 90°, b = 0°; $\vec{e}_{z'}$: b = 90° ($\vec{e}_i$, i = x', y'z', – unit vector). It is obtained x' = 3.12, y' = 0.545, z' = –0.42 (kpc); $\dot{x}$ = = –168, $\dot{y}'$ = –22, $\dot{z}'$ = –122 (km s^{-1}). Then the coordinates are transformed into the local coordinate system xyz, with respect to the local standard of rest, a fictive point lying in the galactic plane at the distance R = $R_{\odot}$ = = 8.5 kpc from the galactic axis of rotation. It is assumed that the Sun lies 20 pc above the galactic plane (Kulikovskij, 1985) and that its motion with respect to the LSR is given by $\dot{x}_0$ = 10, $\dot{y}_0$ = 16, $\dot{z}_0$ = 8 (km s^{-1}; Harris, Racine, 1979). Thys the phase coordinates of the cluster are x = 3.12, y = 0.545, z = –0.4 (kpc); x = –158, $\dot{y}$ = –6, z = –114 (km s^{-1}). Finally the phase coordinates of the cluster with respect to the galactic centre are obtained: X = –5.38, Y = 0.545, Z = –0.4 (kpc); X = = –158, Y = 214, Z = –114 (km s^{-1}). It is assumed that the X coordinate of the LSR is equal to –8.5 kpc, so that the system XYZ is a right-handed one. It should be noted that the distance of the cluster to the axis of rotation is Q = 5.4 kpc and that to the galactic centre R = 5.42 kpc. The modulus of the galactocentric velocity is equal to 289 km s^{-1}.

The velocity components along the angles ϑ and φ (the same definition as in Ninković, 1987a) are also calculated and in such a way one obtains the velocity components in the galactocentric cylindrical, i. e. spherical frame of reference: $\dot{Q}$ = 179, θ = –197, Z = = –114 (km s^{-1}); R = 187, θ = –197, Φ = –101 (km s^{-1}). The fraction of the kinetic energy per unit mass belonging to the radial component is about 42%. This fact indicates a moderate eccentricity (Ninković, 1986).

Applying the potential (2) to the cluster one obtains the values of the four integrals of motion

inclination of the orbital plane to the galactic one	i = 153°
longitude of the ascending node (in the galactic plane)	ϑ_n = 2°.45
orbital eccentricity	e = 0.54
mean galactocentric distance	$\bar{R}$ = 7.58 kpc.

The latter two quantities yield R_p = 3.46 kpc as the perigalactic distance R_a = 11.69 kpc as the apogalactic one.

The tidal radius of the cluster is calculated by use of the same formula as in Ninković, 1987a. Following Cudworth (1986) it is assumed that the mass-to-lumisity ratio of the cluster is equal to 1 $M_{\odot}/L_{\odot}$, but with regard to the ucertainty and to the point of view widely accepted in the literature according to which the mean value of this ratio is more than 1 $M_{\odot}/L_{\odot}$ for globular clusters (e. g. Illingworth, 1975) the possibility of 2 $M_{\odot}/L_{\odot}$ is also admitted. It is obtained that the luminosity is equal to 1.9x10^5 $L_{\odot}$ on the basis of m_v = 5.07, spectral class F5 (Alcaino, 1977) ang that the corresponding bolometric correction is zero (Kulikovskij, 1985). Thus the use of formula (1) in Ninković, 1987a yields the interval 42–53 pc for the tidal radius of M 22 depending on the mass assumed ((1.9–3.8) x10^5 $M_{\odot}$).

If one admits that the true tidal radius is only 2/3 of that yielded by formula (1) (Ninković, 1987a), as proposed by Keenan (1981), i. e. by Innanen et al. (1983), one obtaines that the coresponding interval of the tidal radius is equal to28–35 pc; in the case that the tidal radius depends on the instantaneous galactocentric distance, as proposed by the present author (Ninković, 1985), the tidal-radius interval would be 68–86 pc.

All these values should be compared to the tidal radius of M 22 found observationally – r_t = 30 pc (Peterson, King 1975), i. e. r_t = 27.5 pc (Kukarkin, Kireeva, 1979). The latter values are recalculated here in order to correspond to the distance of the cluster assumed in the present paper.

4. DISCUSSION

The first question arising in this section is how reliable the present results are. In order to answer it one should estimate the errors of the data. The errors of the basic data have been already estimated (Cudworth, 1986). With regard to the position of the cluster the x–component of its velocity is affected mainly by the uncertainty of the line-of-sight velocity, the y–component by that of the tangential velocity along the galactic longitude and the z–one by the uncertainty of the tangential velocity along the latitude, as easy to see. In such a way the uncertainties of the three galactocentric velocity components are estimated to be ΔX = = ±5 km s^{-1}, ΔY = ±20 km s^{-1}, ΔZ = ±30 km s^{-1}. The uncertainties of the quantities characterizing the galactocentric position and motion of the Sun are not taken into account. Since the distance error is already included in the error of the velocity components and the proper motion error does the decisive influence, the errors of the coordinates are not given separately. Thus one finds the following values for the errors of the integrals of motion Δi = ±20°, $\Delta\vartheta_n$ = ±2°, Δe = ±0.2, $\Delta\bar{R}$ = ±2 kpc.

The uncertainty of the eccentricity is estimated through the unceptainty of the ratio V_R^2/V^2. One should certainly bear in mind the position of the cluster whose consequence is that the radial galactocentric velocity component is almost equal to that along the X–axis, thus its uncertainty being very small.

The orbit obtained in the present paper agrees well with the present author's result (Ninković, 1983) that even the metal-poor globular clusters situated at present in the inner parts of the Galaxy possess significantly less eccentric orbits, less inclined to the galactic plane, than those situated at present sufficiently far from the galactic centre. This is also confirmed by a comparison with the results for NGC 5466 (Brosche et al., 1983) and for NGC 4147 (Brosche et al., 1985). However, one should be cautious in this statement since the proper motions of the latter two globulars were determined by use of a different approach from that used in the case of M 22. One may add the fact that M 22 seems to be in a sufficiently deep potential well and that if the galactic potential were that of a point mass and if the cluster were an escaper, the mass of the Galaxy would be only about $5x10^{10}$ $M_{\odot}$. This value is approximately equal to the mass within the cluster obtained after integrating the density (1) inside the present galactocentric distance of the cluster. Besides, the small minimal apogalactic distance should be mentioned, too. It is estimated here by examinig what would take place if the radial velocity component, being the most accurate in the present case, were the only nonzero one. A value of 7.8 kpc is found. The sine of the inclination angle determines the maximum value of the distance to the galactic plane and this distance should be about 5.3 kpc. However, preliminary calculations show that due to the presence of a flat component in our Galaxy (the disc) which produces a strong gradient of the potential along the Z–axis this value should be reduced by more than 30%. All these facts are in favour of a galactocentric motion significantly different from that of distant globular clusters of a similar chemical composition.

In the case of the tidal radius it appears, as for M 71 (Ninković, 1987a), that the best agreement with the value based observationally is achieved when the tidal radius is calculated according to Keenan (1981), i. e. Innanen et al. (1983). However, one should bear in mind that both clusters are sufficiently close to both galactic plane and galactic centre. In such situations there are serious difficulties with star counts and it is very possible that the tidal radius is underestimated. This possibility is aslo indicated from the well-known fact that the tidal radii of globular clusters belonging to our Galaxy are correlated with their galactocentric distances. In addition, the tidal radius is also mass dependent and therefore the question of the mass uncertainty arises.

It is attempted, just as it was done for M 71, to estimate the mass of M 22 by applying the method proposed by Naumova and Ogorodnikov (for the details see Ninković, 1987a and the references therein). According to Cudworth's (1986) histogram it is estimated that the stars whose membership probilities are between 10% and 90% are of interest to such an attempt. However, the moduli of the velocities of these stars with respect to the cluster are significantly less than the modulus of the cluster velocity with respect to the mean galactocentric velocity at its position. The latter one is found as the difference between the galactocentric velocity of the cluster and the velocity of the galactic rotation at the place of the cluster. Since the velocity of the galactic rotation is almost constant, its value at the cluster is practicaliy equal to the value at the Sun and consequently the modulus of the velocity of the star stream around the cluster should be almost equal to the heliocentric velocity of the cluster found to be 209 km s^{-1} (section 3). Therefore, it is assumed that the velocity of the stream with respect to the cluster is $\sim$10 km s^{-1}; it is found that the excess in the velocity due to the influence of the cluster is a few km s^{-1} and according to Cudworth's statistical parallaxes it is estimated that the chosen stars are $\sim$10 pc distant from the cluster, finally corresponging to a mass of the cluster of about $(5-10)x10^5$ $M_{\odot}$. The latter value corresponds to a mass-to-luminosity ratio of 2.5 – 5 $M_{\odot}/L_{\odot}$, but it is very uncertain and thus one may accept that the agreement with the value assumed above is quite satisfactory.

5. CONCLUSIONS

The galactocentric orbit of the globular cluster M 22 seems not very eccentric and especially not highly inclined to the galactic plane-the orbital eccentricity appears to be 0.5±0.2, the inclination 150° ±20°, the mean galactocentric distance (7.6±2) kpc. This finding agrees well with the present author's conclusion (Ninković, 1983) that the galactocentric motion of those metal-poor globular clusters situated at present in the inner parts of the Galaxy is characterized by relatively moderate orbital eccentricities and by relatively moderate inclinations to the galactic plane.

It is found that the tidal radius of the cluster is within the limits 28 pc and 86 pc depending on the assumed concept and mass of the cluster. The comparison with the tidal radius estimated observationally is in favour of the tidal-radius concept proposed by Keenan (1981), i. e. Innanen et al. (1983), but with regard to the position of the cluster which is close to both galactic centre and galactic plane, it is premature to claim that any serious argument in favour of the latter concept is found.

This work has been supported by RZNS (Republican Community for Science of Serbia) through the project "Physics and Motions of Celestial Bodies and Artificial Satellites".

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BELGRADE PROGRAM FOR MONITORING OF ACTIVITY–SENSITIVE SPECTRAL LINES OF THE SUN AS A STAR II. Selection of Fraunhofer Lines and Begining of a Study of their Long – term Changes

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(Received: July 4, 1988)

SUMMARY: 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 (about 1% in intensity measurements and 5% to 7% in the equivalent widths) have been estimated and research aims for the near future have been pointed out.

1. INTRODUCTION

Besides being an interesting astrophsical object by itself, the Sun has always been a suitable sample and a suport in stellar physics research. The first theories of stellar atmospheres and models of their inner structure were tested on the Sun. Recently, the investigators turn more and more frequently to the Sun looking for some observational facts that can help understanding of the non-thermal stellar phenomena.

A new research field developed in the 70-ties, stellar activity physics where methods similar to those in solar research are applied in investigating the activity phenomena in stars. Although various aspects of activity of the Sun and stars had been known before 70-ties, the corresponding research fields were quite independent.

The solar research was based on the observations of certain photospheric objects (sunspots, faculae) as well as chromospheric (H_α, CaII H and K lines) and coronal features (coronal shapes, X–and radiofrequency radiation). Such observations and the corresponding theoretical studies led to the conclusions about velocity and magnetic field within the convective zone resulting, eventually, in a fast developement of the theory of solar dynamo – one of the most important global phenomena in the Sun.

The approach to the stellar activity cases, where only the integral radiation flux is observable, was (except in the eclipse binaries) entirely different. The last couple of decades, the solar–like activity in stars was studied using CaII emission lines (Wilson, 1978) whose integrated flux was modulated by the presence of spots or other active features. Some changes of spectral line parameters of ions (e. g. CIV, SIV, MgII...) in the UV–region and of coronal X–radiation were also observed. Nevertheless, the observational results showed a convincing analogy of solar and stellar activities.

Unificating the observational approches to the Sun and stars, one can gain some new possibilities in studying the stellar activity. One of ways is to observe the Sun as a star. As a result one can, then, expect some new global data about the Sun with inferences easily transferable to the problem of the active stars.

Such a relation of solar–stellar problems shifted our solar research toward observing and studying long––term changes of solar radiation by means of a set of selected photospheric spectral lines. It has been understood that the spectrophotometry of the integrated solar disk is the best common approach to the Sun and stars. Contemporary high–quality spectral observations of stars in the visual and infrared regions confirm usfulness of the proposed research program.

2. SOME EARLIER RESULTS

Insufficient attention has been paid to the observations of the solar radiation flux within spectral lines. The greatest endeavours of this type are some atlases of solar integrated light (e. g. Beckers et al., 1976; Tousey et al., 1974). These present a very useful base to study solar––stelar relations, especially since the best stellar photoelectrically recorded atlases (e. g. Griffin, 1978, for α Boo, or Griffin and Griffin, 1979, for α CMi) have approached the quality of some older solar atlases (e. g. Minnaert et al., 1940).

One of the suspected time–scales of spectrophotometric changes might be comparable with the period of solar activity cycle. For a long time some spectral lines have been known as good indicators of nonthermal solar and stellar activity. The most prominent and present in almost all stellar spectra are the resonant lines H and K of CaII. They are even taken as a regular measure of stellar activity – something similar to the Wolf's sunspot number (Wilson, 1978).

Monochromatic observations of the solar disk within various spectral lines, even in different parts of the profile of a given line, exhibit great differences in details of the solar surface. For example, chromospheric plages are grighter in the cores of H α and CaII H and K lines, while in the wings of the same lines they are darker than their surrounding. As size and number of such active features change with the solar activity cycle, their intregral contribution to the spectral line formation, when the Sun is observed as a star, will also vary with the same period – what will be reflected in changes of the spectral line profiles. An example of such changes in Ca II K line has been shown in Figure 1 where the line profiles from periods with low and high solar activity have been shown. The emission peaks K_2 are higher during a period of high activity. Even more conspicuous difference has been found in the case of MgII h and k resonant lines (Lemaire and Skumanich, 1973). The depth of formation of the continuum around MgII and k spectral lines during an active stage is closer to the temperature minimum, i. e. the line is partly formed in the chromosphere (Athay, 1981) where the nonthermal processes are more influential than in the photosphere.

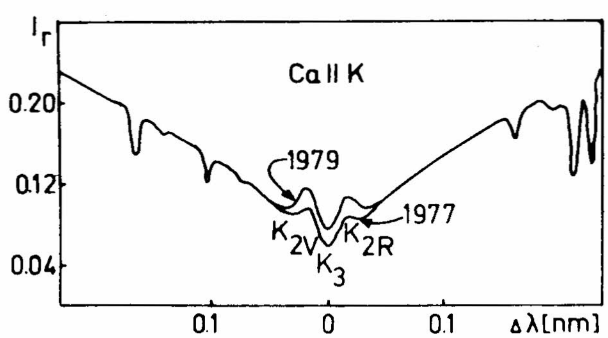

Fig. 1. Emision components, K_{2V} and K_{2R}, of CaII K spectral line profile in the integrated solar light near the activity minimum (1977) and at an active phase (1979), (Athay, 1981).

The photospheric spectral lines, namely those formed mostly within the photosphere, are less sensitive to the solar activity than the choromospheric ones with cores originating above the photosphere. The later are mostly used in watching the solar activity by spectrophotometry. However, the causes of activity are situated in the convective layer more directly influencing the photospheric spectral lines – so that their changes can also yield some informations about the basic activity mechanism.

Kharadze (1935) was, probably, the first investigator who had measured and pointed out some activity–dependent changes of the widths of H α and Hβ spectral line profiles.

Later, Derviz et al. (1961) observing 31 Fraunhofer lines in the period 1951 – 1959, found an activity–dependent increase of the central depth of spectral lines of various origin. No changes of the equivalent widths have been found, however. They secured an integration of the solar radiation from a great part of the solar disk by using an extrafocal image of the Sun.

On the basis of spectral observation of the centre of the solar disk, Mitchell (1969) found a very weak connection of the central intensity in a spectral line with the Wolf sunsport number.

Zhukova i Mitrofanova (1973) established such a dependence for the period 1964 – 1972. However, covering a part of this interval (1969 – 1972), Krat et al. (1975) did not corroborate the results of Zhukova and Mitrofanova.

Studying the Sun as a star at two epoch with different levels of floccular activity and general magnetic field, Stepanjan and Shcherbakova (1979) extracted 63 spectral lines, out of 1000 observed, showing considerable changes of their central depths, half–widths and equivalent widths. 75% of lines from that sample showed an increase, and 25% a decrease of, at least, one of the three observed parameters. The authors' atempt to find a connection of changes of equivalent widths, excitation potential of the lower level of the electronic transitions and the mean optical depths of formation of spectral lines gave no results.

On the basis of the observations from 1969 till 1979. Kokhan (1987) found that the central depth, half– width and equivalent width change in dependence on the solar activity. The most sensitive parameter turn out to be the equivalent width. A certain dependence of all three observed quantities on the excitation potential of lower energetic transition levels has been noticed: the lower the excitation potential, the larger activity–dependent changes of spectral line parameters are.

Theoretical works and model calculations of the heat transfer process from the solar interior show that the presence of magnetic fields in the convective layer depresses convection and decreases luminosity of the Sun. That can be also seen as a changeable asymmetry of special line profiles. For example, the FeI 525.06 nm line in active regions is more symmetric than out of them (Livingston, 1982). The same effect he also found observing the Sun as a star at two different activity phases, Figure 2. However, in this case the asymmetry of the observed spectral line kept decreasing even afer the activity maximum. The phenomenon is explained by the author as a diffusion of local magnetic fields, highly concentrated during the maximum activity phase, to considerably large areas after the maximum. Created in this way, the diffuse, or the general solar magnetic field, disturbs the spectral line symmetry more than the local fields in the active regions.

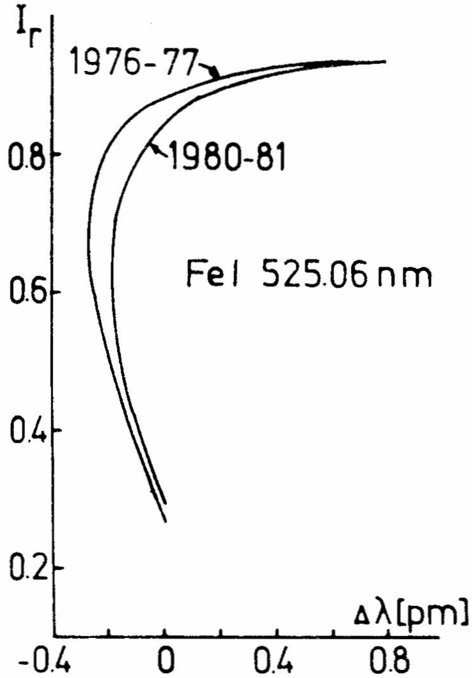

Fig. 2. Bisectors of FeI 525.06 nm in the integrated solar light at minimum (1976–77) and at maximum (1980–81) of solar activity (Livingston, 1982).

A similar conclusion has been derived by Cavallini et al. (1986) on the basis of annual mean values of the observed axymmetries of FeI 629.78 nm, 630.15 nm, and 630.25 nm spectral lines at the center of the solar disk during 1983 and 1984. It should be noticed that these two years belong to the descending phase of a solar activity cycle when the number of tiny magnetic flux tubes, "facular points", varying in antiphase with the sunspot number, increases. Besides, the authors pointed out the increasing of the width of the last two spectral lines, aspecially near the continuum level. This result is in accordance with activity cycle dependence of the line equivalent widths found by Livingston and Holweger (1982).

Calculating the influence of convective motion on the spectral line profiles, Dravins et al. (1981) concluded that the main cause of their asymmetry is a specific distribution of plasma velocities and temperature within the convective cells. A decrease of convective velocity certainly leads to a smaller line profile assymetry.

It should be noticed, however, that a part of the overall asymmetry in some spectral lines may be caused by interatomic collisions of absorbers and perturbing particles (Vince and Dimitrijević, 1986). In such cases a change of plasma parameters will introduce a change in the asymmetry of a spectral line.

The briefly rewiewed results of various authors are very different and some of them are even mutually contradictory. The question of correlation of spectral line parameters with the solar activity has not been finally solved and further studies of variability of Fraunhofer lines can be taken as scientifically interesting.

3. BELGRADE OBSERVATORY PROGRAM

Considering actualness and importance of solar spectral observations, a program aimed at following the long–term changes of equivalent widths, half–widths and central residual intensities of a number of Fraunhofer lines has been established at the solar spectrograph of Belgrade Astronomical Observatory innovated for the purpose (Arsenijević et al., 1988).

Spectral sensitivity of the applied photomultiplier at one side, and the effectiveness of manipulation with the solar scanner at the other side, limit the observable spectral range to a region around 500 nm. Within it, the choice of the spectral lines to be observed was, in general, governed by the following criteria:

1) A possible earlier indication of activity sensitivenes of a spectral line was desirable.

2) The spectral line should have an as blend–free as possible line profile.

3) A well–defined continuum level should be present in the vicinity of a selected spectral line.

4) A large range of atomic parameters (e. g. excitation potential, or magnetic sensitivity) within the entire spectral line sample was needed.

5) The range of photospheric level of formation among various selected spectral lines should be sufficiently large.

6) Different changes of spectral line profiles in sunspot spectra with respect to the photospheric ones had to be represented.

Using these criteria, a working list of 30 selected spectral lines, Table I, has been completed. Here the six columns contain respectively: the element identification of the line, the wavelength, λ, the equivalent width, W, the lower excitation potential, E_p, the magnetic sensitivity Lande factor, g, the indication of the spectral line behaviour in sunspot spectra as taken from Moore et al. (1966) and explained at the bottom of the table, and the corresponding multiplet designation.

Looking at the equivalent widths in Table I, one can see that all selected spectral lines, except the first one, are of a medium strength. The weak lines have been omitted in order to avoid the possible large relative measurement errors. The only one strong line, MgI 518.36 nm, was selected to represent a high level of formation in the photosphere. However, as its wings cover in wavelengths considerably more than the entire field of view, the widths of the line can not be measured.

Table I

The list of spectral lines of Belgrade program for solar activity monitoring

No	Element	λ(nm)	W(nm)	Ep(eV)	g	Spot	Multiplet
1	MgI	518.36	303.0	2.72	–	S	$3\,^3P^o-4\,^3S$
2	FeII	519.76	15.4	3.23	0.700	w	$a^4G-z^4F^o$
3	FeI	519.80	7.1	4.30	–	u	$y\,^5F^o-f\,^5P$
4	FeI	519.87	17.9	2.20	–	s	$a^5P-y\,^5P^o$
5	NiI	519.71	4.8	3.90	–	u	
6	CrII	523.73	9.4	4.07	–	–	
7	ScII	523.98	10.5	1.45	–	–	
8	FeI	525.02	11.6	0.12	3	–	$a\,^5D-z\,^7D^o$
9	CaI	526.17	20.0	2.52	–	s	$3\,^3D-3d4p\,^3F^o$
10	FeI	527.32	19.5	3.29	–	s	
11	FeI	527.34	19.8	2.48	–	u	$a\,^3P-y\,^3D^o$
12	CrI	529.67	17.7	0.98	–	S	
13	CrI	529.74	16.4	2.90	–	s	
14	CrI	529.80	15.7	2.90	–	S	
15	CrI	529.83	20.8	0.98	–	S	
16	CrII	530.59	4.7	3.83	–	w	
17	FeI	530.74	16.6	1.61	–	S	$a\,^3F-z\,^3F^o$
18	TiII	533.68	12.9	1.58	1.071	–	
19	MnI	539.47	7.3	0.0	–	–	
20	FeI	539.83	14.1	4.44	0.333	–	$z\,^5G^o-f\,^5G$
21	FeII	542.53	8.8	3.20	–	w	a^4G-z^4F
22	MnI	543.25	8.5	0.0	–	S	
23	FeI	543.45	34.0	1.01	0	–	$a^5F-z\,^5D^o$
24	FeI	550.68	23.0	0.99	2	S	$a\,^5F-z\,^5D$
25	ScII	552.68	7.6	1.77	1	u	
26	FeI	557.61	11.3	3.43	0	u	$z\,^5F^o-e\,^5D$
27	CaI	558.19	9.1	2.52	1.5	S	$3\,^3D-3d4p\,^3D^o$
28	CaI	560.13	10.0	2.52	–	–	$3\,^1D-3d4p\,^3D^o$
29	NaI	568.26	18.5	2.10	1.067	s	$3\,^2P^o-4\,^2D$
30	NaI	568.82	12.1	2.10	–	S	$3\,^2P^o-4\,^2D$

S – The line is greatly strengthened in the spot spectrum
s – The line is strengthened in the spot spectrum
u – The line is unchanged in intensity in the spot spectrum
w – The line is weakened in the spot spectrum

The depth of the line has to be measured with respect to a near–by continuum level out of the same field of view.

A quite wide range of lower excitation potential, from 0.00 (MnI 539.47 nm) to 4.44 (FeI 539.83 nm) is covered by all the lines in Table I what, at the same time, may offer us a variety of medium photospheric formation levels.

Among the selected spectral lines there are many of them responding very differently to the magnetic field. The line FeI 525.02 nm is of the highest sensitivity, namely g = 3. The other quite sensitive (g = 2) is FeI 550.68 nm, while some other, FeI 543.45 nm and FeI 557.61 nm are insensitive (g = 0). This set of lines may be of interest in the study of the influence of magnetic field on other photospheric parameters governing the formation of spectral lines, especially having in mind their different sensitivity to the temperature changes.

Another aspect of spectral line variability has been taken into account through their sunspot behaviour. The lines change their strength in sunsport spectra with respect to the photospheric ones. Due to the lower temperature and suppressed convection in sunspots, they are stronger, weaker or unchanged, or they may change their profiles. It may be expected that the changeable contribution of these lines in the solar irradiance spectrum might be detected as a time–variability in correlation with the solar activity cycle.

Besides, according to Kokhan and Krat (1981), the spectral line FeI 557.61 nm has a blue satelite line indicating an upward plasma motion from the photosphere. Among the spectral lines in Table I, they also observed the same effect in FeI 530.74 nm line. The time–behaviour of such satelite lines in the integrated photospheric spectrum is not clear yet.

4. THE FIRST ESTIMATION OF THE OBSERVATIONAL ERRORS

During 1986 and 1987, the first spectrophotometric observations were done and some of the corresponding reduction procedures were developed. All the 13 observing days in 1986 were used for technical experimental work, and from 12 days in 1987, six covered the complete run of the selected spectral lines, two were incomplete, and four were also experimental. Some of the results enable us to estimate the quality of the observations.

Due to changes of sky transparency during the scanning runs along the wavelength interval of about 0.2 nm, usually lasting several tens of seconds, the recorded continuum signal can change. Such a remarkable change is shown in Figure 3, where the two successive FeI 526.17 nm records have been overlapped. The difference between the two records is a measure of the instability of the given observing conditions. It can be quantitatively expressed thorugh the standard deviation of a sample of ordinate differences of the two curves. In the considered case the standard deviation amounted to 3.4% of the mean local continuum intensity. We estimate this value as being beyond an acceptable error level in our program. On the other hand, the successive records with the standard deviation of their ordinate differences of about 1% of the mean local continuum are readilly used in further reduction procedures.

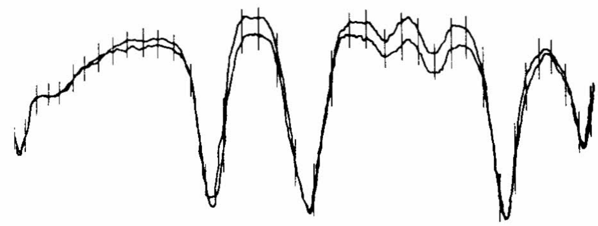

Fig. 3. Two successive records of the solar irradiance spectrum near FeI 526.17 nm in unfavorable observing conditions (unnormalized curves).

A series of reconds of the spectral lines CaI 560.13 nm and FeI 550.68 nm taken in good observing conditions and in a short interval of time, have been compared to estimate an inner error of the obtained equivalent widths. As could be expected, the greatest problem in this kind of measurements is the definition of the local continuum intensity level and the reconstruction of far spectral line wings. Both quantities may be considerably disturbed by the presence of some weak and unresolved spectral lines. The standard deviation of the obtained equivalent widths of the line CaI 560.13 nm is ±7% and of the line FeI 550.68 nm amounts to ±5%. Of course, one would like to have these errors smaller. That can be expected after the introduction of fully automatic or interactive computer determination of the local continuum level – the process now in progress.

Not having the instrumental profile function of the used photoelectric scanner, the errors of the other two parameters to be studied, half–width and depth of the spectral lines, have not been estimated yet.

5. CONCLUSION

The present research program on long–term spectral line changes is not the first one of this sort ever undertaken. There is a need, however, that such a research covers a new solar activity cycle (or, if possible, the whole magnetic cycle) what should include the present sunspot cycle. Also, the spectral line sample is in our case to some extent specific and may open some new questions or offer new solutions.

According to the first estimations of errors and effectiveness of the observations, one can claim that the program has started successfully and at a suitable epoch – the minimum of the solar activity. However, there are some drawbacks, yet:

a) Off–line digitalization of the analog records of spectral line profiles.

b) Incomplete computer reduction procedure concerning the measurements of local continuum level.

c) Lack of the adequate instrumental profile function.

Naturally, these are also the next problems to be urgently solved in the frames of this research program. Some of the solutions are currently considered.

Finally, one can hope that the expected observational results of the present program followed by an adequate theoretical analysis will contribute to a better uderstanding of the nature and global aspects of solar activity.

ACKNOWLEDGEMENTS

This work has been partly supported by Republic Association for Science in Serbia through the project "Physics and Motions of Celestial Bodies and Artificial Satelites".

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COMPARISON BETWEEN DIFFERENT APPROXIMATE APPROACHES FOR THE CALCULATION OF STARK WIDTHS OF DOUBLY – AND TRIPLY–CHARGED ION LINES OF ASTROPHYSICAL IMPORTANCE

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(Received: May 20, 1988)

SUMMARY: Stark widths of spectral lines from 127 astrophysically important multiplets of doubly – and 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, 1988a) derived by using the modified semiempirical method (Dimitrijević and Konjević, 1980).

1. INTRODUCTION

In atmospheres of 0, B and A type stars, and of white dwarfs, where a large number of singly and multiply charged ion lines has been observed (see e. g. Peytremann, 1972, or Lanz et al, 1982), Stark broadening is the dominant pressure broadening mechanism. Even in atmospheres of cooler stars, like our Sun, Stark broadening may be important in line wings or for higher spectral series members (Vince et al, 1985a). Moreover, Stark effect is one of the causes of the stellar spectral line aymmetries (Vince et al, 1985b).

Refined quantum mechanical or semiclassical theories, requiring knowledge of a lot of the atomic data, and time consuming computer codes, are not suitable for large scale calculations when high accuracy of each particular line is not so important and only a reasonable, average accuracy for a number of lines is required. For such purposes, an effort has been made to develop simple approximate formulae with good average accuracy (see e.g. Griem, 1968, Griem, 1974, Hey and Bryan, 1977, Dimitrijević and Konjević, 1980, 1981, 1986, 1987, Dimitrijević and Kršljanin, 1986, Seaton, 1987).

A convenient method for Stark broadening calculations of ion lines, when more sophysticated theories are not needed or not applicable, might be the modified semiempirical approach (Dimitrijević and Konjević, 1980, 1981a, 1987; Dimitrijević and Kršljanin, 1986). This method has been tested several times (Dimitrijević and Konjević, 1981a, b, c; Dimitrijević, 1982a, c, 1983, 1988b, Konjević et al, 1984; Lanz et al, 1988, El–Farra and Hughes, 1983, Ackermann et al, 1985) and on the average it gives a satisfactory agreement with experiments. Recently, the modified semiempirical approach was applied to the Stark broadening of spectral lines from 127 astrophysicaly important multiplets of doubly and triply charged ions (Dimitrijević, 1988a). In this paper calculations for the same 127 multiplets were performed, but using Griem's (1968) semiempirical method, Griem's symplified semiclassical method (1974), and a modified version (Dimitrijević and Konjević, 1980) of this latter one in order to compare the simple approaches to the Stark broadening determination and to provide new data needed in astrophysics.

2. THEORY

According to the Griem's (1968) semiempirical approach, full half–width (FWHM) W of an isolated ion line, is given by the following expression:

$$W = N\frac{8\pi}{3}\frac{\hbar^2}{m^2}\left(\frac{2m}{\pi kT}\right)^{1/2}\frac{\pi}{\sqrt{3}}\left[\sum_{i'}\mathbf{R}^2_{i'i}g\left(\frac{E}{\Delta E_{ii}}\right)+\right.$$

$$\left.+\sum_{f'}\mathbf{R}^2_{f'f}g\left(\frac{E}{\Delta E_{f'f}}\right)\right] \quad (1)$$

Here, i, f and i', f' denote initial and final energy level, as well as their perturbing levels, respectively, $\mathbf{R}^2_{j'j}$ (in units of the Bohr radius a_0) is the square of the coordinate operator matrix element summed over all components of the operator, the magnetic substates of total angular momentum J', and averaged over the magnetic substates of J. $E = 3kT/2$ is the energy of the perturbing electron and $\Delta E_{j'j} = |E_{j'} - E_j|$ is the energy difference between levels j' and j; $g(x) = 0.20$ for $x \leqslant 2$ and $g(x) = 0.24, 0.33, 0.56, 0.98, 1.33$ for $x = 3, 5, 10, 30$ and 100.

If the nearest perturbing level in Eq. (1) is so far from E_i or E_f that the condition $E/\Delta E_{j'j} \lesssim 2$ is satisfied, g becomes a constant (Griem, 1968). Then, the summation in Eq. (1) can be performed straightforwardly, leading to considerable simplification of the

Table 1. Table lists electron impact ful half widths of isolated lines from beryllium through argon at an electron density of 1 x 10^{17} cm^{-3}, and electron temperature from 10000 to 160000 K. Transitions and averaged wavelength for the multiplet (in Angstrom units) are also given. Under W_{SEM} and W_{SE} are given the modified semiempirical results (Dimitrijević, 1988a), and semiempirical results calculated here by using Eq. (2). W_{GM} are semiclassical results obtained by using Eqs. (4–9) with 1.4 instead of 5–4.5/Z on the r.h. s of Eq. (5), and W_G are results obtained by using Eqs. (4–9). The value for 3kT/2ΔE represents the ratio of the thermal electron energy at 10000 K to the energy difference to the nearest perturbing level.

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
BE III $2s\,^1S-2p\,^1P^o$	10000	0.227	0.128	0.197	0.282
	20000	0.160	0.904-1	0.155	0.210
λ=6141.0	40000	0.117	0.711-1	0.131	0.165
3kT/2ΔE=0.64	80000	0.947-1		0.117	0.136
	160000	0.843-1		0.108	0.118
BE III $2s\,^3S-2p\,^3P^o$	10000	0.701-1	0.402-1	0.617-1	0.874-1
	20000	0.496-1	0.284-1	0.471-1	0.644-1
λ=3721.8	40000	0.351-1	0.201-1	0.383-1	0.493-1
3kT/2ΔE=0.39	80000	0.263-1	0.175-1	0.333-1	0.399-1
	160000	0.221-1		0.304-1	0.342-1
BE III $2p\,^1P^o-3d\,^1D$	10000	0.883-2		0.112-1	0.126-1
	20000	0.732-2		0.931-1	0.101-1
λ=746.2	40000	0.599-2		0.797-2	0.836-2
3kT/2ΔE=12	80000	0.591-2		0.698-2	0.717-2
	160000	0.481-2		0.625-2	0.633-2
BE III $2p\,^3P^o-3d\,^3D$	10000	0.559-2		0.809-2	0.945-2
	20000	0.449-2		0.650-2	0.731-2
λ=675.6	40000	0.370-2		0.548-2	0.594-2
3kT/2ΔE=3.4	80000	0.309-2		0.482-2	0.506-2
	160000	0.312-2		0.439-2	0.451-2
B III $2s\,^2S-2p\,^2P^o$	10000	0.191-1	0.115-1	0.176-1	0.244-1
	20000	0.135-1	0.815-2	0.131-1	0.178-1
λ=2066.3	40000	0.953-2	0.576-2	0.103-1	0.134-1
3kT/2ΔE=0.22	80000	0.674-2	0.408-2	0.867-2	0.106-1
	160000	0.516-2		0.778-2	0.892-2
B III $2p\,^2P^o-3d\,^2D$	10000	0.558-2		0.811-2	0.946-2
	20000	0.449-2		0.650-2	0.732-2
λ=677.1	40000	0.370-2		0.547-2	0.594-2
3kT/2ΔE=3.3	80000	0.308-2		0.480-2	0.505-2
	160000	0.310-2		0.437-2	0.450-2

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
B III $4p\,^2P^o$-$5d\,^2D$	10000	10.1		6.72	7.74
	20000	8.46		6.08	6.62
λ =4243.6	40000	6.92		5.39	5.66
3kT/2ΔE= 390.	80000	5.84		4.66	4.79
	160000	4.83		3.96	4.02
B III $4d\,^2D$-$5f\,^2F^o$	10000	12.9		7.62	8.15
	20000	10.0		6.76	7.00
λ =4487.5	40000	8.01		5.86	5.96
3kT/2ΔE= 1000.	80000	6.46		4.96	5.01
	160000	5.20		4.15	4.17
B IV $2s\,^3S$-$2p\,^3P^o$	10000	0.269-1	0.136-1	0.201-1	0.316-1
	20000	0.190-1	0.958-2	0.150-1	0.228-1
λ =2823.4	40000	0.134-1	0.678-2	0.117-1	0.169-1
3kT/2ΔE=0.29	80000	0.966-2	0.513-2	0.986-2	0.131-1
	160000	0.767-2		0.886-2	0.107-1
B IV $2s\,^3S$-$3p\,^3P^o$	10000	0.665-3	0.353-3	0.729-3	0.963-3
	20000	0.496-3		0.587-3	0.734-3
λ =344.2	40000	0.403-3		0.502-3	0.589-3
3kT/2ΔE=2.1	80000	0.343-3		0.449-3	0.497-3
	160000	0.295-3		0.412-3	0.436-3
C III $2p\,^3P^o$-$3s\,^3S$	10000	0.344-2	0.184-2	0.314-2	0.463-2
mult. 5UV	20000	0.243-2	0.130-2	0.244-2	0.344-2
λ =538.2	40000	0.172-2	0.920-3	0.203-2	0.267-2
3kT/2ΔE=0.48	80000	0.139-2		0.180-2	0.218-2
	160000	0.121-2		0.167-2	0.189-2
C III $2p\,^3P^o$-$3d\,^3D$	10000	0.199-2	0.128-2	0.306-2	0.357-2
mult. 6UV	20000	0.141-2	0.907-3	0.236-2	0.269-2
λ =459.6	40000	0.109-2		0.193-2	0.213-2
3kT/2ΔE= 1.0	80000	0.891-3		0.167-2	0.178-2
	160000	0.748-3		0.153-2	0.159-2

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
C III $3s\,^3S-3p\,^3P^o$	10000	0.523	0.263	0.410	0.642
mult. 1	20000	0.370	0.187	0.329	0.482
λ =4648.8	40000	0.274		0.283	0.379
3kT/2ΔE=1.0	80000	0.229		0.256	0.313
	160000	0.203		0.239	0.271
C III $3s'\,^1P^o-3p'\,^1D$	10000	0.486	0.230	0.377	0.589
mult. 7	20000	0.346	0.167	0.314	0.451
λ =4326.0	40000	0.280		0.281	0.363
3kT/2ΔE=1.1	80000	0.249		0.260	0.307
	160000	0.223		0.243	0.268
C III $3p\,^1P^o-3d\,^1D$	10000	0.736	0.410	0.716	0.991
mult. 2	20000	0.521	0.290	0.564	0.745
λ =5696.0	40000	0.384		0.474	0.588
3kT/2ΔE=0.89	80000	0.315		0.422	0.489
	160000	0.279		0.390	0.427
C III $3p\,^1P^o-4d\,^1D$	10000	0.185		0.180	0.233
	20000	0.160		0.158	0.189
λ =1531.8	40000	0.139		0.142	0.159
3kT/2ΔE=6.9	80000	0.125		0.128	0.137
	160000	0.115		0.115	0.120
C III $3d\,^1D-4f\,^1F^o$	10000	0.184		0.258	0.294
	20000	0.147		0.209	0.231
λ =2162.9	40000	0.120		0.177	0.190
3kT/2ΔE=6.9	80000	0.106		0.156	0.162
	160000	0.964-1		0.141	0.145
C III $4p\,^3P^o-5d\,^3D$	10000	3.33		2.83	3.80
mult. 10	20000	2.95		2.54	3.10
λ =3609.3	40000	2.64		2.31	2.62
3kT/2ΔE=8.3	80000	2.26		2.08	2.24
	160000	2.04		1.86	1.94

nued)

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
C III $4f\,^1F^o-5g\,^1G$	10000	1.53		2.42	2.68
	20000	1.26		1.97	2.12
λ=4187.0	40000	1.07		1.67	1.76
3kT/2ΔE=77	80000	1.02		1.47	1.51
	160000	0.981		1.34	1.36
C IV $2s\,^2S-2p\,^2P^o$	10000	0.728-2	0.383-2	0.570-2	0.873-2
mult. 1UV	20000	0.515-2	0.271-2	0.417-2	0.627-2
λ=1549.1	40000	0.364-2	0.192-2	0.318-2	0.460-2
3kT/2ΔE=0.16	80000	0.258-2	0.135-2	0.257-2	0.350-2
	160000	0.187-2	0.107-2	0.224-2	0.281-2
C IV $2s\,^2S-4p\,^2P^o$	10000	0.295-2		0.232-2	0.354-2
mult. 3UV	20000	0.250-2		0.202-2	0.277-2
λ=244.9	40000	0.218-2		0.183-2	0.227-2
3kT/2ΔE=5.2	80000	0.188-2		0.169-2	0.193-2
	160000	0.176-2		0.156-2	0.168-2
C IV $2p\,^2P^o-3s\,^2S$	10000	0.227-2	0.949-3	0.164-2	0.278-2
mult. 6UV	20000	0.161-2	0.671-3	0.128-2	0.204-2
λ=419.6	40000	0.116-2	0.509-3	0.107-2	0.156-2
3kT/2ΔE=0.61	80000	0.936-3		0.954-3	0.125-2
	160000	0.829-3		0.896-3	0.107-2
C IV $2p\,^2P^o-3d\,^2D$	10000	0.106-2		0.139-2	0.173-2
	20000	0.811-3		0.108-2	0.129-2
λ=384.1	40000	0.656-3		0.886-3	0.101-2
3kT/2ΔE=2.2	80000	0.538-3		0.769-3	0.842-3
	160000	0.440-3		0.702-3	0.740-3
C IV $2p\,^2P^o-4d\,^2D$	10000	0.598-2		0.449-2	0.536-2
mult. 9UV	20000	0.503-2		0.397-2	0.445-2
λ=289.2	40000	0.416-2		0.352-2	0.377-2
3kT/2ΔE=110.	80000	0.338-2		0.309-2	0.321-2
	160000	0.286-2		0.270-2	0.276-2

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
C IV $3s\,^2S-3p\,^2P^o$	10000	0.776	0.320	0.495	0.880
mult. 1	20000	0.571		0.402	0.656
λ=5804.9	40000	0.440		0.352	0.511
3kT/2ΔE=2.2	80000	0.368		0.325	0.419
	160000	0.325		0.307	0.359
C IV $4d\,^2D-5f\,^2F^o$	10000	2.16		1.24	1.38
mult. 14UV	20000	1.75		1.12	1.18
λ=2524.4	40000	1.40		0.983	1.01
3kT/2ΔE=1000.	80000	1.11		0.847	0.860
	160000	0.889		0.719	0.724
N III $2p\,^2P^o-3s\,^2S$	10000	0.202-2	0.108-2	0.185-2	0.272-2
mult. 4UV	20000	0.143-2	0.801-3	0.143-2	0.201-2
λ=452.1	40000	0.101-2		0.118-2	0.155-2
3kT/2ΔE=1.1	80000	0.783-3		0.104-2	0.127-2
	160000	0.681-3		0.959-3	0.109-2
N III $2p\,^2P^o-3d\,^2D$	10000	0.130-2	0.832-3	0.200-2	0.235-2
mult. 5UV	20000	0.922-3	0.588-3	0.152-2	0.175-2
λ=374.4	40000	0.652-3	0.416-3	0.121-2	0.137-2
3kT/2ΔE=0.48	80000	0.501-3		0.104-2	0.113-2
	160000	0.413-3		0.947-3	0.100-2
N III $3s\,^4P^o-3p\,^4D$	10000	1.30		2.34	2.47
mult. 3	20000	1.09		1.94	2.02
λ=4517.3	40000	0.967		1.65	1.70
3kT/2ΔE=6.6	80000	0.968		1.44	1.46
	160000	0.946		1.29	1.30
N III $3s\,^4P^o-3p\,^4P$	10000	0.399	0.121	0.188	0.292
mult. 5	20000	0.167	0.853-1	0.149	0.218
λ=3367.3	40000	0.121		0.127	0.170
3kT/2ΔE=0.81	80000	0.984-1		0.114	0.140
	160000	0.863-1		0.106	0.121

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
N III $3p\,^2P^o-3d\,^2D$	10000	0.415	0.236	0.413	0.565
mult. 2	20000	0.294	0.167	0.319	0.421
λ =4640.6	40000	0.208	0.118	0.263	0.328
3kT/2ΔE=0.48	80000	0.163		0.230	0.270
	160000	0.139		0.212	0.235
N III $3p\,^4D-3d\,^4F^o$	10000	0.435	0.241	0.430	0.588
mult. 9	20000	0.307	0.171	0.333	0.439
λ =4864.9	40000	0.218	0.121	0.275	0.342
3kT/2ΔE=0.51	80000	0.173		0.241	0.282
	160000	0.147		0.222	0.245
N III $3d\,^4P^o-4f\,^4D$	10000	0.171		0.246	0.285
mult. 29UV	20000	0.141		0.200	0.223
λ =2063.8	40000	0.116		0.169	0.183
3kT/2ΔE=5.0	80000	0.976-1		0.149	0.156
	160000	0.944-1		0.136	0.140
N IV $2p\,^1P^o-3d\,^1D$	10000	0.780-3	0.459-3	0.999-3	0.127-2
mult. 10UV	20000	0.552-3	0.324-3	0.746-3	0.928-3
λ =335.0	40000	0.390-3	0.229-3	0.585-3	0.705-3
3kT/2ΔE=0.42	80000	0.290-3	0.206-3	0.491-3	0.567-3
	160000	0.232-3	0.226-3	0.445-3	0.490-3
N IV $2p\,^3P^o-3d\,^3D$	10000	0.471-3	0.284-3	0.649-3	0.795-3
mult. 5UV	20000	0.333-3	0.201-3	0.490-3	0.587-3
λ =283.5	40000	0.244-3	0.166-3	0.389-3	0.450-3
3kT/2ΔE=0.74	80000	0.194-3		0.330-3	0.367-3
	160000	0.160-3		0.300-3	0.320-3
N IV $3s\,^3S-3p\,^3P^o$	10000	0.213	0.906-1	0.135	0.242
mult. 1	20000	0.151	0.641-1	0.105	0.177
λ =3480.8	40000	0.108	0.499-1	0.869-1	0.134
3kT/2ΔE=0.74	80000	0.837-1		0.776-1	0.107
	160000	0.715-1		0.728-1	0.898-1

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
N IV $3p\,^3P^o-3d\,^3D$	10000	0.735	0.353	0.588	0.904
mult. 4	20000	0.520	0.250	0.454	0.666
λ=7117.0	40000	0.379	0.211	0.373	0.509
3kT/2ΔE=0.74	80000	0.304		0.329	0.411
	160000	0.259		0.305	0.352
O III $3s\,^3P^o-3p\,^3D$	10000	0.230	0.122	0.183	0.283
mult. 2	20000	0.163	0.863-1	0.142	0.209
λ=3762.3	40000	0.115	0.641-1	0.118	0.161
3kT/2ΔE=0.63	80000	0.866-1		0.104	0.131
	160000	0.742-1		0,967-1	0.112
O III $3s\,^3P^o-3p\,^3S$	10000	0.185	0.981-1	0.148	0.229
mult. 3	20000	0.131	0.694-1	0.115	0.169
λ=3326.6	40000	0.925-1	0.514-1	0.952-1	0.130
3kT/2ΔE=0.63	80000	0.697-1		0.844-1	0.106
	160000	0.598-1		0.782-1	0.908-1
O III $3s\,^3P^o-3p\,^3P$	10000	0.158	0.839-1	0.127	0.197
mult. 4	20000	0.112	0.594-1	0.985-1	0.146
λ=3041.5	40000	0.792-1	0.440-1	0.821-1	0.112
3kT/2ΔE=0.63	80000	0.600-1		0.728-1	0.912-1
	160000	0.515-1		0.675-1	0.782-1
O III $3s\,^5P-3p\,^5D^o$	10000	0.223	0.118	0.177	0.275
mult. 21	20000	0.158	0.836-1	0.138	0.203
λ=3706.1	40000	0.112	0.591-1	0.114	0.157
3kT/2ΔE=0.39	80000	0.841-1	0.513-1	0.101	0.127
	160000	0.722-1		0.939-1	0.109
O III $3s\,^5P-3p\,^5S^o$	10000	0.126	0.673-1	0.103	0.158
mult. 22UV	20000	0.891-1	0.476-1	0.796-1	0.117
λ=2678.2	40000	0.630-1	0.337-1	0.660-1	0.901-1
3kT/2ΔE=0.46	80000	0.479-1		0.585-1	0.732-1
	160000	0.410-1		0.542-1	0.628-1

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
O III $3p\,^3S-3d\,^3P^o$	10000	0.171	0.103	0.181	0.241
mult. 12	20000	0.121	0.726-1	0.138	0.179
λ=3127.3	40000	0.854-1	0.514-1	0.112	0.138
3kT/2ΔE=0.36	80000	0.626-1	0.417-1	0.966-1	0.113
	160000	0.515-1		0.885-1	0.984-1
O III $3p\,^3P-3d\,^3D^o$	10000	0.245	0.144	0.252	0.339
mult. 14	20000	0.173	0.102	0.193	0.252
λ=3712.5	40000	0.122	0.719-1	0.157	0.195
3kT/2ΔE=0.39	80000	0.907-1	0.625-1	0.136	0.160
	160000	0.753-1		0.125	0.139
O III $3p\,^3D-3d\,^3F^o$	10000	0.178	0.103	0.186	0.249
mult. 8	20000	0.126	0.728-1	0.142	0.185
λ=3265.9	40000	0.891-1	0.515-1	0.116	0.143
3kT/2ΔE=0.43	80000	0.668-1		0.101	0.117
	160000	0.556-1		0.922-1	0.102
O III $3p\,^5D^o-3d\,^5F$	10000	0.196	0.113	0.204	0.273
mult. 25	20000	0.139	0.800-1	0.156	0.202
λ=3453.0	40000	0.982-1	0.566-1	0.126	0.157
3kT/2ΔE=0.39	80000	0.727-1	0.480-1	0.109	0.128
	160000	0.601-1		0.100	0.111
O III $3d\,^3P^o-4p\,^3S$	10000	0.321	0.171	0.300	0.437
mult. 20UV	20000	0.227	0.121	0.240	0.330
λ=2601.6	40000	0.175		0.203	0.260
3kT/2ΔE=0.95	80000	0.150		0.181	0.215
	160000	0.137		0.167	0.187
O III $3d\,^1F^o-4p\,^1D$	10000	0.356	0.179	0.333	0.483
mult. 21UV	20000	0.262	0.148	0.272	0.369
λ=2558.1	40000	0.215		0.236	0.295
3kT/2ΔE=1.5	80000	0.189		0.213	0.247
	160000	0.173		0.196	0.215

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
O IV $2p\,^2P^o-3s\,^2S$	10000	0.596-3	0.270-3	0.453-3	0.746-3
mult. 4UV	20000	0.421-3	0.191-3	0.342-3	0.543-3
λ=279.8	40000	0.298-3	0.135-3	0.273-3	0.406-3
3kT/2ΔE=0.32	80000	0.217-3	0.105-3	0.235-3	0.319-3
	160000	0.176-3		0.216-3	0.266-3
O IV $2p\,^2P^o-3d\,^2D$	10000	0.330-3	0.195-3	0.451-3	0.556-3
mult. 5UV	20000	0.233-3	0.138-3	0.336-3	0.408-3
λ=238.5	40000	0.165-3	0.973-4	0.262-3	0.310-3
3kT/2ΔE=0.36	80000	0.120-3	0.792-4	0.219-3	0.249-3
	160000	0.948-4		0.197-3	0.215-3
O IV $3s\,^4P^o-3p\,^4D$	10000	0.168	0.721-1	0.106	0.190
mult. 3	20000	0.119	0.510-1	0.812-1	0.139
λ=3374.3	40000	0.838-1	0.360-1	0.663-1	0.104
3kT/2ΔE=0.39	80000	0.622-1	0.294-1	0.583-1	0.820-1
	160000	0.520-1		0.544-1	0.684-1
O IV $3p\,^4P-3d\,^4D^o$	10000	0.310	0.152	0.252	0.385
mult. 9	20000	0.219	0.107	0.192	0.282
λ=4792.5	40000	0.155	0.758-1	0.154	0.213
3kT/2ΔE=0.50	80000	0.119		0.133	0.170
	160000	0.983-1		0.123	0.144
O IV $3p\,^2D-3d\,^2D^o$	10000	0.400	0.193	0.323	0.495
mult. 11	20000	0.283	0.137	0.246	0.363
λ=5339.5	40000	0.202	0.101	0.200	0.276
3kT/2ΔE=0.56	80000	0.156		0.174	0.221
	160000	0.132		0.161	0.188
F III $3s\,^4P_6-3p\,^4P^o_6$	10000	0.119	0.660-1	0.975-1	0.148
	20000	0.839-1	0.467-1	0.748-1	0.109
λ=2916.3	40000	0.593-1	0.330-1	0.612-1	0.837-1
3kT/2ΔE=0.33	80000	0.431-1	0.258-1	0.535-1	0.676-1
	160000	0.355-1		0.493-1	0.576-1

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
F III $3s^4P-3p^4D^o$	10000	0.134	0.743-1	0.110	0.167
mult. 1	20000	0.949-1	0.525-1	0.842-1	0.123
λ=3124.4	40000	0.671-1	0.371-1	0.689-1	0.944-1
3kT/2ΔE=0.33	80000	0.489-1	0.294-1	0.603-1	0.761-1
	160000	0.403-1	0.318-1	0.556-1	0.649-1
F III $3s^2P_4-3p^2P^o_4$	10000	0.130	0.684-1	0.105	0.162
	20000	0.918-1	0.483-1	0.822-1	0.120
λ=2811.4	40000	0.652-1	0.346-1	0.686-1	0.929-1
3kT/2ΔE=0.53	80000	0.505-1		0.611-1	0.759-1
	160000	0.436-1		0.567-1	0.653-1
F III $3s^2P-3p^2D^o$	10000	0.160	0.843-1	0.129	0.198
mult. 2	20000	0.113	0.596-1	0.101	0.147
λ=3176.9	40000	0.803-1	0.426-1	0.840-1	0.114
3kT/2ΔE=0.53	80000	0.622-1		0.748-1	0.929-1
	160000	0.534-1		0.694-1	0.799-1
F III $3p'^2D^o-3d'^2D$	10000	0.128	0.776-1	0.138	0.182
	20000	0.903-1	0.548-1	0.105	0.135
λ=2788.1	40000	0.638-1	0.388-1	0.846-1	0.104
3kT/2ΔE=0.33	80000	0.463-1	0.306-1	0.729-1	0.835-1
	160000	0.373-1		0.666-1	0.741-1
NE III $3s^3S^o-3p^3P$	10000	0.965-1	0.540-1	0.800-1	0.121
mult. 12UV	20000	0.683-1	0.382-1	0.612-1	0.892-1
λ=2678.2	40000	0.483-1	0.270-1	0.498-1	0.682-1
3kT/2ΔE=0.32	80000	0.348-1	0.200-1	0.434-1	0.549-1
	160000	0.285-1	0.212-1	0.399-1	0.468-1
NE III $3s^5S^o-3p^5P$	10000	0.820-1	0.479-1	0.695-1	0.104
mult. 11UV	20000	0.580-1	0.339-1	0.529-1	0.765-1
λ=2592.3	40000	0.410-1	0.240-1	0.427-1	0.583-1
3kT/2ΔE=0.27	80000	0.292-1	0.175-1	0.370-1	0.467-1
	160000	0.235-1		0.339-1	0.397-1

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
NE III $3s'\,^3D^o-3p'\,^3F$	10000	0.832-1	0.474-1	0.697-1	0.105
	20000	0.588-1	0.335-1	0.532-1	0.771-1
λ=2612.4	40000	0.416-1	0.237-1	0.431-1	0.588-1
3kT/2ΔE=0.29	80000	0.298-1	0.176-1	0.374-1	0.472-1
	160000	0.241-1		0.343-1	0.402-1
NE III $3p\,^3P-3d\,^3D^o$	10000	0.540-1	0.280-1	0.598-1	0.761-1
	20000	0.382-1	0.198-1	0.450-1	0.561-1
λ=2413.0	40000	0.270-1	0.140-1	0.356-1	0.429-1
3kT/2ΔE= 0.28	80000	0.192-1	0.102-1	0.302-1	0.348-1
	160000	0.150-1		0.273-1	0.300-1
NE III $3p'\,^3D-3d'\,^3D^o$	10000	0.625-1	0.395-1	0.722-1	0.928-1
	20000	0.442-1	0.279-1	0.546-1	0.687-1
λ=2091.7	40000	0.312-1	0.197-1	0.436-1	0.530-1
3kT/2ΔE= 0.29	80000	0.223-1	0.147-1	0.373-1	0.432-1
	160000	0.175-1	0.156-1	0.340-1	0.376-1
NE III $3p\,^5P_7-3d\,^5D^o_9$	10000	0.685-1	0.452-1	0.803-1	0.103
	20000	0.484-1	0.319-1	0.606-1	0.760-1
λ=2163.8	40000	0.342-1	0.226-1	0.483-1	0.586-1
3kT/2ΔE=0.27	80000	0.243-1	0.162-1	0.412-1	0.477-1
	160000	0.189-1		0.375-1	0.415-1
NE IV $3s\,^4P-3p\,^4D^o$	10000	0.608-1	0.281-1	0.404-1	0.703-1
	20000	0.430-1	0.199-1	0.303-1	0.509-1
λ=2361.5	40000	0.304-1	0.141-1	0.240-1	0.378-1
3kT/2ΔE=0.25	80000	0.215-1	0.994-2	0.204-1	0.293-1
	160000	0.169-1		0.187-1	0.241-1
NE IV $3s'\,^2D-3p'\,^2F^o$	10000	0.588-1	0.270-1	0.390-1	0.679-1
	20000	0.416-1	0.191-1	0.292-1	0.492-1
λ=2289.1	40000	0.294-1	0.135-1	0.231-1	0.366-1
3kT/2ΔE=0.39	80000	0.208-1	0.106-1	0.197-1	0.284-1
	160000	0.163-1		0.180-1	0.233-1

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
NA III $3s\,^4P-3p\,^4P^o$	10000	0.667-1	0.390-1	0.570-1	0.846-1
	20000	0.472-1	0.276-1	0.432-1	0.621-1
λ=2515.6	40000	0.333-1	0.195-1	0.348-1	0.472-1
3kT/2ΔE=0.26	80000	0.237-1	0.141-1	0.300-1	0.378-1
	160000	0.189-1		0.274-1	0.321-1
NA III $3s\,^4P-3p\,^4D^o$	10000	0.545-1	0.319-1	0.469-1	0.695-1
	20000	0.385-1	0.226-1	0.355-1	0.510-1
λ=2232.5	40000	0.272-1	0.159-1	0.286-1	0.388-1
3kT/2ΔE=0.26	80000	0.193-1	0.114-1	0.246-1	0.311-1
	160000	0.154-1		0.225-1	0.264-1
NA III $3s\,^4P-3p\,^4S^o$	10000	0.441-1	0.260-1	0.384-1	0.568-1
	20000	0.311-1	0.184-1	0.291-1	0.417-1
λ=1971.5	40000	0.220-1	0.130-1	0.234-1	0.317-1
3kT/2ΔE=0.26	80000	0.156-1	0.928-2	0.201-1	0.254-1
	160000	0.124-1		0.184-1	0.216-1
NA III $3s\,^2P-3p\,^2D^o$	10000	0.689-1	0.408-1	0.591-1	0.879-1
	20000	0.487-1	0.289-1	0.449-1	0.645-1
λ=2458.9	40000	0.345-1	0.204-1	0.361-1	0.491-1
3kT/2ΔE=0.26	80000	0.244-1	0.146-1	0.311-1	0.393-1
	160000	0.195-1		0.285-1	0.334-1
NA III $3s\,^2P-3p\,^2P^o$	10000	0.593-1	0.351-1	0.512-1	0.760-1
	20000	0.419-1	0.248-1	0.388-1	0.558-1
λ=2247.4	40000	0.296-1	0.176-1	0.312-1	0.424-1
3kT/2ΔE=0.26	80000	0.210-1	0.125-1	0.269-1	0.340-1
	160000	0.168-1		0.246-1	0.289-1
NA III $3p\,^2D^o-3d\,^2F$	10000	0.558-1	0.377-1	0.672-1	0.851-1
	20000	0.394-1	0.266-1	0.507-1	0.630-1
λ=1995.9	40000	0.279-1	0.188-1	0.403-1	0.485-1
3kT/2ΔE=0.26	80000	0.197-1	0.134-1	0.342-1	0.395-1
	160000	0.152-1	0.130-1	0.311-1	0.344-1

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
NA III $3p\,^4P^o-3d\,^4D$	10000	0.447-1	0.293-1	0.540-1	0.681-1
	20000	0.316-1	0.207-1	0.407-1	0.503-1
λ=1852.0	40000	0.223-1	0.146-1	0.323-1	0.387-1
3kT/2ΔE=0.26	80000	0.158-1	0.104-1	0.274-1	0.315-1
	160000	0.121-1	0.103-1	0.249-1	0.274-1
NA III $3p\,^4D^o-3d\,^4F$	10000	0.514-1	0.343-1	0.620-1	0.784-1
	20000	0.363-1	0.243-1	0.467-1	0.579-1
λ=1947.1	40000	0.257-1	0.172-1	0.370-1	0.446-1
3kT/2ΔE=0.23	80000	0.182-1	0.121-1	0.314-1	0.363-1
	160000	0.139-1	0.114-1	0.286-1	0.316-1
MG IV $3s\,^4P-3p\,^4S^o$	10000	0.199-1	0.969-2	0.140-1	0.236-1
	20000	0.140-1	0.685-2	0.104-1	0.170-1
λ=1477.8	40000	0.993-2	0.484-2	0.810-2	0.126-1
3kT/2ΔE=0.20	80000	0.702-2	0.342-2	0.678-2	0.972-2
	160000	0.520-2	0.284-2	0.612-2	0.795-2
MG IV $3s\,^4P-3p\,^4P^o$	10000	0.314-1	0.152-1	0.217-1	0.368-1
	20000	0.222-1	0.107-1	0.161-1	0.266-1
λ=1911.5	40000	0.157-1	0.758-2	0.126-1	0.197-1
3kT/2ΔE=0.20	80000	0.111-1	0.536-2	0.106-1	0.152-1
	160000	0.828-2	0.477-2	0.953-2	0.124-1
MG IV $3s\,^4P_6-3p\,^4D^o_8$	10000	0.249-1	0.120-1	0.174-1	0.294-1
	20000	0.176-1	0.852-2	0.129-1	0.212-1
λ=1683.0	40000	0.125.1	0.602-2	0.101-1	0.157-1
3kT/2ΔE=0.20	80000	0.882-2	0.426-2	0.842-2	0.121-1
	160000	0.654-2	0.362-2	0.760-2	0.988-2
MG IV $3p\,^4S^o_4-4d\,^4P_6$	10000	0.238-1	0.133-1	0.230-1	0.324-1
	20000	0.169-1	0.941-2	0.170-1	0.236-1
λ=1548.1	40000	0.119-1	0.665-2	0.132-1	0.176-1
3kT/2ΔE=0.16	80000	0.843-2	0.470-2	0.109-1	0.138-1
	160000	0.611-2	0.371-2	0.975-2	0.116-1

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
AL III $3s^2S-3p^2P^o$	10000	0.303-1	0.193-1	0.277-1	0.398-1
mult. 1UV	20000	0.214-1	0.136-1	0.208-1	0.291-1
λ=1857.4	40000	0.151-1	0.963-2	0.165-1	0.220-1
3kT/2ΔE=0.19	80000	0.107-1	0.681-2	0.140-1	0.175-1
	160000	0.801-2	0.592-2	0.126-1	0.148-1
AL III $3s^2S-4p^2P^o$	10000	0.136-1	0.837-2	0.138-1	0.199-1
mult. 2UV	20000	0.964-2	0.592-2	0.107-1	0.148-1
λ=696.0	40000	0.688-2	0.446-2	0.886-2	0.115-1
3kT/2ΔE=0.60	80000	0.549-2		0.777-2	0.940-2
	160000	0.494-2		0.718-2	0.815-2
AL III $3s^2S-5p^2P^o$	10000	0.238-1	0.145-1	0.254-1	0.361-1
mult. 3UV	20000	0.172-1	0.115-1	0.204-1	0.274-1
λ=560.4	40000	0.142-1		0.173-1	0.217-1
3kT/2ΔE=1.3	80000	0.130-1		0.154-1	0.180-1
	160000	0.122-1		0.141-1	0.157-1
AL III $3p^2P^o-3d^2D$	10000	0.316-1	0.230-1	0.415-1	0.509-1
	20000	0.224-1	0.163-1	0.312-1	0.376-1
λ=1609.9	40000	0.158-1	0.115-1	0.246-1	0.290-1
3kT/2ΔE=0.38	80000	0.112-1	0.919-2	0.208-1	0.236-1
	160000	0.825-2	0.974-2	0.188-1	0.206-1
AL III $3d^2D-4f^2F^o$	10000	0.148		0.214	0.244
	20000	0.121		0.173	0.191
λ=1935.9	40000	0.998-1		0.147	0.157
3kT/2ΔE=5.7	80000	0.833-1		0.129	0.134
	160000	0.798-1		0.117	0.120
AL III $4s^2S-4p^2P^o$	10000	1.48	0.859	1.20	1.87
mult. 2	20000	1.04	0.607	0.951	1.40
λ=5705.9	40000	0.751	0.462	0.805	1.09
3kT/2ΔE=0.60	80000	0.616		0.720	0.895
	160000	0.569		0.666	0.768

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
AL III $4p\,^2P^o-4d\,^2D$	10000	1.45		1.37	1.90
mult. 3	20000	1.14		1.14	1.47
λ=4523.2	40000	0.909		0.983	1.19
3kT/2ΔE=5.7	80000	0.764		0.876	1.00
	160000	0.727		0.797	0.867
AL III $4d\,^2D-6f\,^2F^o$	10000	6.51		4.82	5.40
	20000	5.48		4.27	4.58
λ=2762.8	40000	4.35		3.72	3.87
3kT/2ΔE=320.	80000	3.69		3.18	3.25
	160000	3.09		2.70	2.73
AL III $4f\,^2F^o-5d\,^2D$	10000	4.42		4.14	5.25
mult. 6	20000	3.77		3.60	4.25
λ=4701.6	40000	3.23		3.18	3.56
3kT/2ΔE=10.	80000	2.80		2.83	3.03
	160000	2.56		2.52	2.63
AL III $4f\,^2F^o-6g\,^2G$	10000	4.04		3.69	3.87
	20000	3.32		3.14	3.23
λ=2907.0	40000	2.77		2.67	2.71
3kT/2ΔE=1700.	80000	2.34		2.26	2.28
	160000	1.97		1.94	1.94
SI III $3p\,^3P^o-3d\,^3D$	10000	0.894-2	0.761-2	0.148-1	0.165-1
mult. 5UV	20000	0.632-2	0.538-2	0.110-1	0.122-1
λ=1111.6	40000	0.447-2	0.380-2	0.856-2	0.938-2
3kT/2ΔE=0.32	80000	0.316-2	0.290-2	0.713-2	0.767-2
	160000	0.223-2		0.641-2	0.676-2
SI III $3p\,^3P^o-4s\,^3S$	10000	0.175-1	0.109-1	0.165-1	0.242-1
mult. 6UV	20000	0.124-1	0.772-2	0.129-1	0.180-1
λ=996.1	40000	0.876-2	0.546-2	0.106-1	0.139-1
3kT/2ΔE=0.48	80000	0.702-2		0.936-2	0.114-1
	160000	0.613-2		0.865-2	0.983-2

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
SI III $4s\,^3S-4p\,^3P^o$	10000	0.728	0.438	0.604	0.932
mult. 2	20000	0.514	0.310	0.473	0.693
λ=4560.1	40000	0.364	0.219	0.395	0.538
3kT/2ΔE=0.48	80000	0.289		0.350	0.438
	160000	0.257		0.324	0.376
SI III $4p\,^3P^o-4d\,^3D$	10000	0.762	0.456	0.746	1.06
mult. 5	20000	0.546	0.347	0.590	0.800
λ=3801.4	40000	0.411		0.496	0.630
3kT/2ΔE=1.3	80000	0.342		0.438	0.520
	160000	0.316		0.403	0.451
SI III $4p\,^3P^o-5s\,^3S$	10000	0.793	0.438	0.680	1.04
mult. 6	20000	0.571	0.326	0.555	0.792
λ=3237.8	40000	0.458		0.481	0.628
3kT/2ΔE=1.2	80000	0.411		0.433	0.521
	160000	0.379		0.399	0.449
SI IV $3s\,^2S-3p\,^2P^o$	10000	0.141-1	0.733-2	0.104-1	0.170-1
mult. 1UV	20000	0.995-2	0.518-2	0.764-2	0.122-1
λ=1396.7	40000	0.703-2	0.366-2	0.588-2	0.902-2
3kT/2ΔE=0.15	80000	0.497-2	0.259-2	0.484-2	0.691-2
	160000	0.356-2	0.195-2	0.431-2	0.561-2
SI IV $3p\,^2P^o-3d\,^2D$	10000	0.109-1	0.659-2	0.116-1	0.156-1
mult. 3UV	20000	0.768-2	0.466-2	0.856-2	0.114-1
λ=1126.4	40000	0.543-2	0.329-2	0.659-2	0.851-2
3kT/2ΔE=0.18	80000	0.384-2	0.233-2	0.541-2	0.670-2
	160000	0.273-2	0.186-2	0.482-2	0.564-2
SI IV $4s\,^2S-4p\,^2P^o$	10000	0.605	0.281	0.388	0.700
mult. 1	20000	0.428	0.199	0.298	0.512
λ=4097.9	40000	0.302	0.140	0.245	0.386
3kT/2ΔE=0.43	80000	0.230		0.216	0.305
	160000	0.196		0.201	0.255

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
SI IV $4p\,^2P^o-4d\,^2D$	10000	0.467	0.233	0.355	0.576
mult. 2	20000	0.346		0.281	0.429
λ=3160.3	40000	0.267		0.237	0.332
3kT/2ΔE=2.5	80000	0.213		0.211	0.270
	160000	0.180		0.195	0.230
SI IV $4d\,^2D-5p\,^2P^o$	10000	1.19	0.576	0.866	1.46
mult. 3	20000	0.866		0.692	1.09
λ=3766.0	40000	0.675		0.589	0.841
3kT/2ΔE=2.5	80000	0.568		0.529	0.683
	160000	0.507		0.491	0.581
SI IV $5p\,^2P^o-6s\,^2S$	10000	3.37	1.46	2.29	4.03
mult. 4	20000	2.55	1.27	1.89	3.03
λ=4323.5	40000	2.14		1.66	2.37
3kT/2ΔE=1.7	80000	1.89		1.51	1.93
	160000	1.71		1.40	1.64
SI IV $5d\,^2D-6f\,^2F^o$	10000	8.51		6.03	7.67
mult. 5	20000	7.23		5.39	6.34
λ=4212.4	40000	6.08		4.80	5.32
3kT/2ΔE=140.	80000	4.92		4.22	4.49
	160000	4.20		3.66	3.80
P III $3d\,^2D-4p\,^2P^o$	10000	0.343	0.242	0.367	0.492
mult. 1	20000	0.242	0.171	0.280	0.365
λ=4066.2	40000	0.171	0.121	0.226	0.282
3kT/2ΔE=0.44	80000	0.128		0.195	0.230
	160000	0.106		0.178	0.200
P III $4s\,^2S-4p\,^2P^o$	10000	0.531	0.326	0.446	0.682
mult. 3	20000	0.375	0.230	0.347	0.507
λ=4230.4	40000	0.265	0.163	0.289	0.392
3kT/2ΔE=0.44	80000	0.206		0.255	0.319
	160000	0.180		0.236	0.274

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
P III $4s\,^4P^o-4p\,^4P$	10000	0.462		0.388	0.594
mult. 9	20000	0.327		0.301	0.441
λ=3943.5	40000	0.231		0.250	0.341
3kT/2ΔE=8.9	80000	0.176		0.220	0.277
	160000	0.154		0.204	0.237
P IV $3p\,^3P^o-3d\,^3D$	10000	0.350-2	0.260-2	0.477-2	0.573-2
mult. 3UV	20000	0.248-2	0.184-2	0.350-2	0.417-2
λ=826.3	40000	0.175-2	0.130-2	0.267-2	0.313-2
3kT/2ΔE=0.15	80000	0.124-2	0.920-2	0.216-2	0.248-2
	160000	0.876-3	0.690-3	0.190-2	0.211-2
P IV $4s\,^3S-4p\,^3P^o$	10000	0.330	0.158	0.216	0.385
mult. 1	20000	0.233	0.112	0.165	0.281
λ=3355.9	40000	0.165	0.790-1	0.134	0.211
3kT/2ΔE=0.35	80000	0.121	0.648-1	0.117	0.166
	160000	0.100		0.108	0.138
P IV $4s\,^1S-4p\,^1P^o$	10000	0.565	0.264	0.363	0.653
mult. 2	20000	0.399	0.186	0.279	0.477
λ=4249.6	40000	0.282	0.132	0.229	0.360
3kT/2ΔE=0.44	80000	0.215		0.202	0.285
	160000	0.183		0.188	0.238
S III $3d\,^3P_o-4p\,^3P$	10000	0.202	0.135	0.216	0.289
mult. 2	20000	0.143	0.954-1	0.164	0.214
λ=3346.2	40000	0.101	0.675-1	0.132	0.165
3kT/2ΔE=0.41	80000	0.745-1		0.114	0.134
	16000C	0.609-1		0.104	0.116
S III $3d\,^3P^o-4p\,^3S$	10000	0.193	0.128	0.205	0.275
mult. 3	20000	0.136	0.904-1	0.156	0.203
λ=3233.4	40000	0.963-1	0.640-1	0.126	0.157
3kT/2ΔE=0.40	80000	0.708-1		0.108	0.128
	160000	0.580-1		0.983-1	0.110

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
S III $3d^3D^o-4p^3P$	10000	0.284	0.193	0.302	0.404
mult. 8	20000	0.201	0.137	0.230	0.299
λ=3950.5	40000	0.142	0.966-1	0.185	0.231
3kT/2ΔE=0.46	80000	0.104		0.159	0.188
	160000	0.853-1		0.145	0.163
S III $4s^3P^o-4p^3D$	10000	0.472	0.277	0.388	0.598
mult. 4	20000	0.334	0.196	0.303	0.444
λ=4287.1	40000	0.236	0.139	0.252	0.343
3kT/2ΔE=0.46	80000	0.183		0.223	0.280
	160000	0.159		0.207	0.240
S III $4s^3P^o-4p^3S$	10000	0.364	0.214	0.302	0.465
mult. 6	20000	0.258	0.152	0.235	0.345
λ=3692.3	40000	0.182	0.107	0.195	0.266
3kT/2ΔE=0.45	80000	0.140		0.173	0.217
	160000	0.121		0.160	0.186
S III $4s^3P^o-4p^3P$	10000	0.389	0.229	0.322	0.495
mult. 5	20000	0.275	0.162	0.251	0.368
λ=3840.0	40000	0.194	0.115	0.208	0.284
3kT/2ΔE=0.45	80000	0.150		0.184	0.231
	160000	0.130		0.171	0.198
S III $4p^3P-4d^3D^o$	10000	0.248	0.212	0.308	0.396
mult. 18UV	20000	0.175	0.150	0.236	0.296
λ=2961.0	40000	0.124	0.106	0.191	0.230
3kT/2ΔE=0.41	80000	0.909-1		0.165	0.190
	160000	C.814-1		0.151	0.166
S III $4p^3D-4d^3P^o$	10000	0.207	0.178	0.261	0.335
mult. 16UV	20000	0.147	0.126	0.200	0.250
λ=2740.6	40000	0.104	0.892-1	0.162	0.195
3kT/2ΔE=0.46	80000	0.765-1		0.140	0.161
	160000	0.686-1		0.128	0.141

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
S III $4p\,^3D-4d\,^3F^o$	10000	0.222	0.189	0.277	0.356
mult. 15UV	20000	0.157	0.134	0.212	0.266
λ=2865.7	40000	0.111	0.945-1	0.172	0.207
$3kT/2\Delta E$= 0.46	80000	0.819-1		0.148	0.170
	160000	0.729-1		0.136	0.150
S III $4p\,^3P-5s\,^3P^o$	10000	0.129	0.230	0.225	0.268
mult. 19UV	20000	0.914-1	0.163	0.171	0.200
λ=2677.0	40000	0.646-1	0.115	0.138	0.157
$3kT/2\Delta E$=0.41	80000	0.479-1		0.119	0.131
	160000	0.431-1		0.110	0.117
S III $4p\,^3D-5s\,^3P^o$	10000	0.107	0.197	0.193	0.228
mult. 17UV	20000	0.756-1	0.139	0.147	0.170
λ =2495.6	40000	0.534-1	0.985-1	0.118	0.134
$3kT/2\Delta E$=0.46	80000	0.400-1		0.102	0.111
	160000	0.360-1		0.942-1	0.999-1
S IV $3p\,^2P^o-4s\,^2S$	10000	0.396-2	0.202-2	0.306-2	0.503-2
	20000	0.280-2	0.143-2	0.231-2	0.366-2
λ=553.1	40000	0.198-2	0.101-2	0.185-2	0.275-2
$3kT/2\Delta E$=0.32	80000	0.144-2	0.784-3	0.159-2	0.217-2
	160000	0.118-2	0.798-3	0.147-2	0.181-2
S IV $4s\,^2S-4p\,^2P^o$	10000	0.245	0.118	0.162	0.287
mult. 1	20000	0.173	0.838-1	0.123	0.209
λ=3104.1	40000	0.122	0.592-1	0.991-1	0.156
$3kT/2\Delta E$=0.35	80000	0.886-1	0.476-1	0.861-1	0.123
	160000	0.723-1		0.796-1	0.102
CL III $3d\,^4P-4p\,^4P^o$	10000	0.257	0.175	0.178	0.367
mult. 7	20000	0.182	0.123	0.211	0.271
λ=4045.8	40000	0.129	0.873-1	0.169	0.209
$3kT/2\Delta E$=0.47	80000	0.931-1		0.144	0.170
	160000	0.744-1		0.131	0.147

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
CL III $3d^4F-4p^4D^o$	10000	0.452-1	0.296-1	0.514-1	0.669-1
mult. 7UV	20000	0.320-1	0.209-1	0.390-1	0.495-1
λ=1825.7	40000	0.226-1	0.148-1	0.312-1	0.381-1
3kT/2ΔE=0.47	80000	0.165-1	0.141-1	0.267-1	0.310-1
	160000	0.134-1	0.156-1	0.243-1	0.269-1
CL III $4s^4P-4p^4D^o$	10000	0.284	0.171	0.238	0.363
mult. 1	20000	0.201	0.121	0.184	0.268
λ=3629.0	40000	0.142	0.855-1	0.151	0.206
3kT/2ΔE=0.47	80000	0.106		0.133	0.167
	160000	0.898-1		0.123	0.143
CL III $4s^4P-4p^4P^o$	10000	0.246	0.148	0.207	0.315
mult. 2	20000	0.174	0.104	0.160	0.233
λ=3330.9	40000	0.123	0.739-1	0.132	0.179
3kT/2ΔE=0.42	80000	0.912-1		0.116	0.145
	160000	0.773-1		0.107	0.124
CL III $4s^4P-4p^4S^o$	10000	0.226	0.135	0.190	0.290
mult. 3	20000	0.160	0.956-1	0.147	0.214
λ=3160.1	40000	0.113	0.676-1	0.121	0.165
3kT/2ΔE=0.40	80000	0.836-1		0.106	0.134
	160000	0.707-1		0.980-1	0.114
CL III $4s^2P-4p^2D^o$	10000	0.314	0.194	0.266	0.404
mult. 5	20000	0.222	0.137	0.206	0.299
λ=3739.4	40000	0.157	0.982-1	0.170	0.231
3kT/2ΔE=0.53	80000	0.118		0.149	0.187
	160000	0.101		0.138	0.160
CL III $4s^2P-4p^2P^o$	10000	0.243	0.157	0.212	0.318
mult. 6	20000	0.172	0.111	0.164	0.236
λ=3300.9	40000	0.121	0.784-1	0.135	0.182
3kT/2ΔE=0.45	80000	0.903-1		0.118	0.147
	160000	0.768-1		0.109	0.126

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
CL III $4s'^2D-4p'^2F^o$	10000	0.271	0.165	0.229	0.348
mult. 10	20000	0.192	0.117	0.177	0.257
λ=3543.8	40000	0.136	0.859-1	0.145	0.198
3kT/2ΔE=0.59	80000	0.100		0.128	0.160
	160000	0.852-1		0.118	0.137
CL III $4s'^2D-4p'^2D^o$	10000	0.252	0.153	0.213	0.324
mult. 11	20000	0.178	0.108	0.165	0.240
λ=3394.2	40000	0.126	0.785-1	0.135	0.184
3kT/2ΔE=0.55	80000	0.933-1		0.119	0.149
	160000	0.790-1		0.110	0.128
CL III $4s'^2D-4p'^2P^o$	10000	0.204	0.123	0.173	0.263
mult. 11UV	20000	0.144	0.871-1	0.134	0.195
λ=2975.4	40000	0.102	0.616-1	0.110	0.150
3kT/2ΔE=0.45	80000	0.752-1		0.963-1	0.121
	160000	0.634-1		0.889-1	0.104
CL III $4p^2D^o-4d^2F$	10000	0.164	0.149	0.217	0.273
mult. 18UV	20000	0.116	0.106	0.166	0.204
λ=2581.6	40000	0.820-1	0.754-1	0.133	0.159
3kT/2ΔE=0.53	80000	0.593-1		0.115	0.131
	160000	0.527-1		0.105	0.115
CL III $4p^2D^o-4d^2D$	10000	0.135	0.132	0.190	0.235
mult. 19UV	20000	0.952-1	0.936-1	0.145	0.175
λ=2324.3	40000	0.673-1	0.667-1	0.117	0.137
3kT/2ΔE=0.53	80000	0.489-1		0.100	0.113
	160000	0.441-1		0.921-1	0.100
CL III $4p^4P^o-4d^4D$	10000	0.174	0.151	0.222	0.283
mult. 16UV	20000	0.123	0.107	0.170	0.211
λ=2668.2	40000	0.872-1	0.754-1	0.137	0.164
3kT/2ΔE=0.42	80000	0.628-1		0.117	0.135
	160000	0.548-1		0.108	0.118

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
CL III $4p\,^4S^o-4d\,^4P$	10000	0.182	0.160	0.233	0.296
mult. 20UV	20000	0.129	0.113	0.178	0.221
λ=2700.2	40000	0.909-1	0.798-1	0.143	0.172
3kT/2ΔE=0.40	80000	0.654-1	0.633-1	0.123	0.141
	160000	0.572-1		0.113	0.124
CL III $4p\,^4P^o-5s\,^4P$	10000	0.888-1	0.167	0.163	0.191
mult. 17UV	20000	0.628-1	0.118	0.124	0.143
λ=2416.9	40000	0.444-1	0.836-1	0.991-1	0.111
3kT/2ΔE=0.42	80000	0.321-1	0.649-1	0.849-1	0.927-1
	160000	0.283-1	0.707-1	0.784-1	0.831-1
CL III $4p\,^4D^o-5s\,^4P$	10000	0.779-1	0.147	0.145	0.169
mult. 15UV	20000	0.551-1	0.104	0.110	0.126
λ=2281.0	40000	0.390-1	0.736-1	0.879-1	0.987-1
3kT/2ΔE=0.47	80000	0.283-1	0.585-1	0.754-1	0.822-1
	160000	0.251-1	0.636-1	0.697-1	0.738-1
CL IV $4s\,^3P^o-4p\,^3D$	10000	0.162	0.991-1	0.122	0.200
	20000	0.114	0.701-1	0.924-1	0.146
λ=3082.2	40000	0.808-1	0.496-1	0.743-1	0.110
3kT/2ΔE=0.32	80000	0.589-1	0.391-1	0.643-1	0.870-1
	160000	0.479-1		0.549-1	0.731-1
CL IV $4s\,^3P^o-4p\,^3P$	10000	0.131	0.819-1	0.100	0.164
	20000	0.924-1	0.579-1	0.760-1	0.119
λ=2767.6	40000	0.653-1	0.409-1	0.609-1	0.899-1
3kT/2ΔE=0.32	80000	0.474-1	0.314-1	0.526-1	0.710-1
	160000	0.384-1		0.486-1	0.597-1
A III $3d\,^5D^o_9-4p\,^5P_7$	10000	0.342-1	0.222-1	0.394-1	0.508-1
mult. 6UV	20000	0.242-1	0.157-1	0.298-1	0.376-1
λ=1669.7	40000	0.171-1	0.111-1	0.237-1	0.289-1
3kT/2ΔE=0.34	80000	0.123-1	0.883-1	0.202-1	0.235-1
	160000	0.986-2		0.184-1	0.203-1

ued)

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
A III 3d′ $^3D^o$–4p′ ^3D	10000	0.911-1	0.623-1	0.104	0.134
mult. 9UV	20000	0.644-1	0.440-1	0.789-1	0.990-1
λ=2690.3	40000	0.456-1	0.311-1	0.630-1	0.763-1
3kT/2ΔE=0.36	80000	0.330-1	0.254-1	0.537-1	0.621-1
	160000	0.265-1	0.284-1	0.488-1	0.539-1
A III 3d″ $^3P^o$–4p″ ^3P	10000	0.164	0.114	0.183	0.238
mult. 6	20000	0.116	0.806-1	0.139	0.176
λ=3432.6	40000	0.822-1	0.570-1	0.110	0.135
3kT/2ΔE=0.42	80000	0.587-1		0.938-1	0.110
	160000	0.461-1		0.851-1	0.949-1
A III 4s $^5S^o$–4p ^5P	10000	0.208	0.128	0.178	0.268
mult. 1	20000	0.147	0.906-1	0.137	0.198
λ=3296.6	40000	0.104	0.641-1	0.112	0.152
3kT/2ΔE=0.35	80000	0.763-1	0.522-1	0.978-1	0.123
	160000	0.637-1	0.578-1	0.902-1	0.105
A III 4s′ $^3D^o$–4p′ ^3D	10000	0.238	0.144	0.200	0.304
mult. 2	20000	0.168	0.102	0.155	0.225
λ=3492.1	40000	0.119	0.720-1	0.127	0.173
3kT/2ΔE=0.37	80000	0.877-1	0.603-1	0.111	0.140
	160000	0.741-1		0.103	0.120
A III 4s′ $^3D^o$–4p′ ^3F	10000	0.221	0.134	0.187	0.283
mult. 3	20000	0.156	0.946-1	0.144	0.209
λ=3344.8	40000	0.110	0.669-1	0.118	0.161
3kT/2ΔE=0.37	80000	0.814-1	0.553-1	0.104	0.130
	160000	0.685-1		0.956-1	0.111
A IV 4s ^4P–4p $^4D^o$	10000	0.117	0.716-1	0.888-1	0.145
mult. 4UV	20000	0.829-1	0.506-1	0.670-1	0.106
λ=2810.9	40000	0.586-1	0.358-1	0.536-1	0.795-1
3kT/2ΔE=0.29	80000	0.422-1	0.271-1	0.461-1	0.626-1
	160000	0.340-1		0.425-1	0.525-1

Table 1 (Continued)

Element/Transition	T(K)	W_{SEM}(Å)	W_{SE}(Å)	W_{GM}(Å)	W_G(Å)
A IV $4s\,^4P-4p\,^4P^o$	10000	0.102	0.631-1	0.781-1	0.127
mult. 5UV	20000	0.721-1	0.446-1	0.589-1	0.926-1
λ=2617.5	40000	0.510-1	0.315-1	0.470-1	0.696-1
3kT/2ΔE=0.29	80000	0.366-1	0.234-1	0.404-1	0.548-1
	160000	0.294-1		0.372-1	0.459-1
A IV $4s\,^2P-4p\,^2D^o$	10000	0.133	0.813-1	0.101	0.165
mult. 2	20000	0.943-1	0.575-1	0.761-1	0.120
λ=2925.4	40000	0.667-1	0.407-1	0.610-1	0.905-1
3kT/2ΔE=0.31	80000	0.482-1	0.313-1	0.526-1	0.714-1
	160000	0.389-1		0.485-1	0.599-1
A IV $4s'\,^2D-4p'\,^2F^o$	10000	0.114	0.701-1	0.868-1	0.142
mult. 6UV	20000	0.806-1	0.496-1	0.654-1	0.103
λ=2769.2	40000	0.570-1	0.350-1	0.523-1	0.775-1
3kT/2ΔE=0.29	80000	0.410-1	0.263-1	0.449-1	0.610-1
	160000	0.330-1		0.414-1	0.511-1

relation. The line width (FWHM) in Å units then becocomes

$$W(\AA) = 0.4430 \cdot 10^{-8}\,\frac{\lambda^2(\mathrm{cm})N(\mathrm{cm}^{-3})}{T^{1/2}}\,(\mathbf{R}^2_{ii} + \mathbf{R}^2_{ff}), \qquad (2)$$

$$\mathbf{R}^2_{jj} = \sum_{j'} \mathbf{R}^2_{j'j} \simeq \frac{1}{2}\left(\frac{n_j}{Z}\right)^2 [5n_j^2 + 1 - 3l_j(l_j+1)], \qquad (3)$$

where n_j is the effective principal, and l_j the orbital angular momentum quantum numbers, while (Z–1) is the ionic charge.

Within more refined, simple semiclassical approach (Griem, 1974) the Stark width is given by

$$W = N\frac{8\pi}{3}\frac{\hbar^2}{m^2}\int_0^\infty \frac{f(v)}{v}\,dv \Bigg\{\Bigg[\left(\mathbf{R}^2 \ln\frac{\epsilon_{max}}{\epsilon_{min}}\right)_{l_i,l_i+1} + \left(\mathbf{R}^2 \ln\frac{\epsilon_{max}}{\epsilon_{min}}\right)_{l_i,l_i-1} + \left(\mathbf{R}^2 \ln\frac{\epsilon_{max}}{\epsilon_{min}}\right)_{l_f,l_f+1} + \left(\mathbf{R}^2 \ln\frac{\epsilon_{max}}{\epsilon_{min}}\right)_{l_f,l_f-1}\Bigg]_{\Delta n=0} \sum_{i'} (\mathbf{R}^2_{i'i})_{\Delta n\neq 0}\left(\ln\frac{\epsilon_{max}}{\epsilon_{min}}\right)_{n_i,n_i+1} + \sum_{f'} (\mathbf{R}^2_{f'f})_{\Delta n\neq 0}\left(\ln\frac{\epsilon_{max}}{\epsilon_{min}}\right)_{n_f,n_f+1}\Bigg\} + W_c. \qquad (4)$$

For $\Delta n = 0$,

$$\left(\ln\frac{\epsilon_{max}}{\epsilon_{min}}\right)_{l,l'} = \ln\left\{5 - \frac{4.5}{\sqrt{Z}} + \xi^{-1}_{l,l'}\left[1 + \frac{mv^2 n_l^2}{2E_H Z(Z-1)}\right]^{-1}\right\}, \qquad (5)$$

$$\xi_{l,l'} = \frac{(Z-1)e^2\omega_c}{mv^3}, \qquad (6)$$

$$\omega_c = \max\{|\omega_{l,l'}|, \omega_P, \omega_F, \Delta\omega_i\}. \qquad (7)$$

$$\mathbf{R}^2_{l,l'} \simeq \left(\frac{3n}{2Z}\right)^2 \frac{\max(l,l')}{2l+1}[n^2 - \max^2(l,l')]\phi^2, \qquad (8)$$

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

Here, ϵ is the eccentricity of the hyperbolic perturber path, $\omega_{l,l'}$ is the frequency separation between l, l' levels, $\omega_p = (4\pi Ne^2/m)^{1/2}$ is the plasma frequency, ω_F is the fine structure splitting and $\Delta\omega_i$ is the ion splitting. The cases where the one–electron model (i. e. only one energy level for each nl electons) assumed in Eq. (4) is not satisfied, are analyzed in detail by Dimitrijević (1982b). For example for a multiplet as a whole,

$R^2_{j'j}$ should be multiplied by R^2_{mult} $(2l + 1)/(2L + 1)$. The multiplet factor R^2_{mult} can be found in Tables of Shore and Menzel (1965). E_H is the hydrogen ionization energy, the residual ionic charge is denoted by Z, while ϕ^2 is the Bates–Damgaard (1949) factor (Tabulated e. g. in Oertel and Shomo, 1968).

For the transitions with $\Delta n \neq 0$, in Eq. (4), $5 - (4.5/\sqrt{Z})$ must be replaced by 1.4, the value which corresponds to the Gaunt factor 0.2 for energies up to about three times the threshold energy. Furthermore, since the $n \to n + 1$ transitions dominate between all $\Delta n \neq 0$ contributions, one should take

$$\hbar\,\omega_c \approx 2Z^2 E_H / n^3 .$$

In Eq. (4), W_c is the line width induced by strong collisions and higher multipole interactions (Griem, 1974), i. e.

$$W_c = 2\pi N \left(\frac{2m}{\pi kT}\right)^{1/2} \left(\frac{\hbar}{mZ}\right)^2 n_i^4 \left[1 + \frac{kT}{E_H\left(1 + \frac{kT}{E_H} + \frac{Z^2}{n_i^4}\right)}\right] \tag{10}$$

In order to compensate for the overestimation of the line width, since the possible cancelation of elastic contributions to the width was ignored, Dimitrijević and Konjević (1980) proposed that 1.4 instead of $5 - 4.5/Z$ have to be used on the r. h. s. of Eq. (5), on the basis of the following argument: below the inelastic transition threshold, the elastic contribution is taken into account twice, via the strong collision correction and via the extrapolated Gaunt factor. At higher temperatures, the difference between these two versions of Eq. (4) is small, well within theoretical uncertainties for this relation.

3. RESULTS

The results of electron-impact line calculations (FWHM) for the prominent isolated lines of Be III through Ar III and B IV through Ar IV are given in Table 1. Besides the modified semiempirical widths (W_{SEM}) (Dimitrijević, 1988a), present calculations according to Griem's (1968) semiempirical approach were also shown (W_{SE}) in the cases when the condition $3kT/2\Delta E_{jj'} \lesssim 2$ is satisfied. Under W_G are given present simple semiclassical results obtained by using the method proposed by Griem (1974) (Eq. (4)), and under W_{GM} widths obtained by using the same method, but with modified Gaunt factor treshold value for the $\Delta n = 0$ transitions.

For evaluation of the radial integrals, Coulomb approximation (Bates and Damgaard, 1949; Oertel and Shomo, 1968) has been used. Cases with an initial atomic state with equivalent electrons were avoided, when possible. If not, corresponding coefficients of fractional parentage (Shore and Menzel, 1965) are included.

All four methods are compared with available experimental values by Dimitrijević and Konjević (1980). The average values of the ratios of measured to calculated widths are as follows: for doubly-charged ions, $R_{SEM} = 1.06 \pm 0.32$; $R_{SE} = 1.53 \pm 0.46$; $R_{GM} = 0.96 \pm 0.24$; $R_G = 0.72 \pm 0.19$; for triply-charged ions: $R_{SEM} = 0.91 \pm 0.42$; $R_{SE} = 1.56 \pm 0.85$; $R_{GM} = 1.08 \pm 0.41$ and $R_G = 0.72 \pm 0.32$. We can conclude that modified semiempirical method and the modified simple semiclassical method (Dimitrijević and Konjević, 1980) compare best with the experimental data. Hence, we expect that both methods, and especially the simpler, modified semiempirical one, may be quite useful for astrophysical purpose.

ACKNOWLEDGEMENT

This work has been supported by Republic Association for Science in Serbia through the project "Physics and Motions of Celestial Bodies and Artificial Satelites.

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ATMOSPHERIC DRAG EFFECTS FROM THE MOTION OF THE ANS SATELLITE

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(Received: May 5, 1988)

SUMMARY: By usage an analytical interpretation of the satellite orbital element perturbation under influence of a drag we compute perturbations for the semi-major axis of the ANS satellite. The agreement with observed values is very good.

S. Šegan: Polazeći od analitičkih rešenja izračunate su vrednosti poremećaja velike poluose ANS satelita i izvršeno je upoređenje sa posmatračkim vrednostima. Slaganje je dobro.

1. INTRODUCTION

Similar to the construction of the gravity field models, we will use a model of the upper atmosphere density distribution wich allow to compute analiticaly a drag effects on artificial Earth satellites (Sehnal, 1977, 1983, 1986; Šegan, 1987).

In previous paper (Šegan, 1987) were developed some of the formulas for the atmospheric drag effects computation.

2. THE ANS SATELLITE

The ANS satellite was the first Netherlands Astronomical Satelite (1974 70A) launched on August 30, 1974 wich decayed on June 14, 1977. The data of its sun–sinhronous orbit with the orbital plane perpendicular to the direction to the Sun were already the subject of analysing in detail (Wakker and al., 1981; Sehnal, 1982).

We had at our disposal the orbital data from NASA centre. The area–to–mass ratio is necessary for computing the atmospheric drag effects and take it from the data for satellite dimensions and mass as given by Wakker (1978) and Sehnal (1982).

The theory for the computation of the drag effects in the motion of an artificial satellite is performed by the method of variation of the elements, well known from the mechanics. The changes of the semi–major axis in this care are expressed by Lagrangian equation of motion in Gaussian form (Sterne, 1960; King–Hele, 1964).

By using FORTRAN program DRAG (Šegan, 1987) were computed and analysed values Δa.

The formulation of the model is given in (2.1) in the Sehnal's notation (1986). The density at a specific surface of constant altitude is given by seven additive terms each of which has its own height dependence.

$$\rho = k_0 f_0 f_x \sum_{n=1}^{7} h_n g_n , \tag{2.1}$$

where is

$$f_x = 1 + a_1 (F_x - F_b) ,$$

$$f_0 = a_2 + F_m :$$

$$f_m = \frac{F_b - 60}{160} ,$$

$$k_0 = 1 + a_3 (K_p - 3) ,$$

K_p – daily geomagnetic index,
F_x – solar flux,
F_b – mean solar flux, and
$a_1, a_2, \ldots$ are model coefficients.

Some of the functions g_n are time dependent (diurnal, annual, . . .) while the other ones describe a dependence on the physical parameters. The height dependence is expressed by the h_n terms,

$$h_n = K_{n0} + \sum_{j=1}^{3} K_{nj} A_j e^{c_j \cos 2u_e p_j \cos E} ,$$

where

$$A_j = e^{\frac{120 + R_e (1 - \epsilon \sin^2 i) - a}{40 j}} ,$$

$$z_j = \frac{ae}{40j} , \quad j = 1,3 \tag{2.2}$$

where R_e is the equatorial radius of the Earth, ϵ is the feattening of the Earth and i is the orbital inclination.

Now we can rewrite the basic equations for the density (2.2) as

$$\rho = \sum_{n=1}^{7} g_n K_{n0} + \sum_{n=1}^{7} g_n \sum_{j=1}^{3} K_{nj} A_j C_j e^{z_j \cos E} , \tag{2.3}$$

where C_j represents an expanding into power series

$$C_j = 1 + c_j \cos 2u + \frac{c_j^2}{2} \cos^2 2u + \frac{c_j^3}{3!} \cos^3 2u + 0\,(c_j^4).$$

After expansion of all factors of the integrand in formula (2.2) as power series in e and E and their transformation we have

$$\Delta a = -a^2 \delta K_0 f_0 f_x \sum_{\substack{n=1 \\ n \neq 3}}^{5} \Big(g_n K_{no} \int_0^{2\pi} L_a dE + g_n \sum_{j=1}^{3} K_{nj} A_j \int_0^{2\pi} C_j L_a e^{zj \cos E} dE\Big) + \sum_{n=367} \Big(K_{no} \int_0^{2\pi} g_n L_a dE + \sum_{j=1}^{3} K_{nj} A_j \int_0^{2\pi} g_n C_j L_a e^{zj \cos E} dE\Big). \quad (2.4)$$

From the equation (2.4) we can derive the expressions for perigee distance, orbital period and time. The coefficient k in equation has a multiplying factor ρ_{po} which is unknown. We will determine it from some of the recently published models of the Earth's atmospheric density distribution (CIRA 72, (1972); CIRA 86, (Hedin, 1986); MSIS, (Hedin et al., 1977); DTM, (Barlier et al., 1977); C, (Köhnlein, 1980)).

We used for the balistic coefficient δ an average value

$$\delta \doteq 2.2 \frac{\text{effective cross} - \text{section}}{\text{mass}} \approx 0.156 \frac{\text{cm}^2}{\text{g}}$$

3. CONCLUSIONS

For the comparison were developed observed values. The results are presented by figure F1. It can be seen that agreement is good and method is effective. It is clear that at the low heights (under 200 km) the influence of the drag is underestimated. The model of the atmospheric total density assume that perigee heights are greater then 200 km.

This work is part of the research project supported by the Fund for Scientific Research of the S. R. Srbia.

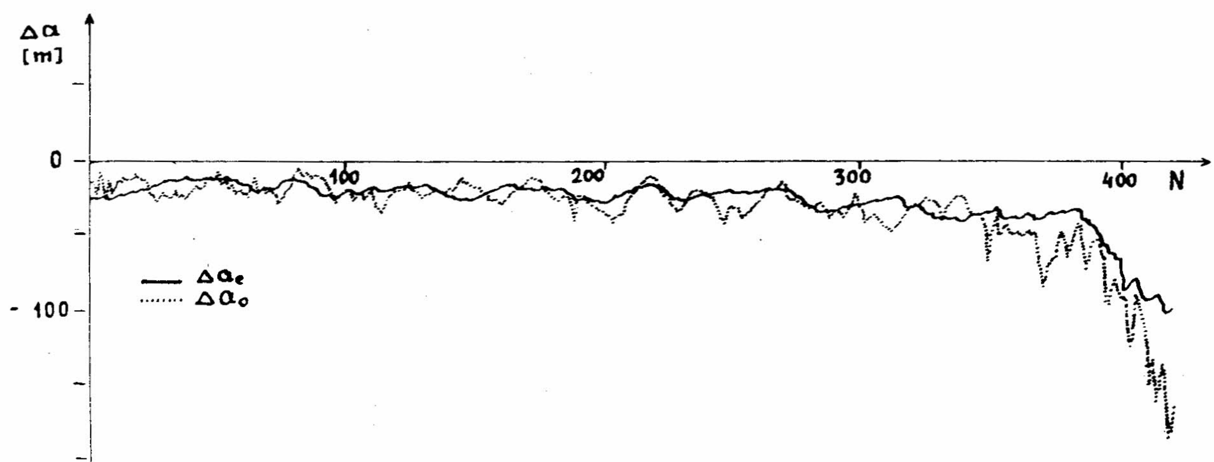

Fig. F1. The changes of the semi–major axis of the satellite ANS in the interval 1975–1977. Continued line–analytical values, dashed line–observed values. Last part of the figure is unprecious (e = 0) and we must use the theory for the circular orbits.

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Bull. Obs. Astron. Belgrade, N° 139 (1988)

UDC 523.44

ASTROGRAPHIC POSITIONS OF 19 BRIGHT ASTEROIDS

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(Received: May 9, 1988)

SUMMARY: A total of 64 precise topocentric positions of 19 bright asteroids are presented. The asteroids were observed between 1979 and 1983 at Belgrade Astronomical Observatory by means of the astrograph Zeiss 16/80 cm.

1. INTRODUCTION

Systematic observations of minor planets have been carried out at Belgrade Observatory since 1932. Nowadays, the number of observable objects is limited both by the size of the instrument and by the astroclimate conditions. Although the main characteristic of our programme is observing of the objects from the socalled "Leningrad List" (Olević et al., 1986), in this paper we present the observations of asteroids which are not included in that list.

The reduction of observations was done by means of the Turner's method (dependences).

Coordinates of the reference stars are taken from the AGK3 and SAO catalogues.

2. RESULTS

Table I constains: observation number, object identification, plate designation, epoch of the obsevation, topocentric positions for the ecliptic and equinox 1950.0 and the corresponding residuals. The residuals are calculated on the basis of the data published in the "Ephemerides of Minor Planets" (Institut of Theoretical Astronomy, Leningrad).

Table II containts the observation number corresponding to that of Table I and the designation of reference star. If a reference star is from the AGK3, its catalogue identifier is preceded by (1). In the case of a reference star from the SAO the corresponding label is (0).

This table contains also the equatorial coordinates of the reference stars represented, however, by their smallest units parts only (seconds in α, i. e. seconds of arc in δ) as well as the corresponding dependences.

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TABLE I

N	OBJECT	PLATE	DATE			ALPHA 1950			DELTA 1950			$(O-C)^{m}_{\alpha}$	$(O-C)''_{\delta}$
						h	m	s	°	'	"		
1.	5 ASTREA	8/83	1983	MAR	13.885150	10	36	0.216	12	50	40.86	-0.01	0.0
2.		8/83	1983	MAR	13.896930	10	35	59.681	12	50	31.57	-0.01	-0.3
3.		8/83	1983	MAR	13.906220	10	35	59.342	12	50	49.62	-0.01	0.0
4.		11/83	1983	MAR	18.911461	10	32	48.914	13	22	30.63	-0.01	0.0
5.		11/83	1983	MAR	18.924299	10	32	48.467	13	22	34.70	-0.01	0.0
6.	8 FLORA	19/83	1983	MAY	13.911675	14	41	17.859	-6	25	5.57	-0.01	0.0
7.		19/83	1983	MAY	13.930640	14	41	16.959	-6	25	5.07	0.00	-0.1
8.		19/83	1983	MAY	13.942100	14	41	16.327	-6	25	1.10	0.00	0.0
9.		22/83	1983	MAY	15.933880	14	39	17.321	-6	19	20.35	-0.01	-0.1
10.		22/83	1983	MAY	15.945330	14	39	16.858	-6	19	17.27	0.00	0.0
11.	10 HYGIEA	5/82	1982	FEB	16.819201	7	52	11.463	18	54	28.65	0.00	0.0
12.		5/82	1982	FEB	16.828480	7	52	11.253	18	54	31.68	0.00	0.0
13.		5/82	1982	FEB	16.836821	7	52	10.877	18	54	31.82	0.00	0.0
14.	12 VICTORIA	37/82	1982	NOV	21.791140	0	0	31.227	6	55	12.08	0.00	-0.1
15.		37/82	1982	NOV	21.800159	0	0	31.485	6	55	10.10	0.00	-0.1
16.	14 IRENA	36/82	1982	NOV	8.963860	4	10	50.878	13	7	16.56	0.01	0.0
17.		41/82	1982	NOV	21.925159	3	58	15.292	13	58	32.46	0.00	0.0
18.		41/82	1982	NOV	21.934191	3	58	14.721	13	58	31.99	0.00	0.0
19.	19 FORTUNA	34/82	1982	NOV	8.855100	0	55	12.706	6	0	21.03	-0.01	-0.1
20.		34/82	1982	NOV	8.864050	0	55	12.529	6	0	19.37	-0.01	-0.1
21.		34/82	1982	NOV	8.873370	0	55	12.319	6	0	16.15	-0.01	-0.2
22.	20 MASSALIA	13/79	1979	SEP	13.945504	23	19	10.524	-3	37	54.24	0.00	0.0
23.		24/79	1979	SEP	21.930340	23	11	55.242	-4	26	16.14	0.00	0.0
24.		24/79	1979	SEP	21.939020	23	11	54.788	-4	26	19.72	0.00	0.0
25.	43 ARIADNE	21/79	1979	SEP	20.121960	3	51	53.453	23	41	48.35	-4.78	-0.1
26.		27/79	1979	SEP	22.093689	3	52	21.549	23	45	32.63	0.07	1.7
27.	44 NYSA	15/79	1979	SEP	13.985790	0	30	24.914	-1	43	30.55	-0.05	-2.0
28.		18/79	1979	SEP	19.986799	0	25	44.126	-2	25	30.77	0.12	-2.5
29.		25/79	1979	SEP	21.969259	0	23	55.638	-2	37	10.57	0.01	-0.2
30.	51 NEMAUZA	7/79	1979	JUL	18.952620	20	49	8.974	-4	36	26.59	0.01	0.0
31.		8/79	1979	JUL	18.977980	20	49	7.781	-4	36	33.11	0.01	0.0
32.	54 ALEXANDRA	17/79	1979	SEP	14.069820	2	9	11.354	29	42	33.52	-0.07	-1.2
33.		17/79	1979	SEP	14.099820	2	9	11.299	29	42	42.44	-0.08	-1.0
34.	55 PANDORA	35/82	1982	NOV	8.908430	2	5	1.743	19	7	23.64	0.00	-0.1
35.		35/82	1982	NOV	8.920390	2	5	1.046	19	7	23.74	0.00	0.0
36.		35/82	1982	NOV	8.932010	2	5	0.306	19	7	25.73	0.00	0.0
37.		39/82	1982	NOV	21.850679	1	54	46.055	18	39	36.72	-0.01	-0.1
38.		39/82	1982	NOV	21.861971	1	54	45.658	18	39	35.23	-0.01	-0.1
39.	80 SAPPHO	5/79	1979	JUN	7.024650	18	7	4.195	-12	13	19.71	0.00	-0.1
40.	129 ANTIGONA	6/81	1981	JUN	3.008010	18	48	40.267	-7	54	42.42	0.00	-0.1
41.		6/81	1981	JUN	3.018420	18	48	40.630	-7	54	39.92	0.01	0.0
42.		6/81	1981	JUN	3.028150	18	48	40.895	-7	54	38.26	0.02	0.0
43.		10/81	1981	JUL	1.936470	18	27	50.694	-9	49	49.99	0.00	0.0
44.		10/81	1981	JUL	1.946540	18	27	50.240	-9	49	55.49	0.00	0.0
45.		16/81	1981	JUL	8.888190	18	22	15.865	-10	37	4.64	-0.01	-0.1
46.		16/81	1981	JUL	8.899770	18	22	15.413	-10	37	8.81	-0.01	-0.1
47.	185 EUNIKE	4/79	1979	JUN	7.001040	17	45	27.751	9	56	57.04	0.02	-0.1
48.	230 ATHAMANTIS	44/82	1982	NOV	22.035231	6	35	16.865	17	15	56.16	0.01	-0.1
49.		44/82	1982	NOV	22.047850	6	35	16.446	17	15	52.73	0.01	0.0
50.		44/82	1982	NOV	22.059191	6	35	16.027	17	15	49.66	0.01	0.0
51.		17/81	1981	JUL	8.931960	20	3	43.209	-6	39	10.09	-0.02	0.0
52.		17/81	1981	JUL	8.942500	20	3	43.727	-6	39	16.24	0.00	-0.1
53.		17/81	1981	JUL	8.953120	20	3	44.319	-6	39	14.84	0.02	-0.1
54.		18/81	1981	JUL	8.973610	20	3	40.899	-6	39	4.89	-0.02	0.0
55.		18/81	1981	JUL	8.984550	20	3	41.585	-6	39	5.86	0.00	-0.1
56.		18/81	1981	JUL	8.985970	20	3	42.081	-6	39	11.70	0.01	-0.2
57.	349 DEMBOVSKA	42/82	1982	NOV	21.956640	4	42	51.016	29	49	25.97	0.01	0.0
58.		42/82	1982	NOV	21.964050	4	42	50.523	29	49	25.08	0.01	0.0
59.		42/82	1982	NOV	21.974810	4	42	50.085	29	49	28.32	0.01	0.0
60.	354 ELEONORA	20/83	1983	MAY	13.990020	17	15	30.707	3	1	33.51	0.00	0.0
61.		20/83	1983	MAY	14.000900	17	15	30.369	3	1	36.03	0.00	0.0
62.		20/83	1983	MAY	14.011200	17	15	29.889	3	1	39.19	0.00	0.0
63.	387 AQUITANIA	4/81	1981	JUN	2.929880	15	53	6.726	9	37	26.72	0.00	-0.1
64.		4/81	1981	JUN	2.941920	15	53	6.286	9	37	30.26	0.00	0.1

TABLE II

OBSERVATIONS			CATALOGUE	POSITIONS USED		DEFENDANCES		
				s	"			
1	2	3	1 12 1244	13.927	17.017	0.1932270	0.1952363	0.1938956
			13 1057	22.346	32.927	0.2964351	0.2953223	0.2994211
			12 1251	58.589	24.432	0.1983942	0.1995824	0.1946645
			13 1062	38.318	21.105	0.3119436	0.3098589	0.3120187
4	5		1 13 1051	37.397	36.363	0.2856892	0.2870641	
			14 1132	33.894	20.673	0.2475095	0.2486285	
			13 1057	22.346	32.926	0.4668013	0.4643074	
6	7	8	0 140080	18.263	-17.221	0.2527910	0.2574092	0.2605682
			140098	12.062	-36.328	0.2485587	0.2486528	0.2485967
			140110	12.458	-0.157	0.2695583	0.2695417	0.2708781
			140115	31.789	-59.890	0.2290921	0.2243963	0.2199569
9	10		0 140065	20.782	-41.527	0.5151780	0.5194884	
			140080	18.263	-17.221	0.3203535	0.3172786	
			140110	12.458	-0.157	0.1644685	0.1632330	
11	12	13	1 19 768	34.375	47.383	0.1661235	0.1665818	0.1671903
			18 792	51.643	25.197	0.1606905	0.1609967	0.1615894
			18 795	59.598	22.570	0.1348909	0.1345588	0.1348021
			19 772	2.700	14.823	0.1518654	0.1521392	0.1521358
			19 778	8.282	20.976	0.1361415	0.1361317	0.1356331
			18 800	21.202	40.290	0.1223745	0.1218902	0.1215463
			18 803	45.008	14.885	0.1279138	0.1277017	0.1271030
14	15		1 7 3448	58.248	20.369	0.1887153	0.1882765	
			6 3252	49.403	47.669	0.1672182	0.1670841	
			6 3254	50.755	18.081	0.1554256	0.1554394	
			7 5	29.969	33.874	0.1504097	0.1502229	
			6 3	7.353	38.495	0.1304868	0.1306969	
			6 9	30.243	50.514	0.1046600	0.1049822	
			7 9	44.411	30.936	0.1030844	0.1032980	
16			1 13 333	22.922	29.048	0.3314609		
			14 370	23.283	18.478	0.4017217		
			14 384	6.604	34.356	0.2668174		
17	18		1 13 313	39.263	50.330	0.2622936	0.2639112	
			14 352	28.180	56.162	0.2820374	0.2843252	
			13 317	58.301	56.538	0.2177312	0.2155887	
			14 356	17.865	46.418	0.2379377	0.2361749	
19	20	21	1 5 105	0.436	55.720	0.1242288	0.1244499	0.1247186
			6 910	43.921	0.575	0.1247261	0.1247675	0.1246829
			5 107	47.223	53.217	0.1402362	0.1404622	0.1408483
			6 950	43.703	28.606	0.1411058	0.1410064	0.1407920
			5 113	12.226	28.226	0.1560209	0.1560324	0.1561835
			6 97	14.024	49.773	0.1529906	0.1528547	0.1526903
			6 102	9.961	13.048	0.1606916	0.1604270	0.1600845
22			0 146645	40.341	-31.882	0.1658873		
			146646	48.837	-25.058	0.4583726		
			146685	30.035	-20.894	0.3757401		
23	24		0 146551	2.533	-20.932	0.2568716	0.2562096	
			146592	45.225	-24.352	0.6954915	0.7000699	
			146621	18.900	-43.967	0.0476369	0.0437205	
25			1 23 346	8.500	14.310	0.1649253		
			23 349	2.842	42.495	0.4152967		
			23 351	49.098	2.805	0.4197779		
26			1 23 346	8.500	14.310	0.0013567		
			23 349	2.842	42.495	0.5893412		
			23 351	49.098	2.805	0.4093021		
27			0 128788	17.158	-49.748	0.2612172		
			128806	7.198	-9.664	0.5064800		
			128877	45.467	-31.258	0.2323027		
28			0 128742	44.824	-4.694	0.3191135		
			128787	5.391	-59.599	0.5076809		
			128806	7.198	-10.436	0.1732056		
29			0 128734	6.216	-3.493	0.3877466		
			128762	19.451	-22.829	0.3044135		
			128787	5.391	-59.600	0.3078399		
30			0 144876	4.103	-42.318	0.1321663		
			144867	42.126	-28.485	0.6568262		
			144913	13.198	-17.274	0.2110075		
31			0 144876	4.103	-42.318	0.1394434		
			144867	42.126	-28.485	0.6554510		
			144913	13.109	-17.274	0.2051056		
32	33		1 29 257	6.561	0.172	0.3461512	0.3455884	
			31 203	29.354	30.408	0.3342623	0.3353123	
			28 254	16.730	4.501	0.3195865	0.3190993	
34	35	36	1 19 162	22.469	23.002	0.0881961	0.0893133	0.0905125
			18 157	21.161	56.016	0.1255586	0.1264328	0.1272896
			20 187	33.269	5.763	0.1328230	0.1329375	0.1332198
			18 161	15.168	29.657	0.1833731	0.1835991	0.1837117
			20 192	56.296	38.135	0.2118989	0.2106456	0.2094691
			18 162	18.898	54.555	0.2581503	0.2570717	0.2557973

37	38		1	18	145	16.800	7.585	0.2771801	0.2781559	
				19	152	43.941	8.133	0.2849775	0.2856747	
				18	148	36.936	53.673	0.1443639	0.1444718	
				19	155	13.053	2.419	0.1623893	0.1621026	
				18	151	7.972	38.098	0.0684211	0.0678283	
				18	152	46.406	46.472	0.0626681	0.0617668	
39			0		161100	30.041	-14.189	0.3107672		
					161113	12.240	-11.241	0.4743870		
					161203	15.302	-29.451	0.2148458		
40	41	42	0		142660	51.540	-30.720	0.2780582	0.2781733	0.2781827
					142664	7.777	-5.086	0.2270481	0.2250715	0.2237087
					142745	23.789	-59.564	0.4948937	0.4967552	0.4981086
43	44		0		161514	1.734	-32.267	0.3691731	0.3713221	
					142364	50.397	-22.521	0.3385175	0.3375915	
					161608	2.015	-56.129	0.1579690	0.1579466	
					142394	36.869	-40.988	0.1343404	0.1331398	
45	46		0		161397	45.174	-4.252	0.4196600	0.4202325	
					161448	1.049	-31.764	0.2820532	0.2830327	
					161514	1.734	-32.267	0.2982869	0.2967348	
47			1	9	2098	24.851	12.862	0.5174300		
				10	2116	1.656	11.527	0.3426768		
				9	2114	12.752	10.634	0.1398932		
48	49	50	1	17	660	57.319	30.080	0.1334115	0.1337220	0.1340726
				16	646	58.508	16.735	0.0766898	0.0773112	0.0778880
				17	661	59.006	3.039	0.1703499	0.1705206	0.1706742
				16	653	1.661	53.707	0.0381306	0.0386009	0.0390296
				17	669	7.755	1.621	0.1722654	0.1720172	0.1718057
				16	654	14.523	53.242	0.0991795	0.0992667	0.0993945
				17	678	40.266	17.086	0.1575519	0.1569509	0.1563619
				16	661	28.823	44.815	0.0624841	0.0622037	0.0619050
				16	662	4.011	30.941	0.0899373	0.0894069	0.0888686
51	52	53	0		144028	24.816	-42.648	0.2996443	0.2972831	0.2956956
					144072	2.992	-34.590	0.4897480	0.4920967	0.4925530
					144129	39.329	-28.826	0.2106076	0.2106202	0.2117514
54	55	56	0		144028	24.816	-42.648	0.3072456	0.3050647	0.3028091
					144072	2.992	-34.590	0.4851488	0.4863627	0.4886011
					144129	39.329	-28.826	0.2076056	0.2085726	0.2085898
57	58	59	1	29	488	45.556	50.982	0.3414316	0.3415970	0.3407170
				30	449	18.184	27.438	0.4674075	0.4693582	0.4722630
				30	455	9.482	13.209	0.1911609	0.1890448	0.1870200
60	61	62	1	3	2052	7.118	44.253	0.1830126	0.1844835	0.1864694
				3	2053	14.916	21.635	0.1915431	0.1922435	0.1932326
				2	2063	54.728	56.191	0.2044294	0.2039873	0.2034690
				2	2064	43.745	34.908	0.2078370	0.2071560	0.2062189
				3	2058	12.377	22.414	0.2131779	0.2121296	0.2106102
63	64		1	10	1857	2.643	22.287	0.1558214	0.1567133	
				9	1856	5.342	57.773	0.2145013	0.2146933	
				10	1867	48.227	24.212	0.1635468	0.1638250	
				9	1865	55.046	13.694	0.2524936	0.2516638	
				9	1867	41.154	16.562	0.2136370	0.2131046	

MCR>

RELATIVE MOTION OF THE COMPONENTS OF THE SYSTEM GP 34 AB

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(Received: May 26, 1988)

SUMMARY: 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.

1. INTRODUCTION

In 1969 G. Popović (1970) noticed a duplicity of the BD+34° 3568 ($9^m\!.5$) star and it was registered as a GP 34 AB pair. The difference of apparent magnitudes of the components was estimated to $3^m\!.0$. The coordinates for epoch 2000.0 are:

$$\alpha = 19^h 28^m\!.9, \quad \delta = +35°25'.$$

The pair was regularly observed between 1969 and 1987 at Belgrade Astronomical Observatory and a variation in the position angle of 43° was fuond. To find out whether this is a rectilinear trajectory or an orbital motion the Carte du Ciel was referred to. At the positional angle $\theta \sim 134°.9$ and the ditance $\rho \sim 8''$ related to the BD+34°3568 star, a faint star (13^m) which could respond as a B component of the GP 34 pair, was found. At the same time, an elongation in the direction $\theta \sim 100°$ with the distance of $\sim 4''$ was also noticed by inspecting the Sky Survey of Palomar Observatory. The analysis of the variation in θ with time confirmed that the faint star noticed in the vicinity of BD+34°3568 seen in the Carte du Ciel and in the Palomar Sky Survey corresponds to the registered B component of the pair GP 34. Regarding to the positions of the neighbouring stars it could be concluded that registered variations in θ and ρ are mainly the result of significant proper motion of the B component.

In 1977 G. Popović (1979) also connected to the system component C ($11^m\!.7$) which had a position θ = 3°.8 and ρ = 33″.6. Minor changes exist in the motion component C related to A, (motion is retrograde), but because of an insufficient number of observations certain conclusion of motion characteristics of this component could not be given.

2. ELEMENTS OF THE TRAJECTORY

The relative motion of the pair GP 34 AB is approximated by a rectilinear trajectory

$$\rho^2 = a^2 + (t - T)^2 m^2$$

$$tg(\theta - \phi) = \frac{m}{a}(t - T)$$

where a and ϕ are the polar coordinates of the minimal distance between the components, m is the velocity of the motion along the trajectory and T is the moment corresponding to the polar coordinates a and ϕ. The initial elements a_0 and ϕ_0 are determined by the least square method from all observations of the pair. All the observations are also used in order to determine the quantity. To: the quantity m_0 is determined from the end points of the trajectory. The initial elements determined in this way are corrected by using the equations of Schlesinger and Alter (1912).

A survey of the observations used for the present purpose is given in Table 1. (θ_t and ρ_t are the polar coordinates corresponding to the time of an observation t and n is the number of measurements).

Table 1. GP 34 AB measurements

t	θ_t	ρ_t	n	Source
1969.778	79°.0	2″.88	2	Popović, 1970
1973.648	69.9	2.66	5	Popović, 1975
1975.633	65.3	2.83	4	Popović, 1977
1977.611	59.9	2.72	5	Popović, 1979
1979.678	52.3	3.07	5	Popović, 1982
1981.711	48.0	3.02	7	Popović, 1983
1983.665	44.5	3.14	7	Unpublished
1984.722	45.0	3.57	2	Unpublished
1986.640	39.2	3.25	2	Unpublished
1987.830	36.2	3.12	2	Unpublished

All observations except the last one were carried out by G. Popović and the last one is the mean measurements of G. Popović and D. Zulević.

Before the treatment the observations are reduced to the epoch 2000.0.

In Table 2. the first three columns give the survey of the observations after their reduction to the epoch 2000.0; the fourth column contains $\Delta\theta$ (in degrees) and fifth – residuals $\Delta\rho$ (in arc seconds).

Table 2. Observations calculated for the epoch 2000.0 and residuals 0–C

t	θ_0	ρ_0	$\Delta\theta$	$\Delta\rho$
1969.778	78°.81	2″.88	1°.62	0″.07
1973.648	69.73	2.66	1.75	−0.14
1975.633	65.14	2.83	2.85	0.01
1977.611	59.76	2.72	1.02	−0.14
1979.678	52.17	3.07	−1.97	0.14
1981.711	47.88	3.02	−1.95	0.02
1983.665	44.40	3.14	−1.53	0.04
1984.722	44.90	3.57	1.00	0.42
1986.640	39.12	3.25	−1.32	−0.01
1987.830	36.12	3.12	−2.27	−0.21

The mean square errors of residuals $\Delta\theta$ and $\Delta\rho$ (in arc seconds) are:

$$\sigma_{\Delta\theta} = +0''02 \qquad \sigma_{\Delta\theta} = +0''.13.$$

For the parameters of the trajectory the following values are obtained:

$$a = 2''.793$$
$$\phi = 71^\circ.495$$
$$m = 0''.116273/\text{year}$$
$$T = 1972.172 \text{ year}$$

On the basis of the obtained parameters it follows that the relative proper motion of the component B is

$\mu_{(B)}$ rel. = 0″.116/ year in the direction 341°.5.

Small deviations of $\Delta\theta$ and $\Delta\rho$, as well as the values estimated for θ and ρ in the Carte du Ciel and Palomar Sky Survey, agree well with the ephemeris calculated in the present paper (Table 3.)

This fact is in favour of the conclusion that the motion of the B component within the examined part of the trajectory is rectilinear and uniform, that is the pair GP 34 AB is most likely optical.

Table 3. Empheris

t	θ_0	ρ_0
1988.00	38.11	3.34
1990.00	34.91	3.48
1992.00	31.95	3.62
1994.00	29.23	3.77
1996.00	26.72	3.93
1998.00	24.42	4.10
2000.00	22.29	4.27
2002.00	20.34	4.45
2004.00	18.54	4.64
2006.00	16.87	4.82
2008.00	15.33	5.02
2010.00	13.91	5.21
2012.00	12.59	5.41
2014.00	11.36	5.61
2016.00	10.22	5.81
2018.00	9.16	6.02
2020.00	8.16	6.22

ACKNOWLEDGEMENT

The paper has been supported by the Republican Community of Science of the SR of Serbia through the project "Physics and Motion of Celestial Bodies and Artificial Satellites".

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OCCULTATIONS OF STARS AND PLANET VENUS BY THE MOON OBSERVED AT THE BELGRADE ASTRONOMICAL OBSERVATORY IN THE YEARS 1980 – 1984

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Received: July 8, 1988)

SUMMARY: 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.

The following Table presents the occultations of stars by the Moon observed at the Belgrade Astronomical Observatory during the period 1980–1984 with Askania refractor 135/1600 by the observer V. Protitch –Benishek.

The timings of planet Venus occultation by the Moon in 1980 as well as the occultation of Sigma Sagittarii by Venus in 1981, observed from Hvar Observatory, are included.

Visual observations were carried out on the basis of the preliminary data prepared by U. S. Naval Observatory, and G. Taylor (Taylor, G., 1981), in the case of occultation of Sigma Sagittarii by Venus (Protitch– –Benishek, V., 1986).

Table I. Occultation observations in the years 1980–1984

DATE and TIME (UTC)						ZC	USNO	X Mag	Ph	(O–C)	Remarks
Yr	Mth	Day	Hr	Min	Sec						
80	01	20	16	10	53.54	–	30866	8.4	DD	–	
80	01	20	16	20	16.74	3324	–	7.2	DD	–1.00	
80	01	20	11	57	39.44	4002	–	–3.5	DD	–	a
80	01	20	11	58	02.87	4002	–	–3.5	RB	–	b
80	01	20	13	12	24.78	4002	–	–3.5	RB	–	c
80	01	20	13	12	38.55	4002	–	–3.5	DD	–	d
80	02	20	18	03	12.43	0306	–	6.9	DD	–1.08	
80	02	21	20	31	49.17	0453	–	7.3	DD	0.20	
80	02	21	20	37	00.97	–	04071	8.7	DD	–	
80	03	18	17	34	22.51	0249	–	4.7	DD	0.23	
80	03	21	18	52	58.25	0692	–	1.1	DD	–0.18	
80	06	22	20	58	31.16	1978	–	6.6	DD	–0.39	
80	08	18	20	17	09.44	2223	–	4.0	DD	–0.87	
80	08	19	19	01	49.57	2352	–	6.7	DD	–1.14	
80	08	21	21	38	09.69	2639	–	6.0	DD	–0.87	
80	09	16	17	55	55.84	–	22789	7.4	DD	–	
80	09	20	19	20	21.72	?017	–	5.3	DD	–1.42	
80	10	15	17	57	48.45	2666	–	5.0	DD	–	
80	10	22	19	54	46.39	0150	–	6.2	DD	–	

a – first contact Venus–Moon; b,c – south corn of Venus terminator;
d – the most distant point of terminator by α.

81	01	17	18	57	06.91	0863	–	6.7	DD	–	
81	02	09	17	10	00.16	0236	–	7.9	DD	–	
81	03	14	20	09	19.79	–	10595	8.0	DD	–	
81	03	14	20	48	55.99	–	10639	8.1	DD	–	
81	03	14	22	19	52.50	–	10728	8.4	DD	–	
81	03	14	22	21	30.26	–	10730	8.7	DD	–	
81	03	14	22	35	43.18	–	10710	8.3	DD	–	
81	03	14	22	54	16.08	–	10764	7.2	DD	–	
81	03	14	23	06	15.19	–	10777	8.9	DD	–	

Table I (continued)

DATE and TIME (UTC) Yr Mth Day Hr Min Sec	ZC	USNO	X Mag	Ph	(O–C)	Remarks
81 03 15 18 35 09.32	1217	–	6.1	DD	–	
81 03 16 17 08 15.36	1335	–	6.3	DD	–	
81 04 09 18 22 18.82	–	07749	7.1	DD	–	
81 04 09 18 33 07.86	–	07767	7.8	DD	–	
81 04 09 18 35 28.61	0888	–	6.0	DD	–	
81 04 09 19 28 59.21	0888	–	6.0	RB	–	
81 04 09 19 42 55.02	0895	–	5.9	DD	–	
81 04 09 19 45 50.67	–	07855	8.5	DD	–	
81 04 09 19 48 24.19	–	07860	8.4	DD	–	
81 04 09 20 42 12.21	0895	–	5.9	RB	–	
81 04 10 18 07 10.54	–	09921	8.0	DD	–	
81 04 10 18 18 17.32	1048	–	8.6	DD	–	
81 04 12 20 10 16.82	–	13381	8.4	DD	–	
81 04 12 20 19 13.14	–	–	8.8	DD	–	Anonyme
81 04 12 22 00 36.37	–	13470	8.8	DD	–	
81 06 10 19 02 52.35	1781	–	7.7	DD	–	
81 10 08 18 16 44.32	–	29301	8.3	DD	–	
81 10 08 20 40 28.02	3096	–	8.0	DD	–	
81 10 09 18 31 55.24	3225	–	7.1	DD	–	
81 10 09 21 47 39.41	3236	–	7.1	DD	–	
81 11 17 15 30 30.52	–	–	2.1	DD	–	Sigma Sagit. by Venus
81 11 17 15 40 07.52	–	–	2.1	RB	–	
82 04 01 16 55 38.23	1110	–	3.5	DD	−0.92	
82 04 01 18 36 56.31	1110	–	3.5	RB	–	
82 04 01 18 42 19.50	–	11013	8,6	DD	−0.94	
82 04 01 18 48 11.92	–	11020	8.7	DD	−0.90	
82 04 01 19 09 02.70	–	11025	8.0	DD	−0.38	
82 04 01 20 21 53.68	1125	–	6.4	DD	−1.44	
82 04 01 21 08 31.32	–	11135	7.1	DD	−1.10	
82 04 01 21 28 29.90	–	11149	8.2	DD	−0.59	
82 04 01 21 50 25.43	1129	–	5.3	DD	–	
82 04 01 23 01 13.49	1143	–	6.8	DD	−1.06	
82 04 01 23 05 31.12	–	11257	8.2	DD	0.95	
82 04 27 18 30 32.77	–	08202	7.5	DD	0.23	
82 05 31 20 59 33.99	1783	–	7.6	DD	−0.28	
82 06 01 23 08 42.36	1902	–	8.8	DD	0.11	
82 06 29 21 38 58.93	1976	–	6.9	DD	−0.09	
82 07 02 21 38 33.28	2316	–	6.4	DD	−0.86	
82 10 26 19 09 20.02	–	30045	7.5	DD	−0.78	
82 11 20 16 14 12.58	–	27450	8.6	DD	−0.67	
82 11 22 18 07 45.17	–	29692	8.7	DD	1.17	
83 01 18 18 28 56.09	3438	–	7.6	DD	−0.51	
83 01 20 19 05 49.77	–	01217	7.7	DD	−0.99	
83 01 20 20 21 54.17	0126	–	7.7	DD	1.49	
83 01 25 20 53 37.45	0817	–	4.8	DD	−1.41	
83 01 31 21 50 53.93	1702	–	4.2	DB	1.53	Perhaps early
83 01 31 22 48 30.18	1702	–	4.2	RD	1.72	
83 03 19 17 50 02.39	0554	–	8.4	DD	0.17	
83 03 19 17 58 47.97	–	04930	8.4	DD	−3.32	
83 03 21 20 07 08.43	0876	–	8.2	DD	−0.46	
83 03 21 20 07 46.57	–	07598	7.5	DD	−1.52	
83 03 21 20 58 30.18	–	07677	8.7	DD	−1.53	
83 03 21 21 20 35.99	–	07687	8.2	DD	0.45	
83 09 14 17 32 26.92	2577	–	6.1	DD	−1.80	
83 09 14 18 30 43.78	–	24213	8.5	DD	−2.98	
83 09 14 18 56 43.81	–	24222	8.8	DD	−2.63	
83 09 14 19 13 46.96	–	24254	8.6	DD	0.28	
83 11 18 16 01 46.95	0327	–	4.5	DD	−0.74	
83 11 18 21 12 19.69	0344	–	8.4	DD	−1.28	
83 12 12 16 05 30.77	3484	–	6.8	DD	0.53	

Table I (continued)

DATE and TIME (UTC) Yr Mth Day Hr Min Sec	ZC	USNO X	Mag	Ph	(O–C)	Remarks
84 03 15 21 49 12.80	1544	–	5.7	DD	–	
84 04 06 19 20 51.6	–	06482	8.2	DD	–	TM: eye &ear
84 04 06 19 41 03.81	0761	–	6.7	DD	–	gradually
84 05 06 19 33 55.63	1180	–	7.1	DD	–	
84 05 06 19 51 38.66	–	11738	8.1	DD	–	by averted vision
84 05 06 20 04 16.08	–	11752	9.0	DD	–	
84 05 06 20 24 35.03	–	11765	7.0	DD	–	
84 06 04 20 56 26.59	1417	–	8.7	DD	–	byaverted vision
84 06 02 19 27 26.86	–	11315	8.6	DD	–	
84 07 10 21 47 09.71	–	23566	7.1	DD	–	gradually
84 07 11 22 16 15.98	2669	–	6.2	DD	–	
84 07 11 22 24 52.0	2673	–	6.3	DD	–	TM: eye & ear

Time was registered by chronograph predominantly, using the time signals of quartz oscillator Rohde & Schwartz.

The value of personal equation has been already subtracted in the given UTC timing data.

In the Table the following designations of the coloumns are used:

DATE and TIME: The date and time in UTC when the phenomenon was observed. UTC time is corrected for personal equation in amount of 0".40 given by ILOC (International Lunar Occultation Centre);

ZC: Robertson's Zodiacal Catalog number;

X : US Naval Observatory Ref. No;

Mag: visual magnitude of occulted star or planet;

PH: phenomenon: DD – disappearance at dark limb, DB – dissppearance at bright limb, RD – reappearance at dark limb, RB – reappearance at bright limb.

O–C: residual distance (in seconds of arc) of the star, including the limb correction, from the computed position of the Moon's outline for the given time of occultation. For the years 1981 and 1984 and in the case of some stars ILOC did not report the O–C because of unidentified reason.

ACKNOWLEDGEMENTS

The author would like to express her gratitude to the USNO and Dr G. Taylor, HMNAO, for the occultation predictions for Belgrade station.

This work has been supported by RZNS through the present "Physic and Motions of Celestial Bodies and Artificial Satellites".

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ON THE STARK BROADENING OF C IV LINES

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(Received: June 6, 1988)

SUMMARY: 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.

1. INTRODUCTION

In a number of astrophysical, as well as physical problems the konwledge of CIV Stark broadening data is very important due to its high cosmical abudance and its presence as impurity in various plasma sources. The aim of this paper is to report the results of semiclassical calculations of electron–impact Stark widths for two astrophysically important C IV multiplets: $2s^2S - 2P^2P^0$ and $3s^2S - 3p^2P^0$. Our results are compared with available experimental (Bogen, 1972; El–Farra and Hughes, 1983; Ackermann et al., 1985) and theoretical (Dimitrijević and Sahal–Bréchot, 1987; Dimitrijević, 1988) data.

2. RESULTS AND DISCUSSION

For this calculation, the computer code originally developed by Jones, Benett and Griem (1971) for the evaluation of Stark broadening parameters of spectral lines of singly ionized atoms, has been modified to allow computations for multiply charged ion lines. Necessary atomic energy levels data were taken from Bashkin and Stoner (1975). All details of calculations are published elsewhere (Jones et al., 1972, Dimitrijević and Konjević, 1982). The obtained results are presented in Table 1 as a function of temperature. In order to illustrate the completeness of the set of perturbing energy levels for dipole matrix elements, for each particular line in Table 1, the parameter $\Delta S/S$ is introduced (Jones et al, 1972) as follows:

$$\frac{\Delta S}{S} = \frac{\sum_{i'} \vec{R}^2_{ii'} + \sum_{f'} \vec{R}^2_{ff'} - \langle i|r^2|i\rangle - \langle f|r^2|f\rangle}{\langle i|r^2|i\rangle + \langle f|r^2|f\rangle}$$

where

$$\langle j|r^2|j\rangle = \frac{n_j^{*2}}{2Z^2}[5n_j^{*2} + 1 - 3l(l+1)]$$

$$n_j^{*2} = Z^2 \frac{E_H}{E_\infty - E_j}$$

Here, E_H is the ionization energy of the hydrogen atom, E_∞ is the energy of the state to which the given spectral series converge, Z – 1 is the ionic charge, n^* the effective principal quantum number, l the angular momentum quantum number, j = i, f initial and final energy level and i′, f′ their perturbing levels respectively, while $\vec{R}^2_{jj'}$ (in units of Bohr radius a_0) is the square of the coordinate operator matrix element summed over all components of the operator and the magnetic substates of total angular momentum J′, and averaged over the magnetic substates J.

In Figs. 1 and 2, the obtained results are compared with existing experimental data (Bogen, 1972; El–Farra and Hughes, 1983; Ackermann et al, 1985). The comparison is also made with the semiclassical – perturbational calculations by Dimitrijević and Sahal–Bréchot (1988) and with calculations (Dimitrijević, 1988) according to the modified semiempirical approach (Dimitrijević and Konjević, 1980).

Table 1. Calculated C IV halfwidths in Å at $N_e = 10^{17}$ cm^{-3} vs the electron temperature. $kT/\Delta E$ is the ratio of the thermal energy at $T = 10^4$ K to the energy separation from the nearest perturbing level; $\Delta S/S$ is a measure of the failure to satisfy the sum rules for the squares of the dipole matrix elements (S is the sum of the squares of these matrix elements).

Transition	Wavelength (Å)	Full halfwidth (Å)					
		T = 10000K	20000K	30000K	60000K	$\Delta S/S$	$kT/\Delta E$
C IV $2s^2S-2p^2P^0$	1549.1	0.026	0.020	0.016	0.012	–0.095	0.11
C IV $3s^2S-3p^2P^0$	5804.9	1.57	1.14	0.954	0.730	–0.033	1.44

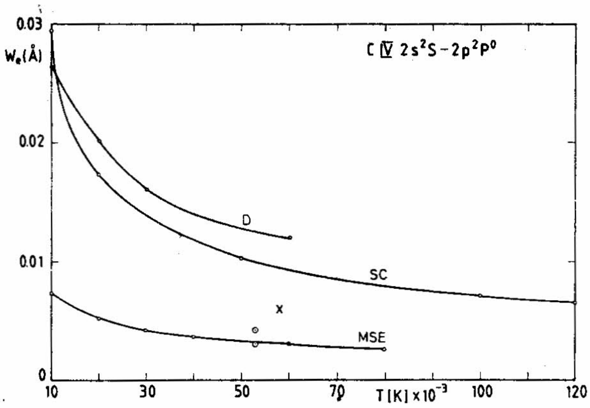

Fig. 1. Full Halfwidths for the C IV $2s^2S-2p^2P^0$ multiplet (λ = 1549.1 Å) as a function of electron temperature: $N_e = 10^{17}$ cm^{-3}. Experimental points: X. Bogen (1972); O – El–Farra, Hughes (1983). Calculations: D–present results; SC–semiclassical (Dimitrijević, Sahal–Bréchot, 1988); MSE–modified semiempirical (Dimitrijević, 1988).

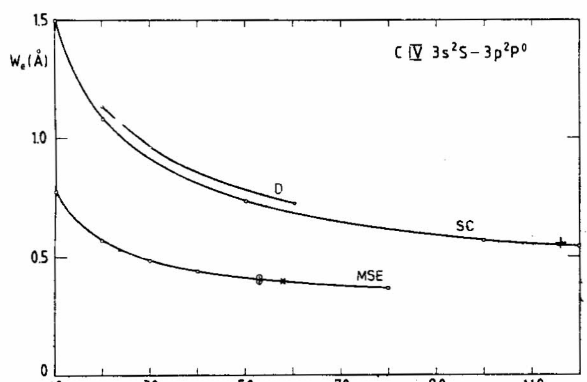

Fig. 2. Full halfwidths for C IV $3s^2S-3p^2P^0$ multiplet (λ = = 5804.9 Å) as a function of electron temperature: $N_e = 10^{17}$ cm^{-3}. Experimental points: X–Bogen (1972); O – El–Farra, Hughes (1983); +– Ackermann et al. (1985). Calculations: D–present calculations; SC–semiclasical (Dimitrijević, Sahal–Bréchot, 1988); MSE–modified semiempirical (Dimitrijević, 1988).

From the comparison of theoretical and experimental data we can conclude that the semiclassical results are larger than experimental data which compare well with the modified semiempirical approach. On the other way, calculations according to the two different semiclassical approaches are in relatively good agreement in spite of the different starting assumptions. The better agreement with experiment for the modified semiempirical approach, may be explained by the influence of strong collisions as well as by the influence of resonances below the threshold for inelastic collisions in the case of 3s –3p and especially 2s–2p C IV multiplet. This contribution is included in the empirical part of the modified semiempirical approach (Dimitrijević and Konjević, 1980). On the other hand, the contribution of strong collisions and resonances is one of the weakest points within the semiclassical method.

ACKNOWLEDGEMENTS

This work has been supported by RZNS thorugh the project "Physics and Motions of Celestial Bodies and Artificial Satelites".

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II WORKSHOP: ASTROPHYSICS IN YUGOSLAVIA

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(Received: June 6, 1988)

After the first meeting of Yugoslav astrophysicists held from 13 to 14 february 1986. in Ljubljana, II workshop: Astrophysics in Yugoslavia was held from 8 to 10 September 1987 in National Library in Belgrade, during the celebration of the centenary of Belgrade astronomical observatory. About fifty astrophysicists from Belgrade, Zagreb, Ljubljana, Sarajevo, Novi Sad, France, the USSR and Hungary attended the meeting, presenting 36 communications from all domains of astrophysics.

The first session of this meeting was devoted to stars and galaxies, and was opened by the talk of J. Arsenijević *Be stars, a challenge to observers and theoreticians.* The main historical steps in the investigation of Be stars with emission lines and the achievements of the Belgrade program of long–term polarimetric study of Be stars, which started in 1974, were reviewed. Observational results in the confrontation with the theoretical interpretations, from Struve's hypothesis to the contemporary empirical Be stars models were also presented and discussed.

B. Balazs spoke on the influence of the angular velocity of spiral arms and the spatial distribution of galactic civilizations. He assumed that the case of mankind is about average and, that the longevity of a civilization might be limited with high probability by catastrophic events treatening during the crossing of the galactic arms. He concluded that intelligent life is presumably concentrated on a belt in the Galaxy which is a narrow annulus including the galactic orbit of our Sun. Consequently, from a heliocentric point of view, the distribution of our potential extraterestrial partners is highly anizotropic.

S. Ninković discussed the role of some special types of stars in contemporary galactic astronomy and T. Zwitter informed the conference on the recent investigations of SS 433 object. Finaly, I. Vince and M. S. Dimitrijević presented the results of their examinations of C IV line profiles in white dwarfs.

The afternoon session started with the talk on cosmic synchrotron radiation by J. Milogradov–Turin and was devoted to the theoretical investigations in astrpohysics. A number of communications (B. S. Milić) *Quasi–perpendicular ion–cyclotron instability in plasmas containing ion with two temperatures;* S. R. Krstić, B. S. Milić: *Landau damping of the transverse electromagnetic waves in multi–special plasmas with polarizable heavy paricles;* A. A. Mihajlov, M. S. Dimitrijević: *Influence of ion–atom impact complexes on different processes in low temperature weakly ionized plasmas;* V. Vitel, M. Skowronek, M. S. Dimitrijević, M. M. Popović: *Electron impact broadening along homologous sequence of noble gases)* was devoted to the theoretical investigations of different processes in solar and stellar plasmas. In two papers (J. Vranješ: *Influence of radiative processes on gravitational instability in homogeneous magnetized fluid,* and B. Gaković, V. Čadež: *Resonant excitation of MHD surface waves by streaming fluid)* MHD investigations of astrophysical interest were given. O. Atanacković–Vukmanović and E. Simonneau presented an approximative solution in the frame of the kinetic non–LTE approach of Ly alfa line transfer in chromospheric conditions. Finally, I. Lukačević discussed some metric properties of Rosen's *bimetric gravitation theory,* and Logunov's *relativistic gravitation theory.*

Morning session of 9. September was devoted to the Sun and started by the talk of M. Karabin on variations in Solar constant followed by the report on spectral analysis of a white light flare by P. Sotirovski, with particular emphasis on the Stark effect and the continuum emission.

The need for various research programs at Belgrade equatorial solar spectrograph motivated the construction of a manual solar spectrum scanner described by A. Kubičela, I. Vince and S. Jankov. N. K. Todorović and S. Todorović discussed the 22 year cycle of sunspots and, J. Arsenijević, M. Karabin, A. Kubičela and I. Vince informed on the beginning of a study of long–term changes of selected Fraunhofer spectral lines. The measurements of the depth, half–width and equivalent width of some selected lines, have been started at Belgrade astronomical observatory with the Solar spectrograph and its new scanner. The program is aimed to last at least trough one 11–year cycle.

The afternoon session started with the paper on the influence of Stark broadening on equivalent widths of Si II visible lines in stellar atmospheres by T. Lanz, M. S. Dimitrijević and M. C. Artru. S. Jankov presented two papers: *Constrained deconvolution and indirect stellar imaging from spectroscopic and photometric observations.* An investigation of the formation of O I lines observed in the infrared spectrum of γ Cas, was reported by M. S. Dimitrijević, N. Feautrier and S. Sahal–Bréchot. In the communication: *Close binary systems with accretion disk,* G. Đurašević discussed the possibility to determine parameters of close binary systems with accretion disk, from the curve of luminosity analysis. The system's model, giving the synthetic curve of luminosity has been made and the inverse problem method was presented, too. In two contributions: *The chemical composition of the Galileian satellites* by V. Čelebonović, it was shown that the theory proposed by Savić and Kašanin can be used in studies of planetary satellites, and that it seems reasonable to attempt using it in studies of asteroids.

The last day of the conference was dominated by contributions to practical astrophysics, amateur's reports and contributions dealing with educational side of astrophysics and astrophysics in literature. After the contributions: *Astrophysics in the nineteenth century serbian literature* by N. Janković and: *On the astronomy text books and their representation of contemporary science* by V. Vujnović, J. Francisti spoke on developement of amateur radioastronomy for improvement of activity of astronomical societies and people's observatories.

In a series of communications (A. Tomić, M. Vuletić, S. Marković: *Some characteristics of the sky brightness in Belgrade;* A. Tomić, Lj. Jovanović: *On the photographic observation of double stars,* A. Tomić, Z. Glišić, M. Muminović, M. Stupar: *On the photographic determination of Lunar librations;* A. Tomić, M. Muminović, M. Stupar; *The limiting stellar magnitude of the Sarajevo sky atlas;* A. Dolžan: *Photoelectric photometry of eclipsing binary stars;* A. Dolžan: *Photography of Supernova 1987a*) various aspects of practical astrophysics and amateur's observations were examined.

During the round table discussion, it was decided that the next meeting of Yugoslav astrophysicists would be organized in 1989 by Hvar observatory, since National conference of Yugoslav astronomers would be held in Sarajevo 1988.

The number of contributions presented during this conference on various topics of astrophysics, short time after the first astrophysical meeting in Ljubljana, give evidence of developement of astrophysical investigations in Yugoslavia.

Bulletin de l'Observatoire astronomique de Belgrade No. 139,1988.

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