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IN MEMORIAM

ĐORĐE TELEKI

On February 23, this year Dr George Teleki passed away. He was with regard to his diligence and results of the scientific work a real doyen of Belgrade Astronomical Observatory. His human qualities did that the memory of his is unforgetable for us, his colleagues.

Dr George Teleki, a Hungarian with regard to the mother language, but a Yugoslav in conviction, was born on April 20, 1928 in Senta, finished his secondary school education in Subotica in 1948 and took a degree in astronomy at Belgrade University in 1952. At the same university he obtained his Ph. D. degree in 1964 – „A Contribution to the Study of Astronomical Refraction" being the title of the thesis which acquired a noticeable reputation in this contry and beyond it. At Belgrade Observatory he was engaged from 1954 to 1968 in the group studying changes in geographic latitude and he led the group of absolute declinations since its foundation in 1959 until his death, where he did many efforts to release the Large Vertical Circle of production errors and to put it to work. He obtained all the scientific posts and he performed at Belgrade Observatory many working and leading functions.

Teleki was an indifatigable scientist in the areas of astronomical refraction, motion of the Earth poles and fundamental astrometry. From these activities resulted a total of 120 papers, original scientific and professional ones, published in Yugoslav and foreign scientific journals. He led scientific projects of Belgrade Observatory, edited its scientific publications, organized national conferences of astronomers and was a member of several scientific organizing committees of international meetings, symposia, colloquia, etc. He was for several years Chairman of the National Astronomical Committee of the SFR of Yugoslavia and member of the Chaircouncil of the Union of Societes of mathematicians, physicists and astronomers of the SFR of Yugoslavia.

Based on results of his work on refraction and as a result of his proposal the IAU organized in the framework of its Commission 8 (fundamental astrometry) a working group for refraction studies whose head since its foundation until his death was Teleki. Due to his engagement this body achieved worthwhile results.

He took part in a number of international scientific meetings, allways presenting a paper, either an original scientific, or a review one. He was invited to many European observatories as a visiting professor and also in the same capacity to India, Australia, China, Japan and to the USA, where he duly represented Yugoslav science.

Teleki was an unselfish scientist. He conveyed his rich astronomical knowledge and experience, both observational and theoretical, to younger scientists, who can nowadays, though with difficulties, become his successors, proudly mentioning that they were his students. He was a unique fellow at faculties where astronomy is thaught. More than two hundred engineers of geodesy were his students and also several astronomers possessing the Msc, or the PhD degree owe their success to his unselfish aid.

Teleki was among the founders of the Astronomical Society „Rudjer Bošković" and a life–long member of its Board of Directors and of the Editorial Board and a collaborator to Belgrade Popular Observatory and Planetarium. He published more than two hundred popular articles and deliverd many lectures covaring almost all astronomical branches at all media. In this way he was an indefatigable populariser of culture. On this front he was irreconcilable in the struggle against false science – astrology.

After all what has been said and much of that which exceeds the physical possibilities of the present article, it is clear why his valuable life was terminated too early and at the desk, a life which was without reserve dedicated to Belgrade Astronomical Observatory, to the science of astronomy and to its role in the mass education. To us, it remains to express with respect our gratitude to him for such work benefiting all of us and to me, additionally, for his frank and great friendship. Younger astronomers should follow his fine example.

B.Ševarlić

THE HUNDREDTH ANNIVERSARY OF BELGRADE ASTRONOMICAL OBSERVATORY

A hundred years ago, in 1887, in Belgrade, in the Kingdom of Serbia, an astronomical and meteorological observatory was founded as a part of the High School, which later on grew into University. This is an important date since then an organized work in the area of the latter two branches of science was initiated in the territory of Serbia. The meteorological research was first to begin achieving a high level, whereas in astronomy a lack of adequate instruments deprived this scientific branch of acquiring a deserved position. A more intensive progress could be achieved as late as after the first World War, when the newly founded state of Yugoslavia received several telescopes from Germany as a result of the war reparations. Until 1924 there was only one observatory covering both the meteorological and the astronomical research, but since that year the investigations in the two areas have been carried out at two different observatories, both working as parts of Belgrade University. In 1930 builiding of a new astronomical observatory began at the place where it is situated nowadays. Permanent astronomical observations at that place were begun in 1936. The development intensified after the end of the second World War, when new telescopes were put to work and the number of astronomers increased. Now the observatory is already surrounded by the city–being a limitation factor to its observation activity growing in the importance with time. Thus some steps aimed at building a new observatory beyound Belgrade have been undertaken. This building is expected to commence in the near future in the central part of Serbia, near Prokuplje, at an altitude of 1020 m above the sea level.

This is a very short review on the history of Belgrade Astronomical Observatory, the details shall be given in Publ, Astron. Obs. Belgrade, No. 36.

The results of the work of astronomers belonging to the Observatory Staff have been published in a number of national and international journals and books. A large body of data has been published in *Bulletin de l'Observatoire astronomique de Belgrade* (founded in 1936) and in Publication de l'Observatoire astronomique de Belgrade (founded in 1947). Both publications are still published, though the data were also published in some earlier publications such as : *Annuaire, Memories, Astronomska i meteorloška saopštenja, Godišnjak našeg neba,* etc.

A working character of the celebration of the Belgrade Astronomical Observatory anniversary is prefered. For this purpose several scientific meetings will be organized and special publications will be published. The following meetings are foreseen.

– IAU Colloquium No. 100 :*Fundamentals of Astrometry,* Sept. 8–11, 1987;

– International Workshop on Atmospheric Refraction, Sept. 3–5, 1987;

– Second Internationala Workshop on Catastrophic Disruption of Small Solar System Bodies, Sept. 8–10, 1987;

– Second National Seminar: *Astrophysics in Yugoslavia,* Sept. 8–11, 1987.

A solemn academy dedicated to the jubilee will be held on September 7, 1987 in Belgrade.

Because of the lack in space and time it is impossible to present a list of all the former and contemporary members of the staff whose contribution to a successful activity of the establishment has been decisive. We owe to all of them our deep gratitude. Certainly, the greatest contribution is due to the two founders: to Prof. M. Nedeljković who founded the Observatory and to Prof. V.V. Mišković under whose directorship building of the new observatory was initiated. Their enthusiasm is still an example to be followed.

There is a lot of persons and establishments in Yugoslavia and beyond her, who have aded the devleopment of Belgrade Astronomical Observatory. We owe our deepest gratitude to all of them.

Director
M.Mitrović

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Nº 137

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BELGRADE CATALOGUES OF DECLINATIONS AND PROPER MOTIONS OF ZENITH STARS

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(Received :January 15, 1987)

SUMMARY: The analyses are given of three Belgrade catalogues of declinations and proper motions in declination of 36 zenith stars for the equinox and epoch 1970.0. These stars were observed with zenith telescope. The catalogues are based on the observation data collected in the period 1960.0 – 1981.0. The conclusion is that the results are highly satisfying.

1. INTRODUCTION

From 1960, the Belgrade zenith telescope (Askania, 110/1287 mm) is also used for the determination of declinations as well as proper motions in declination of zenith stars. The present programme (Ševarlić, Teleki, 1960) includes 36 stars.

On the basis of the observational data collected in the period 1960.0 – 1981.0, the declinations and proper motions in declination of these stars for the equinox and epoch 1970.0 are calculated. Three kinds of data were utilized for latitude (φ) and thus three systems of declinations and proper motions were given. The abbreviations of obtained catalogues are: $BZS1_{70}$, $BZS2_{70}$ and $BZS3_{70}$ (meaning: Belgrade Zenith Stars, system 1,2 and 3, for the equinox and epoch 1970.0).

Our conclusion is that relatively the most accurate and reliable is the system 1 of declinations and proper motions. The catalogue $BZS1_{70}$, which contains these data, was already published (Teleki, Grujić, 1987).

New the catalogues $BZS2_{70}$ and $BZS3_{70}$ as well as the analyses of all three catalogues are presented. For this reason some results of our previous paper (Teleki, Grujić, 1987) will be repeated.

2. OBSERVATIONS

The observers of this programme were as follows: R.Grujić (all of 1997 observations), M.Đokić (447), G.Teleki (120), V.Milovanović (108) and L.Đurović (3).

There was total 2675 observations, i.e. every star has, on the average, was observed 74 times. However, the number of actual observations of each star runs from 18 to 189.

Table 1 gives the informations on observation numbers at different years.

It must be mentioned that the number of the used observational data is not the same for different systems. For the system 1, which is based on the latitude φ resulting from observations on the same night (see later), 2351 basic data are used (because in 324 cases we have no adequate latitude observations). For the system 2 and 3 all 2675 observations have been taken into consideration.

3. PROCESSING

The well-known formula

$$\delta = \varphi \pm z \tag{1}$$

has been used for the declination (δ) determinations. The observed zenith distance is denoted with z.

Three kinds of data are used for the adopted latitude φ : first, the latitude resulting from observations on the same night (system 1), second, the latitude inferred from the Belgrade latitude variation curve, plotted from the international polar coordinates (system

Table 1. The number of observations at different years

Star	1960 +																					
Nº	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Sum total
1	–	6	16	19	3	6	3	8	11	18	–	–	–	10	8	7	8	18	5	2	5	143
2	–	6	13	20	3	3	3	7	14	17	–	–	–	10	6	8	9	7	6	2	5	139
3	–	1	–	–	–	1	2	4	2	3	1	–	–	–	5	–	–	1	–	–	1	21
4	–	1	1	–	–	1	–	2	–	2	3	–	–	–	8	–	–	–	–	–	–	18
5	–	1	–	1	–	2	–	2	–	3	5	–	–	–	8	–	–	–	–	–	–	22
6	–	2	2	5	3	1	2	2	–	9	–	–	–	9	10	1	7	4	4	3	2	66
7	–	2	4	7	3	2	2	7	3	15	2	–	–	9	10	7	6	4	3	3	1	90
8	–	–	3	6	3	2	2	8	3	15	5	–	–	10	9	6	4	4	3	3	2	88
9	1	–	1	1	–	2	3	1	2	3	3	–	–	–	4	–	–	1	–	1	3	26
10	1	–	–	2	–	–	–	–	2	–	5	–	–	–	5	–	–	3	–	–	1	19
11	3	3	10	13	4	6	4	2	11	7	11	–	6	8	8	3	2	6	3	4	3	117
12	1	3	12	14	4	6	4	3	13	6	12	–	8	10	9	3	3	6	3	4	4	128
13	1	2	11	13	7	5	6	2	13	8	13	–	8	6	3	3	3	7	1	2	2	116
14	6	–	3	6	5	3	4	4	5	1	5	–	–	5	2	–	–	2	2	1	–	54
15	3	–	3	8	5	3	5	4	6	2	4	–	–	5	2	–	–	2	1	2	–	55
16	5	3	9	8	6	3	7	6	10	12	12	–	3	12	8	5	6	9	7	5	–	136
17	7	7	10	16	8	5	11	11	14	13	12	–	6	11	7	8	6	6	6	4	2	170
18	1	–	–	11	3	2	3	3	3	–	2	–	–	3	2	–	–	2	–	1	2	38
19	4	–	2	11	4	4	1	4	2	1	2	–	–	6	–	–	–	4	–	–	–	45
20	5	5	15	11	8	10	4	17	8	20	6	–	4	9	7	7	1	5	5	4	5	156
21	2	4	12	10	5	7	4	16	5	17	5	–	3	9	8	9	5	8	8	2	3	142
22	5	3	19	18	9	8	4	19	11	25	6	–	5	10	8	12	6	7	6	3	5	189
23	–	2	5	10	8	6	3	14	2	11	–	–	1	5	7	4	4	5	5	2	2	96
24	–	1	1	10	4	4	–	2	1	10	–	–	–	4	–	–	–	–	–	–	–	37
25	–	1	–	9	3	5	1	2	2	9	–	–	–	3	–	–	–	–	–	–	–	35
26	–	–	1	8	3	6	2	2	2	9	–	–	–	2	–	–	–	–	–	–	–	35
27	–	1	1	6	3	4	2	2	1	8	1	–	–	2	–	–	–	–	–	–	–	31
28	–	1	1	6	3	4	1	2	1	6	–	–	–	–	–	–	–	–	–	–	–	25
29	–	–	2	10	2	5	1	5	2	8	1	–	–	3	–	–	–	1	1	–	1	42
30	–	–	1	7	2	4	1	4	–	4	1	–	–	1	–	–	–	–	1	–	1	27
31	–	–	1	7	3	4	2	3	2	5	–	–	–	1	–	–	–	–	–	–	–	28
32	–	–	2	5	2	3	4	–	2	9	–	–	–	3	–	–	–	1	–	–	–	31
33	–	–	2	5	2	4	2	–	3	10	–	–	–	3	–	–	–	1	–	–	–	32
34	–	6	7	8	6	2	5	6	4	5	–	–	–	7	5	6	6	8	5	3	2	91
35	1	5	7	7	6	2	4	4	8	12	–	–	–	8	4	4	6	7	7	2	–	94
36	–	6	5	7	6	2	3	6	10	11	–	–	–	5	3	4	3	10	8	1	3	93
Sum total	46	72	182	305	136	137	105	184	178	314	117	–	44	189	156	97	85	129	90	54	55	2675

2), and, third, the latitude deduced from the smoothed latitude variation curve (obtained with the same instrument) (system 3).

The most probable values of declinations (δ_{BZS}) and proper motions in declinations (μ'_{BZS}) were, for all three systems determined by the method of least squares, using the formula

$$\delta = \delta_{BZS} + \mu'_{BZS}\,(t - 1970.0) \qquad (2)$$

where

δ– declinations is reduced to the equinox 1970.0 and to the epoch of the begining of the nearest year (t).

After these calculations the values δ_{BZS} and μ'_{BSZ} are refered to the equinox and epoch 1970.0. It has to be mentioned that the coefficient of correlation of δ and μ' determined by the formula (2) is very changeable : from 0.00 to 0.93. This speaks on the non–homogenity of data. The highest mean value of r is for system 1 ($\sim$ 0.50) – for both other systems are smaller ($\sim$ 0.44 resp. $\sim$ 0.45).

The Table 2 includes the values δ_{BZS2} and μ'_{BZS2} for the system 2 – this is the catalogue $BZS2_{70}$. The Table 3 comprises the data of the catalogue $BZS3_{70}$.

The explanations of these tables :

Nº– number of stars on the Belgrade list (Ševarlić, Teleki, 1960);

GC – number in the Boss' General Catalogue (GC);

n – number of observations;

α_{70} – calculated right ascensions for 1970.0;

δ_{BZS2} resp. δ_{BZS3} – declinations for the equinox and epoch 1970.0 determined by the formula (2);

μ'_{BZS2} resp. μ'_{BZS3} – annual proper motions, determined by the formula (2);

ϵ_δ – mean square error of one determination of declination;

ϵ_μ' – mean square error of one determination of proper motion;

r – coefficient of correlation of δ and μ' determined by the formula (2):

$\Delta\delta = \delta_{GC} - \delta_{BZS2}$ (resp. BZS3) – differences of δ for the equinox and epoch of 1970.0 given by GC and the formula (2); and

$\Delta\mu' = \mu'_{GC} - \mu'_{BZS2}$ (resp. BZS3) – differences between μ' given by GC and the formula (2)

4. ANALYSES

4.1. The internal errors of the declination (ϵ_δ) and proper motion in declination (ϵ_μ') determinations are presented in the Table 4. It has to be mentioned that not one single observation was eliminated.

As it appears from this table, the most accurate are the declination system 1. Practically then are no differences between the accuracy of proper motion determination in various systems.

The accuracy change during the observation period 1960.0 – 1981 is worthy of attention. After the modifications which have been implemented on the instrument, on the pavilion and on the mode of observation (Milovanović et al., 1981) in the period 1969–1970, the internal accuracy is markedly increased. Now the mean error is ± 0".220, while in the period 1960.0–1968.5 it was ± 0".294.

By the formula

Table 2. The catalogue $BZS2_{70}$ – declinations and proper motions in declination of 36 Belgrade zenith stars – system 2

N°	GC	n	α_{70}	δ_{BZS2}	ϵ_δ	μ'_{BZS2}	ϵ_μ'	r	$\Delta\delta$	$\Delta\mu'$
				44° +						
1	918	143	$0^h\ 44^m.5$	41' 51".926	±0".337	+0".013	±0".005	+0.22	−0".006	−0".020
2	999	139	0 48. 6	50 20.618	0.236	−0.018	0.003	−0.40	−0.208	+0.023
3	1539	21	1 15. 3	44 40.118	0.248	−0.014	0.012	−0.24	−0.218	−0.029
4	3423	18	2 49. 9	46 17.746	0.221	−0.006	0.013	−0.11	−0.446	−0.011
5	3755	22	3 7. 5	44 42.472	0.322	−0.075	0.019	−0.67	−0.512	−0.080
6	4217	66	3 30. 6	45 18.172	0.274	−0.061	0.006	−0.77	−0.232	+0.049
7	4320	90	3 36. 2	42 16.436	0.274	−0.076	0.006	−0.82	−0.066	+0.039
8	4597	88	3 48. 0	52 39.839	0.255	−0.082	0.006	−0.84	−0.009	+0.054
9	7543	26	5 57. 3	56 46.715	0.286	−0.106	0.010	−0.91	−0.185	+0.102
10	8988	19	6 50. 9	52 40.637	0.283	−0.064	0.012	−0.78	−1.527	−0.021
11	15726	117	11 26. 3	43 52.005	0.277	−0.018	0.004	−0.35	+0.715	+0.021
12	15939	128	11 36. 0	52 56.701	0.331	+0.008	0.005	+0.12	+0.079	−0.017
13	16416	116	11 58. 9	47 49.969	0.273	+0.020	0.005	+0.35	−0.899	−0.034
14	20194	53	14 59. 0	42 16.733	0.267	+0.048	0.007	+0.69	−0.733	−0.060
15	20258	55	15 2. 0	45 39.761	0.256	+0.048	0.007	+0.69	−1.111	−0.043
16	21241	137	15 46. 4	41 24.949	0.250	+0.071	0.004	+0.84	−2.379	−0.092
17	22098	170	16 23. 9	45 27.469	0.292	+0.058	0.004	+0.74	−0.319	−0.068
18	24280	38	17 50. 3	54 53.038	0.443	+0.057	0.013	+0.59	−0.378	−0.042
19	25623	45	18 42. 0	53 40.782	0.403	+0.047	0.012	+0.51	−0.482	−0.066
20	26804	156	19 23. 1	52 25.125	0.311	+0.061	0.004	+0.73	−0.575	−0.028
21	26847	142	19 25. 0	52 13.933	0.284	+0.058	0.004	+0.75	+0.137	−0.135
22	27241	189	19 39. 7	43 5.228	0.279	+0.059	0.004	+0.76	−1.118	−0.033
23	28003	96	20 9. 2	55 37.873	0.304	+0.043	0.006	+0.61	+1.197	−0.016
24	29241	37	20 55. 5	48 31.200	0.287	+0.017	0.014	+0.20	+0.470	−0.010
25	29323	36	20 58. 8	52 43.174	0.268	+0.031	0.013	+0.37	+0.106	−0.028
26	29388	35	21 1. 3	40 18.947	0.435	+0.032	0.026	+0.21	+0.273	−0.030
27	30097	31	21 28. 0	47 28.253	0.370	−0.025	0.021	−0.21	+0.087	+0.021
28	30126	25	21 29. 3	44 32.635	0.257	−0.027	0.020	−0.27	−0.165	+0.025
29	30919	42	22 4. 8	52 4.328	0.304	−0.004	0.012	−0.05	+0.112	−0.010
30	30998	27	22 7. 8	42 25.437	0.322	−0.021	0.019	−0.22	−0.027	+0.018
31	31002	28	22 8. 0	41 55.540	0.331	+0.021	0.023	+0.17	+0.240	−0.018
32	31525	31	22 33. 3	50 58.294	0.302	−0.016	0.015	−0.20	+0.306	+0.016
33	31665	31	22 39. 8	51 5.340	0.256	+0.004	0.012	+0.06	−0.070	+0.008
34	32766	91	23 32. 2	53 31.818	0.266	+0.019	0.004	+0.40	+0.012	−0.008
35	32883	94	23 38. 7	54 26.718	0.266	−0.002	0.005	−0.04	+1.572	+0.018
36	32924	93	23 40. 8	49 31.489	0.239	+0.003	0.004	+0.08	+0.461	−0.012

Table 3. The catalogue $BZS3_{70}$ – declinations and proper motions in declination of 36 Belgrade zenith stars – system 3

N°	GC	n	α_{70}	δ_{BZS3} 44° +	ϵ_δ	μ'_{BZS3}	ϵ_μ	r	$\Delta\delta$	$\Delta\mu'$
1	918	143	$0^h\ 44^m.5$	41' 51".988	± 0".329	+0".016	± 0".005	+0.26	−0".068	−0".023
2	999	139	0 48.6	50 20.677	0.234	−0.021	0.003	−0.46	−0.267	+0.026
3	1539	21	1 15.3	44 40.170	0.256	−0.015	0.014	−0.25	−0.270	−0.028
4	3423	18	2 49.9	46 17.795	0.253	−0.011	0.015	−0.18	−0.495	−0.006
5	3755	22	3 7.5	44 42.531	0.325	−0.081	0.019	−0.69	−0.571	−0.074
6	4217	66	3 30.6	45 18.236	0.278	−0.060	0.006	−0.76	−0.296	+0.048
7	4320	90	3 36.2	42 16.504	0.280	−0.079	0.006	−0.82	−0.134	+0.042
8	4597	88	3 48.0	52 39.917	0.240	−0.085	0.005	−0.86	−0.087	+0.057
9	7543	26	5 57.3	56 46.772	0.262	−0.112	0.009	−0.93	−0.242	+0.108
10	8988	19	6 50.9	52 40.710	0.285	−0.076	0.013	−0.82	−1.600	−0.009
11	15726	117	11 26.3	43 52.072	0.265	−0.027	0.004	−0.50	+0.648	+0.030
12	15939	128	11 36.0	52 56.773	0.324	+0.001	0.005	+0.01	+0.007	−0.010
13	16416	116	11 58.9	47 50.045	0.260	+0.016	0.005	+0.30	−0.975	−0.30
14	20194	53	14 59.0	42 16.730	0.277	+0.045	0.007	+0.65	−0.730	−0.057
15	20258	55	15 2.0	45 39.769	0.248	+0.045	0.007	+0.67	−1.119	−0.040
16	21241	137	15 46.4	41 24.974	0.245	+0.068	0.004	+0.84	−2.404	−0.089
17	22098	170	16 23.9	45 27.490	0.292	+0.055	0.004	+0.72	−0.340	−0.065
18	24280	38	17 50.3	54 53.048	0.441	+0.055	0.013	+0.58	−0.388	−0.040
19	25623	45	18 42.0	53 40.806	0.404	+0.051	0.012	+0.54	−0.506	−0.070
20	26804	156	19 23.1	52 25.137	0.310	+0.060	0.004	+0.73	−0.587	−0.027
21	26847	142	19 25.0	52 13.950	0.265	+0.058	0.004	+0.77	+0.120	−0.135
22	27241	189	19 39.7	43 5.243	0.269	+0.060	0.004	+0.78	−1.133	−0.034
23	28003	96	20 9.2	55 37.896	0.300	+0.043	0.006	+0.62	+1.174	−0.016
24	29241	37	20 55.5	48 31.265	0.294	+0.021	0.014	+0.24	+0.405	−0.014
25	29323	36	20 58.8	52 43.233	0.251	+0.035	0.013	+0.42	+0.047	−0.032
26	29388	35	21 1.3	40 19.007	0.417	+0.037	0.025	+0.25	+0.213	−0.035
27	30097	31	21 28.0	47 28.322	0.366	−0.018	0.021	−0.15	+0.018	+0.014
28	30126	25	21 29.3	44 32.717	0.231	−0.018	0.018	−0.20	−0.247	+0.016
29	30919	42	22 4.8	52 4.394	0.284	−0.001	0.011	0.00	+0.046	−0.013
30	30998	27	22 7.8	42 25.541	0.301	−0.007	0.014	−0.10	−0.131	+0.004
31	31002	28	22 8.0	41 55.584	0.323	+0.020	0.023	+0.17	+0.196	−0.017
32	31525	31	22 33.3	50 58.350	0.277	−0.015	0.014	−0.20	+0.250	+0.015
33	31665	31	22 39.8	51 5.403	0.235	+0.006	0.011	+0.09	−0.133	+0.006
34	32766	91	23 32.2	53 31.856	0.253	+0.020	0.004	+0.44	−0.026	−0.009
35	32883	94	23 38.7	54 26.767	0.258	−0.001	0.005	−0.02	+1.523	+0.017
36	32924	93	23 40.8	49 31.538	0.234	+0.004	0.004	+0.10	+0.412	−0.013

$$\left.\begin{aligned} \epsilon_\delta^2 &= a_1^2 + b_1^2\ tg^2\ z \\ \epsilon_{\mu'}^2 &= a_2^2 + b_2^2\ tg^2\ z \end{aligned}\right\} \qquad (3)$$

the values of the errors ϵ_δ and $\epsilon_{\mu'}$ have been analysed as function of zenith distances (z). Table 5 contains the calculated data. The quantities **b** are relatively high because of the extremly low values of tg z. The caluclated values a are virtually the same. But, by all means, there is some dependance of ϵ_δ values on zenith distances, while at the some time the situation is different concerning the $\epsilon_{\mu'}$ ones.

We have separatly analysed the errors of south and north stars declination and proper motion determinations, and concluded there are sensible differences between them. It can be explained by the fort that it is in a great part due to the consequence of the local anomalous refraction influences (the already performed investigations verified such conclusion).

Table 4. The mean errors of the declination and proper motion determination

	System		
Errors of	1	2	3
declination	±0".270	±0".290	±0".286
proper motion	±0.006	±0.006	±0.006

Table 5. The data determined by the formula (3). The r value is the coefficient of correlation.

Data	system		
	1	2	3
a_1	0".262	0".269	0".268
b_1	82".90	93".92	86".14
r	0.38	0.40	0.35
a_2	0".013	0".010	0".010
b_2	3".07	3".07	2".96
r	0.07	0.12	0.09

4.2. The declinations of Belgrade zenith stars are between $+44^{o}33'$ and $+44^{o}58'$ – namely they are in the narow declination zone. For this reason when we make a comparison between declinaton δ_{BZS} of our catalogues and the declinations δ_i of same stars of the other catalogues, the mean value of all data ($\delta_i - \delta_{BZS}$) has to be treated as $\Delta\delta_\delta$ (the systematic correction to declination) which is a function of declination only) for the zone $+44^{o}48'$.

The data of our catalogues have been compared with the adequate data of following catalogues: Boss' GC, KŠZ (Sadžakov, Šaletić, 1972), Khairin' catalogue (1963) as well as IKŠZ (Sadžakov, 1978). The number of common stars are diferent – see Table 6.

The more complete comparison is with the Boss' GC which contains all of our stars. As Table 6 shows the mean value of ($\delta_{GC} - \delta_{BZS}$) is $-0''.227$, $-0''.164$ and $-0''.214$ respectively for different systems. The average value is $-0''.201$. This one is very comparable with the $\Delta\delta_\delta$ obtained from the systematic differences FK4–GC for 1950.0 (Brosche et al., 1964). Namely the systematic differences GC–FK4 for the zone between $+44^{o}$ and 45^{o} is $-0''.18$. On the basis of these data we can conclude that our system of declination is in accordance with the corresponding FK4 system.

But the things are not the same with the systematic differences in annual proper motion, between GC and our catalogues. Namely, the differences GC–FK4 for 1950.0 (Brosche et al., 1964) are 4–5 times smaller than the differences GC–BZS. Consequently, the agreement between FK4 and BZS system of proper motion is not complete.

The Table 6 contains the results of comparison with other catalogues. As it appears from these facts, the values $\Delta\delta_\delta$ and $\Delta\mu'_\delta$ are different. There are three main explanations about this: first, our programme contains small number of stars whose distribution in right ascension is not even – it is especially valid in the case when the common stars are insufficient, second, the real characteristics of the certain catalogue, and third, the relatively short period of our observations for the determination of proper motion values. In addition to these shortcommings, there is a positive fact: the differences $\Delta\delta_\delta$ and $\Delta\mu'_\delta$ from all comparisons are negative ones which in all probability, is true. It is interesting to notice that the declination and proper motion systems of our catalogues are close to the IKŠZ system (which is in the system FK4).

The values ($\delta_{GC} - \delta_{BZS}$) – $\Delta\delta_\delta$ for all three our systems – see the Table 7 – which are treated as the sytematic corrections to the right ascension $\Delta\delta_\alpha$, were analysed by the formúla

$$\Delta\delta_\alpha = (\delta_{GC} - \delta_{BZS}) - \Delta\delta_\delta = c_o + c_1 \sin(\alpha + a_1) + + c_2 \sin(2\alpha + a_2) + c_3 \sin(3\alpha + a_3) \qquad (4)$$

where α is the right ascension. The similar formula was used for the analysis of the systematic corrections $\Delta\mu'_\alpha$. The values c_i and a_i are determined by the method of least squares. It can be concluded that the $\Delta\delta_\alpha$ and $\Delta\mu'_\alpha$ have practically the same tendency of variations as the adequate differences FK4–GC for 1950.0 (Brosce et al., 1964), but in our case the discrepancy between individual data is larger (which is understable).

Table 6. The values $\Delta\delta_\delta$ and $\Delta\mu'_\delta$ based on the comparisons of catalogues ($\delta_i - \delta_{BZS}$ or ($\mu'_i - \mu'_{BZS}$, where i is notation of adequate catalogue)

Catalogue	Number of common stars	$\Delta\delta_\delta$ system 1	2	3	$\Delta\mu'_\delta$ system 1	2	3	Epoch	Equinox
GC	36	$-0''.227$	$-0''.164$	$-0''.214$	$-0''.016$	$-0''.014$	$-0''.014$	1970.0	1970.0
KŠŽ	32	-0.223	-0.191	-0.209	–	–	–	KŠZ	1950.0
IKŠZ	30	-0.031	$+0.028$	-0.022	-0.0011	-0.0008	-0.0007	1970.0	1970.0
IKŠZ	30	-0.014	$+0.045$	-0.005	-0.0011	-0.0008	-0.0007	IKŠZ	1950.0
Kharin	11	-0.144	-0.074	-0.125	–	–	–	Kharin'	1950.0

Table 7. Values $\Delta\delta_\alpha$ and $\Delta\mu'_\alpha$ for different systems

	system	c_0	c_1	a_1	c_2	a_2	c_3	a_3
$\Delta\delta_\alpha$	1	-0.188	$+0.324$	-3.2	$+0.468$	$+38.5$	$+0.209$	$+35.3$
	2	-0.191	$+0.544$	-7.2	$+0.476$	$+37.2$	$+0.213$	$+30.0$
	3	-0.191	$+0.335$	-3.0	$+0.460$	$+37.2$	$+0.210$	$+33.6$
$\Delta\mu'_\alpha$	1	$+0.006$	$+0.054$	-83.8	$+0.008$	$+62.9$	$+0.017$	-70.9
	2	-0.0001	$+0.044$	-75.9	$+0.008$	$+58.6$	$+0.024$	-71.5
	3	$+0.004$	$+0.048$	-82.9	$+0.009$	$+70.0$	$+0.021$	-74.0

4.3. The Table 8 presents the differences of declinations and paper motions between our three systems. The mean differences between the systems are as follow :

	1–2	1–3	2–3
$\Delta\delta_\delta$	+0.″063 ±0.041	+0.″013 ±0.035	−0.″050 ±0.025
$\Delta\mu'_\delta$	+0.″002 0.013	+0.″002 ±0.011	0.″000 ±0.005

Table 8. Systematic differences of declinations and proper motions in declination given by the catalogues $BZS1_{70}$, $BZS2_{70}$, and $BZS3_{70}$. The unit: 0.″001

Number of stars	differences between systems $\Delta\delta_\delta$ 1–2	$\Delta\delta_\delta$ 1–3	$\Delta\delta_\delta$ 2–3	$\Delta\mu'_\delta$ 1–2	$\Delta\mu'_\delta$ 1–3	$\Delta\mu'_\delta$ 2–3
1	+ 71	+ 9	− 62	0	− 3	− 3
2	+ 69	+ 10	− 59	+ 1	+ 4	+ 3
3	+ 95	+ 43	− 52	−10	− 9	+ 1
4	+183	+134	− 49	−33	−28	+ 5
5	+ 57	− 2	− 59	−18	−12	+ 6
6	+ 46	− 18	− 64	0	− 1	− 1
7	+100	+ 32	− 68	− 7	− 4	+ 3
8	+ 95	+ 17	− 78	− 4	− 1	+ 3
9	+ 71	+ 14	− 57	− 4	+ 2	+ 6
10	+ 84	+ 11	− 73	−19	− 7	+ 12
11	+ 68	+ 1	− 67	−10	− 1	+ 9
12	+ 77	+ 5	− 72	− 9	− 2	+ 7
13	+ 62	− 14	− 76	− 6	− 2	+ 4
14	+ 18	+ 21	+ 3	+ 4	+ 7	+ 3
15	+ 26	+ 18	− 8	+ 4	+ 7	+ 3
16	+ 40	+ 19	− 21	− 2	+ 1	+ 3
17	+ 31	+ 10	− 21	− 1	+ 2	+ 3
18	+ 34	+ 24	− 10	+ 1	+ 3	+ 2
19	− 8	− 32	− 24	+ 11	+ 7	− 4
20	+ 18	+ 6	− 12	+ 3	+ 4	+ 1
21	+ 12	− 5	− 17	+ 7	+ 7	0
22	+ 6	− 9	− 15	+ 9	+ 8	− 1
23	+ 41	+ 18	− 23	+ 2	+ 2	0
24	+ 64	− 1	− 65	+ 16	+ 12	− 4
25	+ 84	+ 25	− 59	+ 4	0	− 4
26	+189	+129	− 60	+ 48	+ 43	− 5
27	+ 45	− 24	− 69	+ 9	+ 2	− 7
28	+ 52	− 30	− 82	− 5	−14	− 9
29	+ 97	+ 31	− 66	+ 20	+ 17	− 3
30	+ 74	− 30	−104	+ 12	− 2	−14
31	+ 93	+ 49	− 44	+ 4	+ 5	+ 1
32	+ 73	+ 17	− 56	+ 13	+ 12	− 1
33	+ 46	− 17	− 63	+ 4	+ 2	− 2
34	+ 32	− 6	− 38	+ 5	+ 4	− 1
35	+ 65	+ 16	− 49	+ 4	+ 3	− 1
36	+ 63	+ 14	− 49	+ 4	+ 3	− 1

This shows that the differences between our three systems are not negligible: the maximum individual difference in declination is 0.″189 as well as 0.″048 in proper motion. The open question is which of our systems is the most real because there is no a perfectly reliable point of support (catalogue, reference of frame). In absence of this support, for the basis of valuation we will use the internal accuracy – from this point of view the system 1 is the most authentic. But apart from this conclusion, we will continue to calculate the declinations and proper motions of the Belgrade zenith stars in three mentioned systems

5. CONCLUSIONS

Our estimation is that the Belgrade zenith telescope is suitable to the relatively accurate determination of declinations and proper motions of zenith stars. We believe that this fact can also be useful for the observens on other zenith telescopes.

The observations of zenith stars will be continued in the Belgrade Observatory.

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REFERENCES

Brosche, P., Nowackki, H., Strobel, W.: 1964, *Veroff. Astron. Rechen. Inst. Heidelberg,* **15**, 6.

Kharin, A.S.: *Katalog sklonenij zvezd zenit–teleskopov v sisteme FK4 dlya epohi nablyudeniya i ravnodenstviya 1950.0,* Akad. nauk USSR, Kiev, 1.

Milovanović, V., Teleki, G., Grujić, R.: 1981, *Publ.Astron. Obs. Sarajevo,* **1**, 131.

Sadžakov, S.: 1978, *Publ.Obs. Astron. Belgrade,* **24**, 1.

Sadžakov, S., Saletić, D.: 1972, *Publ.Obs.Astron. Belgrade,* **17**, 1.

Ševarlić, B., Teleki, G.: 1960, *Bull. Obs. Astron. Belgrade,* **24**, 3–4, 27

Teleki, G., Grujić, R.: 1987, *Astron. Astrophys* , **177**, 313(1987).

INVESTIGATIONS OF THE EW–WE EFFECT IN THE LATITUDE DETERMINATIONS WITH THE BELGRADE ZENITH–TELESCOPE IN THE PERIOD 1969.0–1981.0

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ABSTRACT: The EW–WE effect in the latitude determinations with the Belgrade zenith–telescope in the period 1969.0–1981.0 have been analysed and it was concluded that they are smaller ones as well as more accuretely determined than in the period 1960.0–1969.0 (Teleki, Grujić, 1982). This is due to alterations (thermal insulation of the instrument, rebuilding of the pavilion improvements in the observational procedure and data processing) executed in the period 1968–1970 (Milovanović et al., 1981). The results obtained by formula (3) point to several sources giving rise to the EW–WE effects, but it can be proved that the influences of these sources are remarkably weaker in the period 1969.0–1981.0 then before that.

1. PREFACE

In the previous paper (Teleki, Grujić, 1982) we have analysed the EW–WE – or shortly EW – effects in the latitude determinations with the Belgrade zenith–telescope in the period 1960–1969.0. Now we continue these investigations – by the same method of analysis as before – using the observation material collected from 1969.0 to 1981.0. We decided to do this research although some alterations of the instrument (thermal insulation), of the pavilion (it is now more closed than before), of the observational procedure and of data processing, effected in the period 1968–1970 (Milovanović et al., 1981), which in principle could change the character of EW–WE effects. We have to point out that in the material of the period 1969.0–1981.0 the calculation of micrometer corrections was more rigorous than before that.

2. THE METHOD OF ANALYSIS

The observational programme of the Belgrade zenith–telescope comprises 6 groups of 10 Talcott pairs each. As the basis of our analysis we used the mean values of observational data of 5 Talcott pairs of the same group.

The following formulae have been used:

$$\Delta\varphi_{EW,ab} = \varphi_{Ea} - \varphi_{Wb} \quad (1)$$

$$\Delta\varphi_{EW,ba} = \varphi_{Eb} - \varphi_{Wa} \quad (2)$$

$$\Delta\varphi_{EW,ab}\ (\text{or}\ \Delta\varphi_{EW,ba}) = B_o + B_1\ (t-t_o) + B_2(\Delta M - \Delta M_o) + B_3\ (\Delta\beta - \Delta\beta_o) \quad (3)$$

where are :

φ_{Ea} – the mean value of latitude obtained by the pairs numbered 1,3,5, 7 and 9 of the same group, in which the first star was observed at clamp E,

φ_{Eb} – the same as for the φ_{Ea}, with the difference that the pairs numbered 2, 4, 6, 8 and 10 were used,

φ_{Wa}, φ_{Wb} – similar to φ_{Ea} and φ_{Wb}, but for the case when the first star was observed at clamp, W,

B_o, B_1, B_2, B_3 – the constants, determined by the least square method.

t – the temperature of instrument,

ΔM – the micrometer reading differences,

$\Delta\beta$ – the inclination difference of the Talcott levels,

t_o, ΔM_o, $\Delta\beta_o$ – the mean values adopted.

In the period 1969.0–1981.0 the observers were: R.Grujić (RG), M.Đokić (MD), L.Đurović (LD) and V.Milovanović (VM).

3. THE RESULTS OF ANALYSIS AND CONCLUSIONS

The results of analysis are given in the table I and II. The following conclusions might be drawn:

3.1. The influence of instrument temperature is small; the term is noticeably weaker and determined with smaller errors than in the period 1960.0–1969.0.

3.2. The influence of term depending on the micrometer reading difference is negligible; this term is markedly smaller and more accurately determined than in the previous period.

Table 1. The values B_1, B_2 and B_3 for different observational groups (I, II,...IV) and their mean values. The correlation coefficient is denoted by **r** and the number of the equations of condition by **n.**

Gr.	Combination ab							
	B_1		B_2		B_3		r	n
I	−0.″004	±0.″002	+0.″010	±0.″004	+0.″111	±0.″045	0.40	80
II	−0.002	0.002	−0.001	0.003	−0.012	0.060	0.14	48
III	+0.002	0.002	+0.006	0.008	+0.018	0.009	0.33	55
IV	+0.004	0.002	−0.013	0.008	+0.087	0.012	0.84	53
V	+0.001	0.003	+0.002	0.003	+0.147	0.023	0.51	77
VI	+0.002	0.002	−0.003	0.004	+0.096	0.011	0.47	80
mean value	+0.0004	0.002	+0.001	0.005	+0.084	0.026	0.45	393
	Combination ba							
I	+0.001	0.002	+0.0001	0.005	+0.118	0.079	0.20	72
II	−0.008	0.003	−0.011	0.004	+0.179	0.082	0.48	46
III	−0.001	0.002	+0.010	0.008	+0.066	0.019	0.44	54
IV	+0.002	0.003	+0.002	0.009	−0.018	0.011	0.39	59
V	+0.008	0.003	+0.002	0.003	+0.106	0.013	0.69	77
VI	+0.001	0.002	+0.012	0.005	+0.071	0.044	0.25	93
mean value	+0.001	0.002	+0.003	0.005	+0.087	0.040	0.43	403

Table II. The values B_1, B_2 and B_3 from the entire material for different combinations ab and ba as well as for different observers. The correlation coefficient is denoted by **r**, and the number of the equations of condition by **n.**

Observer	Combination ab					Combination ba				
	B_1	B_2	B_3	r	n	B_1	B_2	B_3	r	n
All Obser.	+0.″004	+0.″001	+0.″084	0.45	393	+0.″001	+0.″003	+0.″087	0.43	403
RG	−0.001	+0.001	+0.052	0.52	181	−0.001	+0.001	+0.020	0.17	192
MD	+0.003	+0.005	+0.055	0.51	129	+0.002	+0.004	+0.023	0.22	113
LD	+0.004	−0.025	−0.270	0.27	29	+0.006	+0.085	+0.004	0.80	28
VM	−0.004	+0.012	+0.148	0.82	35	+0.001	+0.017	+0.120	0.63	53
	+0.002	+0.0001	+0.061			+0.001	+0.005	+0.067		

General mean value $\left\{ \begin{array}{ll} B_1 & +0.''001 \\ B_2 & +0.002 \\ B_3 & +0.064 \end{array} \right.$

3.3. The B_3 quantity is practically the same as in the period 1960.0–1969.0, but the total influence of $B_3(\Delta\beta - \Delta\beta_o)$ is significantly smaller in the period 1969.0–1981.0 than before that, because from 1969.0 the inclination values were very near to zero as the result of mechanical adjustment; it is interesting to notice that the B_3 data, for the period 1969.0–1981.0, are determined with higher accuracy than in the previous period.

3.4. The differences in the results obtained from the different data (ab and ba variants) also show that the declination system of observational programme in the period 1969.0–1981.0 is more homogeneous than before.

3.5. It also follows from the Table II, that personal influences are not negligible; as it appears from r values of the Table I, there are some seasonal variations, too.

3.6. The formula (3) is undoubtedly not an ideal one, but everything points to the fact that nevertheless it approximates the real state very well, which appears from the relatively high – higher than in the period 1960.0–1969.0 – values of the correlation coefficients (r).

In our previous paper (Teleki, Grujić, 1982) it was concluded that the EW effects after 1969.0 are reduced while the accuracy of their determination has increased.

Now we are able – on the basis of a more complete analysis – to bear out this statement. In support of that we used the values of B_0, which in a proper sense are $\Delta\varphi_{EW}$ for the t_0, ΔM_0 and $\Delta\beta_0$.

Table III. The values B_0 in two observational periods, for the variants ab and ba.

Period	1960.0–1969.0		1969.0–1981.0	
Variant	ab	ba	ab	ba
B_0	$-0''.078$	$-0''.009$	$+0''.010$	$+0''.026$
Error of B_0 determinations	±0.045	±0.045	±0.010	±0.012

We can conclude from the Table III, that the mean value of B_0 for the first period is -0.052 ± 0.045 and for the second period $+0.018 \pm 0.011$. Accordingly the sign of the EW effects in changed and it is of the utmost importance that the effects are reduced and more accurately determined. The influences of different sources – mentioned in points 3.1 to 3.6 – invariably exist, but their effects are appreciably reduced, compared with the period 1969.0–1969.0.

This analysis shows that we realized the target – envisaged in our previous paper (Teleki, Grujić, 1982) – to reduce the E Weffects in the Belgrade latitude data by means of these necessary steps.

REFERENCES

Milovanović, V., Teleki, G., Grujić, R.: 1981, *Publ. Astron.Obs. Sarajevo*, **1**, 131.

Teleki, G., Grujić, R.: 1982, *Hvar Obs.Bull.*, **6**, Suppl. 1, 61.

THE WIDENED BELGRADE LATITUDE OBSERVATIONAL PROGRAMME AND ITS CHARACTERISTICS

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SUMMARY: The original Belgrade latitude observational programme (Šavarlić, Teleki, 1960), which was observed from 1960.0, needed some improvement and teherfore a widened programme was developed. The paper gives some informations on the characteristics of this new, widened programme. The preliminary value of systematic differences between the latitudes obtained in the complete and the original programmes is 0."010.

1. INTRODUCTION

The observational programme of the Belgrade zenith–telescope (Askania, 110/1287 mm) contains six groups of Talcott–pairs (Ševarlić, Teleki, 1960). The groups are divided into two subgroups and each subgroup includes 5 Talcott–pairs. In all, the programme takes 13.4 hours in the right ascension. Fig. 1 graphically shows the distribution of the groups – notations: I, II, III, IV, V and VI – and their subgroups – notations: Ia, Ib, IIa, ..., VIa, VIb – platted against right ascensions.

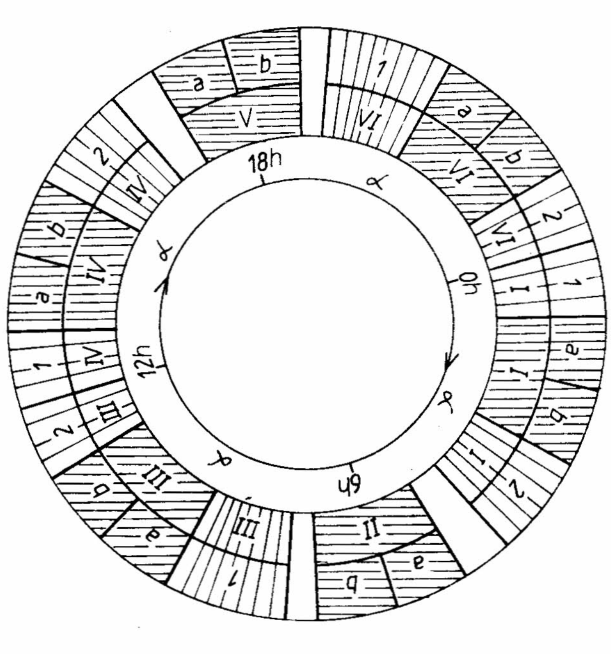

Fig. 1. The distribution of the original (Ia, Ib,...) and the additional (I–1, I–2...) parts of observational programme platted against right ascensions (α).

This programme has been observed from 1960.0. Our main wish is to observe them much longer, in particular groups II and V – around the right ascension 6^h and 18^h – in which the changes of zenith distance differences of pairs are small. It means that our important intention is to investigate the long (or, better to say, longer) term variations of latitude as well as the constant of nutation.

As a matter of course, to reach this goel, it is not enough to protect only groups II and V, but the „bridge" between these groups, too. And, it was exactly, this bridge that ran into difficulties in later years. Therefore on the initiative Dr V.Milovanovića we decided to make an alteration of the original observational programme. This paper analyses this problem and its solving.

2. WIDENED OBSERVATIONAL PROGRAMME

Table 1 includes the sum total of pairs zenith distance differences ($\Sigma\Delta z$) of original programme subgroups for the epochs 1960, 1970, 1980, 1985, and 1990. It is apparent that the programme was constructed in relation to the mean epoch 1970. As we depart from this mean epoch, the annual wave of subgroups $\Sigma\Delta z$ is more and more significant and it, of course, influences the latitude data. Therefore we decided to break this wave with a new, additional part of programme. We added eight new subgroups – whose notations are: I 1, II–2, III–1, III–2, IV–1, IV–2, VI–2, VI–1 and VI–2 – between original groups (see Fig. 1). These additional subgroups were selected in that way that their $\Sigma\Delta z$ as much as possible compensate the neighbouring original subgroups $\Sigma\Delta z$. So, we are able to reduce the influence of $\Sigma\Delta z$ factors to the latitude (we very carefully investigate and determine the angular value of micrometer screw, but this value is never fully correct). At the same time the complete programme was subtended from 13.4

hours to, practically, 24 hours in the right ascension (this fact was especially important during the MERIT compaigne).

Table 1. The $\Sigma\Delta z = (\varphi_m - \delta_m)$ values of subgroups for different epochs. The unit: minute of arc.

Subgroup	programme						
	original				complete		
	1960	1970	1980	1990	1980	1985	1990
I 1					1.7	0.1	−1.6
I a	2.9	−0.2	−3.3	−6.4	−3.3	−4.8	−6.4
I b	3.3	0.7	−1.9	−4.4	−1.9	−3.1	−4.4
I 2					3.2	2.2	1.3
II a	0.0	−0.5	−1.1	−1.5	−1.0	−1.3	−1.5
II b	0.1	0.5	1.0	1.5	1.1	1.3	1.5
III 1					−4.4	−3.5	−2.7
III a	−0.1	2.5	5.1	7.7	5.1	6.4	7.7
III b	−4.4	−1.3	1.8	5.0	1.9	3.4	5.0
III 2					−5.0	−3.3	−1.7
IV 1					−5.7	−4.1	−2.4
IV a	−3.8	−0.7	2.2	5.5	2.4	3.9	5.5
IV b	−2.6	0.0	2.6	5.1	2.6	3.9	5.1
IV 2					−4.3	−3.3	−2.4
V a	−0.6	−0.2	0.3	0.7	0.3	0.5	0.7
V b	+0.5	−0.0	−0.6	−1.1	−0.5	−0.8	−1.1
VI 1					5.6	4.8	3.9
VI a	2.0	−0.6	−3.2	−5.8	−3.2	−4.5	−5.8
VI b	2.4	−0.7	−3.8	−6.9	−3.8	−5.5	−6.9
VI 2					2.2	0.6	−1.1
$\Sigma\Delta z$	−0.3	−0.5	−0.9	−0.6	−7.0	−7.1	−7.3

The Table 2 contains the data of new subgroups stars. The stars were selected from the Boss' Catalogue (GC), with the correction to the FK4 system. It is important to notice that the additional subgroups include not exactly 5 pairs – as the original subgroups – but the different number of pairs: from 4 to 7.

Lets go back to the Table 1, which includes the values $\Sigma\Delta z$ for the complete programme. Noticeably the annual wave of $\Sigma\Delta z$ values is broken.

3 ANALYSES

3.1. From 1983.0 to 1986.0 we observed the original programme parallel with the additional one. This three–years period will be used for the analyses and for the establishing of unified latitude data system. All latitude data are in the MERIT–system.

It is important to point out that for the analyses we use the mean values of latitudes obtained from all pairs of subgroup (and not from the separate pairs).

The observers were: R.Grujić (RG), M.Đokić (MD), N.Đokić (ND), S.Šegan (SŠ), and R.Krga (RK). The numbers of their observations of different subgroups are given in the Table 3.

3.2. During the same nights there were observed one or more subroups (sometimes 6). The Table 4 shows the numbers of nights when two neighbouring subgroups were observed. There are 406 such observational data.

3.3. The Table 5 contains the declination corrections $\Delta\delta$ for the complete programme. The same table also includes these corrections for the original programme, obtained for the mean epoch 1970.–75.

Table 2. The list of stars of the additional subgroups.

Sub–group	pair	GC	m	Sp	α_{1950}			δ_{1950}		
					h	m	s			
I_1	1	119	7.1	A5	0	5	26.849	31°	6'	48".45
		193	7.1	B5	0	8	48.555	57	56	2.00
	2	362	4.5	A2	0	15	42.484	36	30	29.90
		488	5.7	B9	0	22	23.371	52	46	11.96
	3	702	7.0		0	33	3.516	48	44	45.22
		829	7.0	F3	0	39	17.588	40	24	54.60
	4	918	6.0	B8	0	43	24.111	44	35	18.67
		999	6.1	A0	0	47	30.138	44	43	48.38
I_2	1	3876	6.7	A0	3	12	13.222	50	46	19.47
		3939	7.4	F5	3	15	17.562	38	16	40.84
	2	4041	1.9	F5	3	20	44.441	49	41	6.08
		4236	5.8	A0	3	30	16.710	39	43	57.38
	3	4320	7.4	A0	3	34	51.312	44	38	20.95
		4597	5.8	G0	3	46	35.044	44	49	1.12
	4	4703	6.3	A5	3	51	45.285	56	46	25.26
		4891	6.7	A3	4	1	32.184	32	26	7.14
	5	4958	6.7	B8	4	4	44.265	43	3	32.87
		5256	4.9	B3	4	17	55.666	46	22	53.02

Tabela 2 (continued)

Sub-group	pair	GC	m	Sp	α_{1950} h	m	s	δ_{1950} °	'	"
III$_1$	1	9897	3.9	K0	7	22	37.392	27	53	57.24
		10036	6.7	G5	7	27	33.429	61	51	57.42
	2	10164	6.0	K0	7	32	43.315	55	52	2.87
		10354	6.0	F0	7	39	29.304	34	7	8.90
	3	10579	6.0	A0	7	47	49.715	33	21	41.29
		10700	6.5	A0	7	52	24.263	56	38	17.08
	4	10877	7.5	A0	7	58	52.812	54	16	16.89
		11061	7.3	K0	8	6	25.182	35	51	2.09
	5	11281	6.9	F0	8	14	36.775	35	53	4.06
		11458	7.2	F2	8	21	21.328	54	5	41.08
	6	11688	6.8	A0	8	29	54.930	58	46	43.73
		12037	6.1	K0	8	42	17.624	30	52	48.97
III$_2$	1	15506	6.0	K0	11	13	53.303	49	44	58.12
		15622	6.6	F5	11	19	58.742	40	26	58.88
	2	15726	6.9	F0	11	25	13.344	44	50	29.19
		15939	6.6	B9	11	34	56.226	44	59	35.70
	3	16066	6.6	F2	11	39	29.519	22	29	20.90
		16186	7.2	F8	11	46	28.116	67	36	23.67
	4	16268	2.5	A0	11	51	12.566	53	58	21.95
		16439	5.6	K0	11	59	6.170	36	19	17.22
IV$_1$	1	16557	7.9	G5	12	4	38.407	69	21	15.49
		16667	5.7	G5	12	9	36.779	20	49	12.94
	2	16750	5.9	K5	12	13	37.463	40	56	18.09
		16814	5.6	K2	12	17	21.299	49	15	41.07
	3	16873	4.8	A3	12	19	59.625	26	7	24.32
		16941	6.4	G5	12	22	46.982	64	4	46.20
	4	17024	7.1	G5	12	27	8.353	67	10	12.20
		17142	4.8	A0	12	32	21.628	22	54	15.38
	5	17224	6.5	K0	12	36	33.174	22	56	3.61
		17387	5.7	K1	12	45	32.205	67	3	46.81
IV$_2$	1	20543	7.1	F8	15	14	26.849	37	15	7.80
		20680	7.5	F2	15	20	0.099	52	31	21.43
	2	20761	5.9	K0	12	24	19.854	34	30	32.55
		20833	6.3	A2	15	27	39.147	55	21	55.55
	3	20956	7.2	K0	15	33	5.787	44	13	55.92
		21141	6.9	F0	15	41	1.044	45	55	7.47
	4	21232	7.2	K0	15	45	20.487	47	8	23.75
		21316	7.2	F2	15	49	15.307	42	42	52.21
	5	21400	5.6	B8	15	53	49.456	42	42	38.23
		21577	5.8–7.2	Mc	16	1	8.860	47	22	35.81
	6	21736	4.3	B9p	16	7	11.505	45	3	54.08
		22098	7.2	F5	16	23	14.788	44	48	11.20
VI$_1$	1	26847	6.7	G5	19	24	25.007	44	49	51.05
		27140	5.2	G5	19	35	4.875	44	35	0.04
	2	27240	6.4	Ma	19	39	3.891	42	57	36.86
		27366	7.1	K2	19	44	20.812	46	21	43.87
	3	27513	6.2	F0	19	49	49.684	47	14	52.35
		27665	6.5	A2	19	56	15.197	42	7	29.58
	4	27869	6.0	A0	20	2	58.955	48	5	11.68
		28019	6.9	A2	20	8	59.618	41	5	50.41
	5	28297	6.2	B0	20	18	20.614	46	40	42.45
		28429	6.8	F5	20	23	41.185	42	26	26.16
	6	28541	4.3	A5	20	28	44.693	62	49	32.24
		28702	5.5	B9	20	34	56.569	26	17	12.96
	7	28854	5.6	B8	20	40	8.041	41	32	13.32
		29012	5.6	K0	20	46	10.499	47	38	47.82
VI$_2$	1	32437	6.3	B90	23	15	34.869	45	12	56.38
		32506	6.1	A3	23	18	21.653	43	50	34.06
	2	32642	7.5	G5	23	25	17.453	44	30	36.64
		32766	6.3	G5	23	31	17.070	44	46	53.94
	3	32850	4.3	B8	23	35	40.602	42	59	28.16
		32988	5.1	K0p	23	43	32.858	46	8	33.59
	4	33160	Var.	F8p	23	51	52.419	57	13	16.59
		33253	6.4	B5	23	56	15.939	32	6	12.64

Table 3. The number of observations of the different subgroups. The observers were: R.Grujić (RG), M.Đokić (MD), N.Đokić (ND), R.Krga (RK) and S.Šegan (SŠ).

	subgroups																				
Observer	I 1	I a	I b	I 2	II a	II b	III 1	III a	III b	III 2	IV 1	IV a	IV b	IV 2	V a	V b	VI 1	VI a	VI b	VI 2	Total
RG	18	25	14	8	11	14	7	12	14	13	8	11	8	8	19	20	8	12	21	21	272
MD	9	4	4	1	1	4	2	3	3	2	–	1	3	1	10	10	5	9	11	4	87
ND	12	7	6	–	–	1	2	5	3	1	1	3	3	9	14	20	16	19	22	18	162
RK	3	–	–	–	1	–	–	–	–	–	–	3	2	1	2	12	12	10	11	4	61
SŠ	1	1	–	–	–	–	–	–	1	1	–	3	5	1	–	1	4	5	3	2	28
Total	43	37	24	9	13	19	11	20	21	17	9	21	21	20	45	63	45	55	68	49	610

Table 4. The total numbers of observations of two neighbouring subgroups during same nights.

subgroups	number	subgroups	number
I 1, I a	30	IV 1, IV a	13
I a, I b	26	IV a, IV b	11
I b, I 2	10	IV b, IV 2	18
I 2, II a	7	IV 2, V a	18
II a, II b	14	V a, V b	34
II b, III 1	9	V b, VI 1	25
III 1, III a	11	VI 1, VI a	34
III a, III b	13	VI a, VI b	40
III b, III 2	14	VI b, VI 2	42
III 2, IV 1	7	VI 2, I 1	30

Table 5. The declination corrections $\Delta\delta$ separately for the original and the complete programmes. Unit: second of arc. The value k is the closing error.

subgroup	programme	
	original	complete
I 1		−0.017
I a	−0.157	0.065
I b	0.318	0.137
I 2		−0.030
II a	−0.161	−0.079
II b	0.094	−0.083
III 1		−0.084
III a	0.345	−0.150
III b	0.350	−0.032
III 2		−0.005
IV 1		0.067
IV a	0.467	0.053
IV b	−0.483	−0.096
IV 2		0.312
V a	0.118	0.053
V b	−0.203	0.012
VI 1		0.016
VI a	−0.462	−0.021
VI b	−0.243	0.038
VI 2		−0.160
k	− 0.039	−0.043

Table 6. The smooted latitude values (44°48' +) obtained by the original and the complete programmes, for each 0.1 year. Unit: second of arc.

Part of year	programme	
	original	complete
1983.1	10.200	10.160
.2	10.220	10.175
.3	10.230	10.185
.4	10.316	10.310
.5	10.440	10.465
.6	10.565	10.588
.7	10.625	10.646
.8	10.565	10.590
.9	10.387	10.445
1984.0	10.215	10.285
.1	10.153	10.160
.2	10.152	10.080
.3	10.135	10.104
.4	10.184	10.195
.5	10.295	10.315
.6	10.485	10.515
.7	10.585	10.623
.8	10.532	10.590
.9	10.438	10.487
1985.0	10.413	10.445
.1	10.305	10.260
.2	10.183	10.122
.3	10.105	10.070
.4	10.085	10.095
.5	10.127	10.160
.6	10.277	10.305
.7	10.433	10.445
.8	10.527	10.554
.9	10.505	10.565

Table 7. The mean latitude differences between two neighbouring subgroups (Δ), their total numbers (n), the mean errors of Δ determination (ϵ_Δ and the mean error of latitude from the pairs (ϵ_p).

	programme	
	original	complete
n	138	406
Δ	−0".020	−0".003
ϵ_Δ	b 0.086	±0.107
ϵ_p	±0.136	±0.170

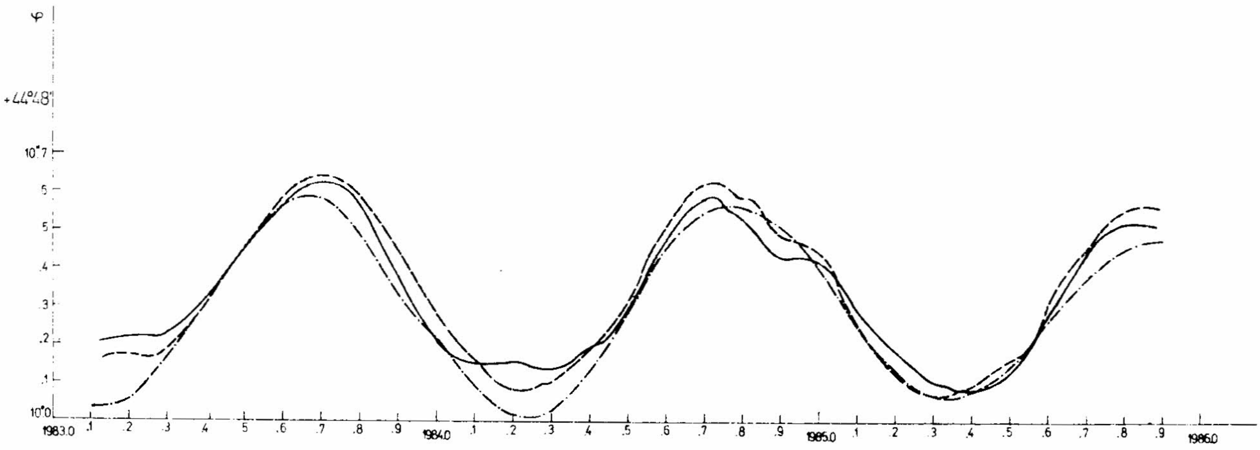

Fig. 2. The smoothed latitude values given by the original programme (——), by the complete one (– – –) and on the basis of BIH data (–·–·–) with the mean latitude of +44°48'10.354.

3.4. The observational data, corected by the $\Delta\delta$ values for the complete programe, are given in the Supplement I. The Fig 2. and Table 6 show the latitude variations – after the process of smoothing.

3.5. In order to estimate the accuracy of our latitude data, we calculated the latitude differences of neighbouring subgroups separately for the original ($\Delta\varphi = \varphi_a - \varphi_b$) and for the complete programmes. On the basis of these data the mean square errors of these differences (ϵ_Δ) and of pairs latitude (ϵ_p) were given – see the Table 7.

This table shows that by the introducing of the additional programme, the accuracy is decreased. It was expected because of the un accurate determination of additional programme subgroups. This state should be changed for the better in the comming years.

Table 8. The mean latitudes (φ_0 = 44°48' +) and z-terms for the original and complete programmes. Unit: second of arc.

Part of year	programme original φ_0	original z	complete φ_0	complete z
1983.9	10.346	0.061	10.358	0.107
1984.0	10.341	0.024	10.355	0.080
.1	10.337	0.086	10.352	0.078
.2	10.338	0.166	10.352	0.070
.3	10.340	0.110	10.352	0.067
.4	10.338	0.066	10.350	0.065
.5	10.335	0.030	10.348	0.037
.6	10.330	0.065	10.344	0.081
.7	10.324	0.073	10.339	0.096
.8	10.322	0.000	10.334	0.046
.9	10.324	−0.044	10.332	−0.003
1985.0	10.327	0.041	10.330	0.070
.1	10.329	0.071	10.331	0.024

3.6. The Orlov–method was used for the calculation of mean latitude values. These values as well as the adequate z–terms – separately for the original and complete programmes – are given in the Table 8.

As it appears from this table, there is the tendency of weak decrease of mean latitude values in both systems. It is doubt less that the data of such a short period cannot give the reliable informations on the mean latitude variation tendency.

The z–term can be represented by the following expressions:
the original programme:

$$z = 0''.063 + 0''.046 \cos(t+85^\circ) + 0''.035 \cos(2t-35^\circ)$$

the complete programme:

$$z = 0''.064 + 0''.005 \cos(t+53^\circ + 0''.011 \cos(2t-45^\circ).$$

It follows that – in the investigated period – the z–term wave of complete programme is less pronounced than of the original one. The investigated period is to short for the final conclusion, but we estimate that this fact is the consequence of the brokened annual wave of $\Sigma\Delta_z$.

We have to point out that for the original programme the following z–term values were given for the period 1960.0–1965.5 (teleki, Grujić, 1969) :

$$z = 0''.005 + 0''.042 \cos(t-89^\circ).$$

In the conclusion it can be stated that the amplitude of annual term of the original programme is about 0".04, but phase angle is changeable.

Supplement I: The latitude values (+44°48'+) obtained by observations of different subgroups.

Date		Julian days	Observer	Group	programme: original subgroup a	original subgroup b	additional subgroup 1	additional subgroup 2
1983								
		2445000+						
I	9	344.360	RG	II	10".142			
	9	344.410	RG	II		10".147		
	12	347.360	RG	II	10.123			
	12	347.400	RG	II		10.116		
	18	353.220	RG	I		10.019		
	18	353.340	RG	II	10.213			
	18	353.390	RG	II		10.115		
	25	360.320	RG	II	10.182			
	25	360.370	RG	II		10.224		
II	1	367.300	RG	II	10.039			
	1	367.350	RG	II		10.103		
	3	369.300	MD	II	10.103			
	3	369.340	MD	II		10.160		
	25	391.280	MD	II		10.112		
	26	392.280	RG	II		10.098		
	26	392.400	RG	III	10.010			
III	8	402.250	RG	II		10.153		
	8	402.370	RG	III	10.056			
	10	404.250	MD	II		10.036		
	10	404.310	MD	III			10".130	
	10	404.370	MD	III	10.057			
	12	406.240	RG	II		10.178		
	12	406.300	RG	III			10.123	
	12	406.360	RG	III	10.045			
	15	409.240	MD	II		10.174		
	15	409.300	MD	III			9.941	
	15	409.350	MD	III	10.068			
	24	418.270	RG	III			10.169	
	24	418.330	RG	III	10.156			
IV	10	435.280	RG	III	10.087			
	10	435.330	RG	III		10.172		
	10	435.380	RG	III				10".343
	17	442.260	RG	III	10.254			
	17	442.320	RG	III		10.204		
	24	449.300	RG	III		10.163		
V	3	458.270	RG	III		10.164		
	3	458.310	RG	III				10.167
	3	458.350	RG	IV			10.319	
	3	458.390	RG	IV	10.001			
	5	460.380	RG	IV	10.133			
	10	465.330	RG	IV			10.257	
	10	465.370	RG	IV	10.293			
	10	465.420	RG	IV		10.234		
	17	472.350	RG	IV	10.208			
	17	472.400	RG	IV		10.154		
VI	2	488.310	RG	IV	10.322			
	2	488.360	RG	IV		10.338		
	5	491.350	RG	IV		10.377		
	5	491.390	RG	IV				10.411
	26	512.410	MD	V	10.486			
VII	6	522.380	MD	V	10.450			
	6	522.430	MD	V		10.602		
	18	534.350	RG	V	10.554			
	18	534.400	RG	V		10.592		
	21	537.390	RG	V		10.702		
	26	542.330	RG	V	10.495			
	26	542.380	RG	V		10.501		

Supplement I: continued

1983								
VIII	10	557.290	MD	V	10".486			
	10	557.330	MD	V		10".556		
	15	562.270	MD	V	10.388			
	15	562.320	MD	V		10.635		
	23	570.300	RK	V		10.674		
	28	575.400	RG	VI	10.656			
	28	575.450	RG	VI		10.641		
	31	578.340	SŠ	VI			10".621	
IX	1	579.270	RG	V		10.576		
	1	579.340	RG	VI			10.582	
	2	580.270	MD	V		10.692		
	3	581.270	RK	V		10.540		
	6	584.260	RK	V		10.586		
	6	584.320	RK	VI			10.558	
	8	586.250	RG	V		10.686		
	9	587.250	MD	V		10.716		
	9	587.310	MD	VI			10.720	
	10	588.250	RK	V		10.554		
	10	588.310	RK	VI			10.674	
	10	588.370	RK	VI	10.696			
	13	591.300	RK	VI			10.842	
	13	591.360	RK	VI	10.740			
	14	592.240	SŠ	V		10.646		
	14	592.300	SŠ	VI			10.604	
	14	592.350	SŠ	VI	10.667			
	15	593.350	RG	VI			10.653	
	15	593.400	RG	VI		10.638		
	16	594.300	MD	VI			10.630	
	21	599.280	SŠ	VI			10.751	
	21	599.340	SŠ	VI	10.546			
	24	602.270	RK	VI			10.613	
	24	602.330	RK	VI	10.712			
	27	605.260	RK	VI			10.831	
	27	605.320	RK	VI	10.865			
	27	605.370	RK	VI		10.736		
	27	605.410	RG	VI				10".671
	27	605.450	RG	I			10.773	
	27	605.480	RG	I	10.889			
	28	606.260	SŠ	VI			10.624	
	28	606.320	SŠ	VI	10.562			
	28	606.370	SŠ	VI		10.560		
	29	607.310	RG	VI	10.705			
X	2	610.350	RG	VI		10.748		
	2	610.400	RG	VI				10.733
	4	612.250	RK	VI			10.551	
	4	612.300	RK	VI	10.715			
	4	612.350	RK	VI		10.742		
	4	612.390	RK	VI				10.598
	5	613.300	SŠ	VI	10.543			
	5	613.350	SŠ	VI		10.463		
	5	613.390	SŠ	VI				10.534
	6	614.290	RG	VI	10.713			
	6	614.340	RG	VI		10.724		
	6	614.380	RG	VI				10.713
	7	615.290	MD	VI	10.554			
	7	615.340	MD	VI		10.551		
	10	618.280	SŠ	VI	10.762			
	10	618.330	SŠ	VI		10.676		
	10	618.370	SŠ	VI				10.750
	11	619.330	RK	VI		10.797		
	13	621.280	RG	VI	10.518			
	13	621.320	RG	VI		10.602		
	13	621.370	RG	VI				10.580
	13	621.400	RG	I			10.639	
	14	622.320	MD	VI		10.560		

Supplement I: continued

1983								
	14	622.360	MD	VI				10.″581
	14	622.400	MD	I			10.″620	
	15	623.320	RK	VI		10.″635		
	15	623.400	RK	I			10.712	
	16	624.320	RG	VI		10.674		
	16	624.360	RG	VI				10.609
	16	624.390	RG	I			10.586	
	16	624.430	RG	I	10.″695			
	22	630.380	RK	I			10.682	
	23	631.300	MD	VI		10.532		
	25	633.290	RK	VI		10.691		
	28	636.230	ND	VI	10.353			
XI	12	651.190	RK	VI	10.392			
	12	651.240	RK	VI		10.638		
	13	652.240	RG	VI		10.473		
	13	652.280	RG	VI				10.649
	13	652.360	RG	I	10.649			
	16	655.310	SŠ	I			10.399	
	16	655.350	SŠ	I	10.552			
	17	656.340	RG	I	10.441			
	18	657.180	ND	VI	10.438			
	18	657.270	MD	VI				10.574
	18	657.300	MD	I			10.364	
	18	657.340	MD	I	10.416			
	19	658.170	RK	VI	10.479			
	19	658.220	RK	VI		10.559		
	20	659.220	RG	VI		10.554		
	20	659.260	RG	VI				10.635
	20	659.340	RG	I	10.505			
	24	663.320	RG	I	10.444			
	24	663.380	RG	I		10.506		
	24	663.420	RG	I				10.390
	25	664.160	ND	VI	10.473			
XII	22	691.250	RG	I	10.456			
	25	694.200	RG	I			10.321	
	25	694.240	RG	I	10.255			
	25	694.290	RG	I		10.140		
	30	699.230	MD	I	10.257			
	30	699.280	MD	I		10.258		
1984								
I	3	703.220	RG	I	10.219			
	3	703.270	RG	I		10.144		
	3	703.310	RG	I				10.077
	31	731.190	RG	I		10.176		
	31	731.240	RG	I				10.208
II	2	733.300	RK	II	10.274			
	2	733.350	RG	II		10.143		
	2	733.410	RG	III			10.121	
	5	736.290	RG	II	10.246			
	5	736.340	RG	II		10.149		
III	15	775.290	RG	III			10.092	
	15	775.350	RG	III	10.076			
	15	775.400	RG	III		10.013		
	15	775.450	RG	III				10.110
	19	779.340	MD	III	10.004			
	20	780.340	RG	III	9.993			
	20	780.390	RG	III		10.031		
	24	784.380	RG	III		9.978		
	27	787.320	RG	III	10.020			
	27	787.370	RG	III		9.988		
	27	787.410	RG	III				10.020

Supplement I: continued

1984								
IV	1	792.400	RG	III				9".970
	1	792.430	RG	IV			10".025	
	7	798.340	RG	III		10".105		
	7	798.380	RG	III				10.077
	14	805.320	RG	III		10.046		
	14	805.360	RG	III				9.997
	14	805.400	RG	IV			9.997	
	14	805.440	RG	IV	10".044			
	16	807.320	SŠ	III		10.149		
	16	807.360	SŠ	III				10.145
V	14	835.360	RG	IV	10.222			
	14	835.400	RG	IV		10.103		
	14	835.450	RG	IV				10.110
	18	839.390	MD	IV		10.030		
	19	840.340	SŠ	IV	10.065			
	19	840.390	SŠ	IV		10.162		
	21	842.290	RG	IV			10.079	
	21	842.340	SŠ	IV	10.042			
	21	842.390	SŠ	IV		10.116		
	21	842.430	RG	IV				10.157
	24	845.330	RK	IV	10.253			
	28	849.320	SŠ	IV	10.133			
	30	851.360	SŠ	IV		10.135		
	31	852.310	RK	IV	10.365			
	31	852.360	RK	IV		10.177		
VI	2	854.350	RG	IV		10.013		
	2	854.400	RG	IV				10.121
	2	854.470	RG	V	10.154			
	3	855.300	ND	IV	10.073			
	5	857.300	RK	IV	10.123			
	5	857.390	RG	IV				10.230
	8	860.340	ND	IV		10.124		
	8	860.380	ND	IV				10.335
	10	862.330	ND	IV		10.243		
	10	862.380	ND	IV				10.483
	10	862.450	ND	V	10.243			
	10	862.500	ND	V		10.318		
	12	864.370	RG	IV				10.383
	12	864.450	RG	V	10.329			
	12	864.490	RG	V		10.391		
	13	865.320	SŠ	IV		10.191		
	13	865.490	ND	V		10.366		
	14	866.320	RK	IV		10.234		
	14	866.370	RK	IV				10.265
	14	866.440	RG	V	10.235			
	14	866.490	RG	V		10.217		
	17	869.430	MD	V	10.227			
	18	870.430	RG	V	10.247			
	18	870.480	RG	V		10.250		
	20	872.300	SŠ	IV		10.159		
	20	872.350	SŠ	IV				10.286
	26	878.410	RG	V	10.405			
	26	878.450	RG	V		10.302		
	27	879.400	ND	V	10.346			
	27	879.450	ND	V		10.386		
VII	1	883.320	ND	IV				10.313
	1	883.390	ND	V	10.354			
	1	883.440	ND	V		10.347		
	9	891.370	MD	V	10.155			
	9	891.420	MD	V		10.203		
	10	892.370	ND	V	10.537			
	10	892.420	ND	V		10.366		
	11	893.370	ND	V	10.130			
	12	894.360	ND	V	10.346			
	12	894.410	ND	V		10.258		

Supplement I: continued

1984								
	15	897.360	ND	V	10".516			
	23	905.330	RG	V	10.343			
	23	905.380	RG	V		10".536		
	25	907.330	RG	V	10.486			
	25	907.380	RG	V		10.322		
	30	912.310	RG	V	10.427			
	30	912.360	RG	V		10.407		
VIII	2	915.310	RK	V	10.548			
	2	915.350	RK	V		10.605		
	3	916.300	RK	V	10.359			
	3	916.350	RK	V		10.595		
	18	931.480	ND	VI		10.816		
	18	931.520	ND	VI				10".451
	21	934.300	RK	V		10.793		
	21	934.420	ND	VI	10.601			
	21	934.470	ND	VI		10.712		
	21	934.510	ND	VI				10.428
	22	935.300	ND	V		10.642		
	22	935.350	ND	VI			10".773	
	22	935.420	MD	VI	10.474			
	22	935.460	MD	VI		10.501		
	23	936.300	RK	V		10.699		
	23	936.360	RK	VI			10.512	
	28	941.280	RK	V		10.477		
	28	941.340	RK	VI			10.725	
	29	942.280	ND	V		10.464		
	29	942.340	ND	VI			10.706	
	29	942.400	MD	VI	10.450			
	29	942.450	MD	VI		10.615		
	30	943.280	RK	V		10.591		
	30	943.340	RK	VI			10.670	
	31	944.390	ND	VI	10.638			
	31	944.440	ND	VI		10.643		
	31	944.480	ND	VI				10.645
IX	3	947.380	MD	VI	10.503			
	3	947.430	MD	VI		10.466		
	3	947.470	ND	VI				10.538
	4	948.260	RK	V		10.593		
	4	948.330	RK	VI			10.394	
	4	948.380	RG	VI	10.531			
	4	948.430	RG	VI		10.522		
	4	948.470	RG	VI				10.590
	5	949.320	ND	VI			10.675	
	5	949.380	ND	VI	10.645			
	5	949.430	ND	VI		10.537		
	6	950.370	RG	VI	10.589			
	6	950.420	RG	VI		10.553		
	9	953.310	ND	VI			10.614	
	9	953.370	MD	VI	10.617			
	9	953.420	MD	VI		10.660		
	11	955.310	RK	VI			10.707	
	11	955.360	RG	VI	10.676			
	11	955.410	RG	VI		10.643		
	11	955.450	RG	VI				10.771
	12	956.300	ND	VI			10.804	
	13	957.400	RG	VI		10.702		
	13	957.450	RG	VI				10.745
	13	957.480	RG	I			10.694	
	14	958.240	ND	V		10.803		
	14	958.350	ND	VI	10.731			
	18	962.220	RK	V		10.652		
	18	962.290	RK	VI			10.770	
	18	962.340	RK	VI	10.647			
	18	962.390	RG	VI		10.574		
	18	962.430	RG	VI				10.743

Supplement I: continued

1984								
	18	962.470	RG	I			10".484	
	19	963.220	ND	V		10".775		
	25	969.370	RG	VI		10.700		
	25	969.410	RG	VI				10".700
	26	970.320	ND	VI	10".911			
	26	970.370	ND	VI		10.899		
X	4	978.350	RK	VI		10.709		
	4	978.390	RK	VI				10.596
	4	978.420	RG	I			10.626	
	4	978.460	RG	I	10.568			
	4	978.510	RG	I		10.563		
	9	983.280	RK	VI	10.623			
	9	983.330	RK	VI		10.635		
	9	983.370	RG	VI				10.553
	9	983.410	RG	I			10.766	
	9	983.450	RG	I	10.642			
	9	983.500	RG	I		10.760		
	10	984.230	ND	VI			10.767	
	10	984.280	ND	VI	10.660			
	13	987.360	RG	VI				10.656
	13	987.400	RG	I			10.708	
	13	987.440	RG	I	10.668			
	17	991.210	ND	VI			10.527	
	17	991.260	ND	VI	10.596			
	17	991.310	ND	VI		10.447		
	18	992.350	RK	VI				10.758
	18	992.390	RK	I			10.571	
	18	992.420	RG	I	10.642			
	19	993.200	ND	VI			10.772	
	19	993.260	MD	VI	10.435			
	19	993.310	MD	VI		10.539		
	22	996.190	ND	VI			10.690	
	22	996.250	MD	VI	10.357			
	22	996.300	MD	VI		10.444		
	23	997.300	RK	VI		10.710		
	23	997.370	RG	I			10.630	
	23	997.410	RG	I	10.698			
	23	997.460	RG	I		10.691		
	24	998.190	ND	VI			10.804	
	24	998.240	ND	VI	10.563			
	24	998.290	ND	VI		10.609		
	24	998.310	MD	VI				10.617
	24	998.370	MD	I			10.595	
	25	999.240	RK	VI	10.610			
	25	999.290	RK	VI		10.695		
	25	999.330	RK	VI				10.569
	25	999.370	RG	I			10.693	
	25	999.400	RG	I	10.610			
		2446000 +						
	27	001.240	RG	VI	10.547			
	27	001.280	RG	VI		10.536		
	27	001.320	RG	VI				10.542
XI	1	006.390	RG	I	10.617			
	1	006.440	RG	I		10.521		
	2	007.220	ND	VI	10.610			
	2	007.270	ND	VI		10.539		
	2	007.310	MD	VI				10.621
	2	007.350	MD	I			10.546	
	5	010.210	MD	VI	10.462			
	5	010.260	MD	VI		10.620		
	6	011.260	RG	VI		10.403		
	7	012.200	ND	VI	10.319			
	7	012.250	ND	VI		10.378		
	7	012.300	ND	VI				10.432
	8	013.250	RG	VI		10.518		

Supplement I: continued

1984								
	8	013.290	RG	VI				10".588
	8	013.330	RG	I			10".608	
	8	013.370	RG	I	10".627			
	9	014.200	ND	VI	10.594			
	9	014.250	ND	VI		10".515		
	9	014.290	ND	VI				10.481
	9	014.330	MD	I			10.343	
	9	014.420	MD	I		10.506		
	11	016.360	RG	I	10.456			
	11	016.410	RG	I		10.504		
	12	017.190	ND	VI	10.495			
	13	018.353	RG	I	10.582			
	14	019.235	ND	VI		10.523		
	14	019.310	MD	I			10.411	
	22	027.290	RG	I			10.530	
	22	027.328	RG	I	10.517			
	22	027.378	RG	I		10.526		
	25	030.280	RG	I			10.509	
	25	030.320	RG	I	10.302			
	25	030.371	RG	I		10.425		
	26	031.202	ND	VI		10.367		
	28	033.197	ND	VI		10.540		
	28	033.230	ND	VI				10.612
	28	033.310	MD	I			10.556	
	28	033.312	MD	I	10.346			
	28	033.362	MD	I		10.429		
	28	033.410	MD	I				10.350
XII	3	038.183	ND	VI		10.482		
	3	038.260	ND	I			10.766	
	4	039.180	ND	VI		10.660		
	4	039.258	MD	I			10.813	
	5	040.177	ND	VI		10.585		
	5	040.218	ND	VI				10.541
	12	047.199	ND	VI				10.651
	12	047.236	ND	I			10.571	
	18	053.183	ND	VI				10.353
	18	053.219	ND	I			10.458	
	18	053.257	ND	I		10.410		
	19	054.352	RG	I				10.402
	19	054.419	RG	II	10.407			
	19	054.469	RG	II		10.346		
1985								
I	4	070.173	ND	I			10.455	
	4	070.210	ND	I	10.469			
	4	070.261	ND	I		10.453		
	13	079.283	RG	I				10.311
	13	079.351	RG	II	10.310			
	17	083.340	RG	II	10.337			
	17	083.390	RG	II		10.537		
	30	096.190	ND	I		10.257		
	31	097.234	RG	I				10.238
	31	0.97.301	RG	II	10.136			
II	4	101.224	RG	I				10.232
	4	101.292	RG	II	10.357			
III	4	129.263	ND	II		10.328		
	5	130.260	RG	II		10.099		
	5	130.322	RG	III			10.205	
	7	132.255	RG	II		9.970		
	7	132.316	RG	III			10.235	
	13	138.300	ND	III			10.215	

Supplement I: continued

1985								
III	25	150.267	ND	III			10″.140	
	25	150.325	ND	III	10″.058			
	30	155.312	RG	III	9.851			
	30	155.362	RG	III		9″.904		
	30	155.405	RG	III				10″.003
	31	156.251	RG	III			10.110	
	31	156.309	RG	III	10.018			
IV	1	157.357	MD	III		9.926		
	3	159.301	ND	III	10.095			
	3	159.351	ND	III		10.184		
	4	160.298	RG	III	10.121			
	4	160.349	RG	III		10.090		
	4	160.391	RG	III				10.040
	5	161.295	ND	III	10.185			
	5	161.346	MD	III		9.871		
	5	161.388	MD	III				9.881
	7	163.290	ND	III	10.170			
	7	163.340	ND	III		10.139		
	10	166.281	ND	III	10.101			
	13	169.367	RG	III				10.081
	13	169.399	RG	IV			10.036	
	13	169.442	RG	IV	10.084			
	20	176.305	RG	III		10.032		
	20	176.347	RG	III				10.254
	20	176.380	RG	IV			10.033	
	20	176.423	RG	IV	10.012			
	21	177.302	ND	III		10.126		
	22	178.299	MD	III		9.954		
	22	178.342	MD	III				10.208
	23	179.297	RG	III		10.080		
	23	179.339	RG	III				9.821
	25	181.333	RG	III				10.036
V	7	193.333	RG	IV			10.036	
	7	193.376	RG	IV	10.110			
	12	198.287	ND	III				10.241
	12	198.319	ND	IV			10.101	
	12	198.362	ND	IV	9.997			
	12	198.411	ND	IV		10.091		
	28	214.319	RG	IV	10.050			
	29	215.316	ND	IV	10.080			
	29	215.411	ND	IV				10.100
VI	5	222.297	MD	IV	9.938			
	5	222.346	MD	IV		10.027		
	5	222.392	ND	IV				10.103
	5	222.465	ND	V	10.062			
	6	223.343	RG	IV		9.920		
	6	223.390	RG	IV				10.099
	12	229.373	ND	IV				10.262
	12	229.493	ND	V		10.019		
	16	233.362	ND	IV				10.280
	18	235.310	RG	IV		10.104		
	18	235.356	RG	IV				10.155
	18	235.429	RG	V	10.045			
	26	243.288	MD	IV		10.162		
	26	243.335	MD	IV				10.135
	26	243.455	ND	V		10.004		
	30	247.324	ND	IV				10.149
	30	247.397	ND	V	10.158			
	30	247.444	ND	V		10.081		
VII	5	252.310	ND	IV				10.220
	5	252.383	ND	V	10.263			
	5	252.430	ND	V		10.197		
	6	253.380	RG	V	10.092			
	9	256.372	RG	V	10.066			
	9	256.419	RG	V		10.197		

Supplement I: continued

1985								
	11	258.367	RG	V	10".146			
	11	258.414	RG	V		10".172		
	12	259.364	ND	V	10.327			
	12	259.411	ND	V		10.256		
	13	260.361	RG	V	9.978			
	13	260.408	RG	V		10.350		
	14	261.358	MD	V	10.256			
	14	261.406	MD	V		10.142		
	15	262.356	ND	V	10.256			
	15	262.403	ND	V		10.227		
	16	263.355	RG	V	10.200			
	16	263.400	RG	V		10.169		
	19	266.344	MD	V	10.143			
	19	266.392	MD	V		10.275		
	20	267.342	RG	V	10.099			
	20	267.389	RG	V		10.187		
	22	269.336	MD	V	10.059			
	22	269.383	MD	V		10.145		
	22	269.447	ND	VI			10".289	
	23	270.381	RG	V		10.280		
	23	270.444	RG	VI			10.297	
	25	272.375	RG	V		10.293		
	26	273.326	MD	V	10.247			
	27	274.370	RG	V		10.222		
	28	275.320	ND	V	10.223			
	30	277.315	RG	V	10.284			
VIII	1	279.309	RG	V	10.355			
	11	289.328	ND	V		10.314		
	11	289.392	ND	VI			10.390	
	12	290.326	MD	V		10.221		
	14	292.274	ND	V	10.317			
	14	292.321	ND	V		10".142		
	17	295.376	MD	VI			10".255	
	17	295.430	ND	VI	10".335			
	17	295.479	ND	VI		10.402		
	21	299.301	ND	V		10.364		
	21	299.365	ND	VI			10.296	
	23	301.359	MD	VI			10.291	
	23	301.413	ND	VI	10.387			
	23	301.462	ND	VI		10.424		
	31	309.338	RG	VI			10.343	
	31	309.392	RG	VI	10.504			
IX	3	312.383	RG	VI	10.273			
	6	315.321	RG	VI			10.705	
	10	319.310	RG	VI			10.403	
	11	320.244	ND	V		10.388		
	11	320.307	ND	VI			10.463	
	12	321.304	RG	VI			10.451	
	12	321.358	RG	VI	10.582			
	13	322.301	MD	VI			10.224	
	13	322.356	MD	VI	10.461			
	13	322.446	ND	VI				10".570
	13	322.483	ND	I			10.718	
	19	328.285	RG	VI			10.308	
	19	328.340	RG	VI	10.483			
	24	333.272	ND	VI			10.518	
	24	333.375	ND	VI		10.553		
	24	333.416	ND	VI				10.493
X	2	341.353	RG	VI		10.496		
	2	341.394	RG	VI				10.453
	6	345.342	RG	VI		10.577		
	6	345.383	RG	VI				10.473
	21	360.301	MD	VI		10.630		
	22	361.340	RG	VI				10.622

Supplement I: continued

1985								
	24	363.371	RG	I			10″.545	
	24	363.408	RG	I	10″.727			
	25	364.187	ND	VI			10.418	
	25	364.241	ND	VI	10.597			
	25	364.290	ND	VI		10″.502		
	25	364.331	ND	VI				10″.593
XI	7	377.255	RG	VI		10.650		
	7	377.296	RG	VI				10.749
	7	377.333	RG	I			10.625	
	7	377.370	RG	I	10.676			
	9	379.249	RG	VI		10.575		
	9	379.290	RG	VI				10.520
	9	379.327	RG	I			10.571	
	10	380.179	ND	VI	10.426			
	10	380.247	ND	VI		10.612		
	10	380.288	ND	VI				10.548
	10	380.324	ND	I			10.562	
	10	380.362	ND	I	10.409			
	29	399.235	ND	VI				10.672
	29	399.272	ND	I			10.628	
XII	3	403.349	RG	I		10.758		
	3	403.397	RG	I				10.469
	4	404.181	ND	VI		10.359		
	4	404.222	ND	VI				10.442
	4	404.258	ND	I			10.615	
	4	404.296	ND	I	10.618			
	4	404.347	ND	I		10.761		
	5	405.256	RG	I			10.328	
	5	405.293	RG	I	10.474			
	6	406.216	ND	VI				10.522
	6	406.253	ND	I			10.548	
	6	406.290	ND	I	10.617			
	6	406.341	ND	I		10.569		
	7	407.288	RG	I	10.514			
	7	407.338	RG	I		10.561		
	8	408.210	ND	VI				10.702
	8	408.247	ND	I			10.682	
	8	408.285	ND	I	10.638			
	8	408.335	ND	I		10.553		
	9	409.244	MD	I			10.388	
	22	422.209	ND	I			10.726	
	22	422.247	ND	I	10.700			
	22	422.297	ND	I		10.746		
	23	423.206	MD	I			10.282	
	23	423.244	MD	I	10.544			
	23	423.294	MD	I		10.407		

4. COMPARISON

Using the data from the Table 6, the following result for the mean difference between latidude data at two programmes is given :

$$\Delta\varphi = \varphi_{comp.} - \varphi_{orig.} = 0''.010 \pm 0''.039$$

If we take the mean latitude values into consideration, the mean difference is

$$\Delta\varphi = \varphi_{o,comp.} - \varphi_{o,orig.} = +0''.011 \pm 0''.004.$$

On the basis of these results, the value of +0.010 will be treated as the systematic difference between the latitude systems given by two programmes. Normally, it is only the preliminary value, which will be improved using the new observational data in the coming years.

5 CONCLUSION

These investigations show that there is no objection to use the widened, complete programme for the latitude determinations with the Belgrade zenith–telescope. Therefore, the latitude data obtained from the complete programme from January 1, 1987 will be sent to the international centres for the calculation of Earth rotation parameters.

REFERENCES

Ševarlić, B., Teleki, G.: 1960, *Bull.Obs.Astron. Belgrade,* **24**, 3–4, 19.

Teleki, G., Grujić, R.: 1969, *Bull. Obs.Astron.Belgrade,* **27**, 2, 68.

Bull. Obs. Astron. Belgrade, Nº 137(1987) UDC 52

POTENTIALITIES OF THE COMPUTER CONTROLLED HORIZONTAL MERIDIAN CIRCLE AT PULKOVO

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SUMMARY: A description of the construction and pavilion of the Pulkovo Horizon Meridian Circle (HMC) is given. Specifications of the registering systems are presented principle of work of the computer control in meridian observations, includi determination of instrumental parameters is shown. The results of a study of the HMC given on the basis of RA and Decl. observations of FK4 stars. The standard deviation o single RA observation is equal± 0ˢ.011 sec δ, a single Decl. observation± 0".20 sec z. T instrument is intended for observations of stars up to 11ᵐ. It doesnot take more tha minutes to observe and reduce one star.

1. INTRODUCTION

Computation of modern catalogs of highly precise stars' coordinates is possible if the meridian instruments give the minimum errors in observations, have high automation of observations and reduction. Development and design of meridian instruments capable of above operations, is realized by way of seeking for optimum, rational constructions, providing for minimum systematic errors, and by way of introduction of objective methods of registration, computer control of the basic operations in determining coordinates of the observed objects. Both ways were taken into account when the work on the design of the Pulkovo Horizontal Meridian Circle began on the initiative and ideas of L.A. Sukharev.

2. DESIGN AND PAVILION

The essential part of the horizontal meridian circle (HMC) is a monolithic two–sided metallic mirror with an axis and a diameter of 300 mm (Figure 1). The axis of rotation of the mirror goes through its gravity center and is fixed by bearings in the prime vertical plane.

On both sides of the mirror the graduated circles are fixed. They are used for readings of rotational angles of the mirror about the horizontal axis. The unloading system uses a column, at the top of which there is a fork with an unloading arm and a counterpoise. The fork supports the mirror from below in two places. The orientation of the mirror can be changed with micrometer's screws of bearings mounted on concrete pillars.

To the South and North of the mirror, in the meridian, on two concrete pillars the primary tubes of the HMC are located. Their focal length 4.2 m; diameter 190 mm.

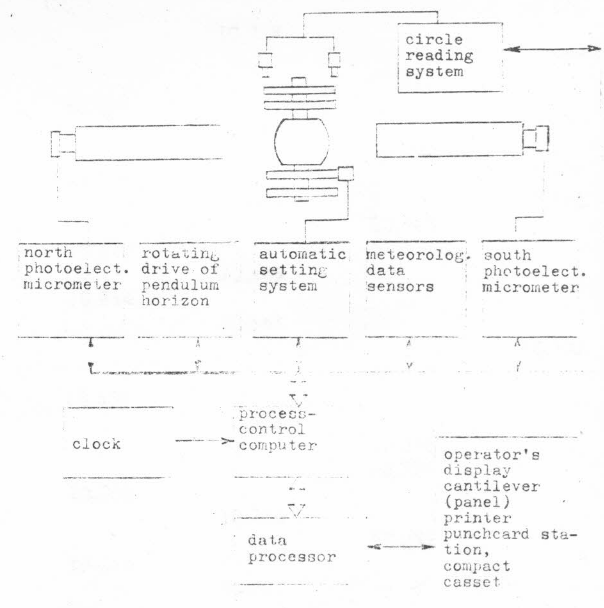

Figure 1. Pulkovo Horizontal Meridian Circle built on L.A. Sukharev's system. Program control.

The object–glasses of the primary tubes consist of glass lenses incorporated into selfcentering objective cells the „bearing" type (as bearings of meridian instruments). The lenses contact the bearings only due to their weight. The bearings are fixed directly on the pillars. Similar bearings are mounted on the pillars of eyepiece ends of the tubes. In each tube there is a glass disc, whose glass quality and diameter is close to the crone lense of the objective glass. There is a hole in the center of the glass where the tube of the eyepiece micrometer is fixed.

The tubes are not connected with the objective glasses, eyepieces, and pillars. They rest on steel supports encircling the pillars without touching them. Thus, the deformation of the tubes does not influence the position of sight axes. Simultaneously, the tubes play the role of a light guide screening the light path of scattered light and turbulent air fluxes. The tubes are double – the inside tube is made of steel and is very heavy, the outer tube is made of aluminium and very light. In between the walls of the tubes there are cable ribbons rolled into lead–in and lead–out spirals (Kirian, 1982).

The HMC is mounted in a pavilion of an original design. The poavilion covers only the upper part of the pillars. The bases of the pillars and the upper part of the foundation are in the open air (diking is absent). According to L.A. Sukharev's idea this should enhance the equalization of temperature inside and outside the pillars, thus establishing a more homogeneous temperature field around the instrument. For this purpose the foundation has through slits. The pavilion is made of metal and the walls inside are faced with wood with a thermalinsulating layer in between.

The bases of the foundation and the pavilion are surrounded with a conelike water proof layer (rammed clay) covered with earth on top. All the water streams down the cone right into the drainage ditches. The radius of the cone playing the role of an umbrella is 10 m. Thus, the stability of the HMC pillars is improved and a better connection of the HMC with earth is provided for.

3. REGISTERING DEVICES

The control of the instrument is carried out in a special cabin in the pavilion where there is a control panel, a visual microscope of the automatic mirror setting system and electronics. A computer control complex is mounted on the Sukharev HMC (Gumerov, 1985). This sytem enables one to automatize the basic operations of meridian observations, the study of the instrument's parameters and the process of stars' coordinate determination as a whole (see Figure 1). The automatic setting system of the HMC consists of a coarse and fine mirror setting, a photoelectric setting microscope and electronics (Gumerov, 1983.). The setting precision is not worse ±2". The maximum time of setting at a turn of 90° is not more than 15 seconds.

High precision measurements of the mirror position of the HMC are provided for by an automatic reading system of the circle (Gumerov, 1982). The reading system of the circle consists of an optical–mechanical part, i.e. of four photoelectric scanning microscopes with illumination, glass annulus of 420 mm diameter with 5 minute divisions. Two additional microscopes are mounted for a study of division errors. The electronics section of the automatic reading system also includes commutation, formation of microscopes signals, logical schemes of formation of readings, a communication channel with a computer control.

The computer control during its work with an automatic reading system controls observations, collects the data, analyses errors and drifts of the circle zero point. It either corrects the error or signals to the observer. The precision of a single circle reading using four microscopes corresponds to a standard error of the order of 0.''02 and takes 12 seconds.

Star transit recording is made with the eyepiece micrometers (Southern and Northern) (Aiupov, 1984). These are photoelectric eyepiece micrometers with an active analyser. The latter is a grid with a system of lambda–like slits. The oscillating motion of the scanning slit system is performed by the motor. Thus, the light of a star is modulated and falls on the photomultiplier operating in the regime of photon counting. A modulated signal carries information on the position of a star in two coordinates. The analyser is supplied with a raster sensor of motion, whose signals give moments of data access from the photon counter. Time intervals between the samples are registered for an account of the variations in the scanning analyser motion, plotting of a temporal registergram scale. A diaphragm sets a limit on the sky field, it is put into operation by a stemp motor. The standard deviation of the autocollimation measurements, the star's magnitude being of about 6, attains ±0.''02. The limiting magnitude is 11^m, the time of registration can very from 20 to 60 sec, the time of reduction is 30 sec.

The position of the vertical line, necessary for a determination of the inclination of the axis of the mirror rotation, points of nadir on the divided circle can be obtained with the use of a pendulum mirror horizon, supplied with a resetting mechanism and situated under the mirror (Sukharev, 1982).

4. COMPUTER CONTROL

Computer control of the HMC realizes automatic regime of the work of the above mentioned devices in the real time scale, reduces the data from measuring mechanes, storage of the results of observations.

Hardware and software consist of two parts: program controller and data processor.

Program controller through its input/ output parts builds the interface of the system and directly controls all the complex, provides for collection, preliminary reduction and storage of information.

The data processor has a trunk line connection with the program controller (there is no direct connection with the interfeace of the system) and solves problems of reduction of the data coming from the program controller and then reduces the results, prepares the initial data for the night of observation, initiates a regime of the operation of the instruments. With the use of terminal devices the data processor forms a cantilever of the operator–observer, provides for the data storage on standard carriers.

A two–component system of the computer control has been chosen due to the following facts:

1. presence of two processors, working simultaneously provides for high speed of response. The productivity of the instrument is determined, in fact, by the time of operation of main devices, reduction of the data also includes/ embraces is included or is embraced in the same cycle and does not require any additional time.

2. The character of the problem to be solved (guiding of the complex in the real time and data reduction) requires a different architecture of calculating devices.

3. Independence of the program controller allows a rapid analysis of the working state of the main units of the instrument and also gives more opportunity to modify the system.

4. While the data processor is also independent, its software uses a high level language (FORTRAN–5M) which makes it very simple to supplant this microsystem with a better one, thus improving the computing capacity of the complex.

The program controller is built on the basis of a set of microprocessing devices „Electronica C5–12". The data processor and an operator's cantilever are realized with the use of a personal computer (system 15 IPG – 32–003), having a parallel communication channel with the program controller.

The computer devices consist of the software of the program controller and data processor.

Programs of the apparatuses service, a monitor and a driver(see Figure 2) refer to the former. The monitor of the program controller provides for organization of a solution of the problems in real time, control of the input/output devices, organization of a multiproblem regime of work for programs, which permits to overlap in time the control of the apparatuses. A list of programs contains programs of control the automatic mirror setting system, of the circle reading system, of the photoelctric eyepiece micrometers, of the pendulum mirror horizon, of the „clock" program. There is a driver for organization of the information exchange between the program controller and the data processor, which realizes a strobed address reception of the data and instructions and data transmittance onto 8 bit. a match of the format of the data and the exchange control.

The system programs are realized in the data processor and are initiated either with the controlling program or by an observed from the display panel. These programs are: programs for computing apparent places with account for refraction, computation of the divided circle readings with account for division errors, a program for a determination of star' positions in the coordinate system of an eyepiece micrometer. The program of determination and study of instrumental parameters also refer here. The monitor of the system enables an observer to control the fulfilment of the program and the process of observation.

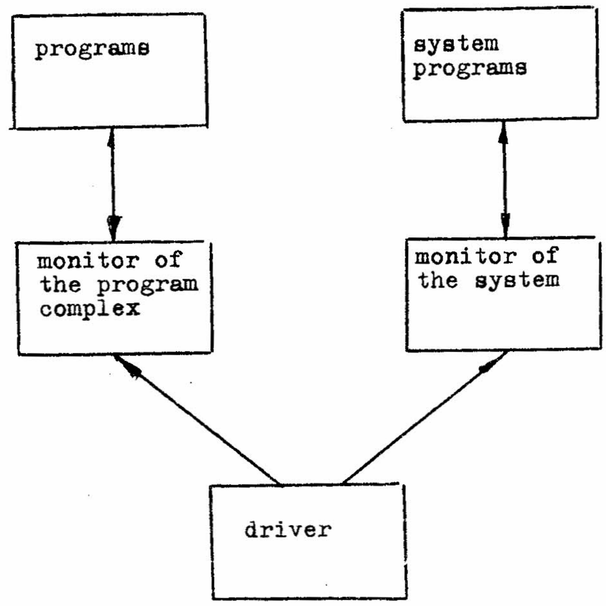

Figure 2. Structure of the software of the measuring complex of the HMC.

A similar approach to the organization of the software for observations can be observed at other automatic meridian circles (Helmer, 1983, Yoshizawa, 1982).

5. THE RESULTS OF THE STUDY AND OBSERVATIONS

A study of the HMC using right ascension observations made during 1968–1970 showed that the instrument gives good results with respect to accidental and systematic errors. The metallic mirror has proven to be rather stable. The variations of the mirror collimation were insignificant (0.″004 per 1°C) within the temperature variation +20° to –16° and correlated well with the temperature. The utilization of photoelectric eyepice micrometers, and also screening of the light beam with the double tubes permits to control the mirror position with respect to the tubes with an accuracy to several hundredths of the arcsecon. Daily and seasonal variations of the reciprocal orientation along the azimuth of the HMC tubes were very small (0.″08 and 0.″1 per

1°C) during the observations. That indicates a good connection of the HMC tubes with the foundation, and the foundation with the earth. Seasonal variation of the instrument's system have not been found. The results of about 3500 observations of right ascensions of 188 stars from the FK4 catalog made with the Northern and Southern HMC tubes proved to be rather close to one another, which indicates high precision of observations with respect to accidental errors. The standard deviation of a single observation of right ascension is $\pm 0^s011 \sec \delta$.

From 1981 to 1985 the system of declinations of the HMC was investigated using autocollimation measurements and test observations of FK4 stars. The following results were obtained :

1. The HMC has a very high accuracy of the determination of stars' declinations, of the order ±0.20 sec z.

2. The system of the instrument is stable with time and temperature, which confirms the correctness of L.A. Sukherev's suggestion that the central unit of the HMC should be a metallic mirror monolithic with the axis.

3. The HMC flexure is determined first of all by the shape of the reflecting surface of the mirror and not by its deformations due to weight as it is the case with the classical meridian instruments.

4. The precision of the determination of declinations with the HMC is very high with respect to systematic errors; it attains $\pm 0''.05$.

5. It should be also noted that the effects of doubling the error of circle readings and the effects of the influence of turbulence on the horizontal section of a high path, generally noted as defects of HMC systems, are insignificant of this is a high precision automatic measuring complex and a satisfactory protection of the horizontal path.

6. CONCLUSION

As a result of the studies made of the HMC using autocollimation measurements and right ascension observations and declination observations, it is shown that the accuracy of the determination of star's positions with the meridian horizontal circle is better than that received with classical meridian circles, in particular, with respect to systematic errors.

The importance of the utilization of the computer control for modern meridian instruments is confirmed.

Thus, a horizontal meridian circle as a highly effective meridian instrument can be used for fulfilment of modern astrometric programs.

REFERENCES

Aiupov F.G., Gumerov R.I., Kapkov V.B. et al, 1984: *Problems of Astrometry*, M., Moscow State University, p. 186. (in Russian).

Gumerov R.I., Kapkov V.B., Pinigin G.I., 1985: *Kinematics and Physics of Celestial Bodies*, **1**, (in Russian).

Gumerov R.I., Kapkov V.B., Pingin G.I., 1983, *Pisma v Astr. Zhurnal*, **9**, 699.

Gumerov R.I., Kapkov V.B., Pinigin G.I. et al., 1982, *Izvestia GAO*, **200**, 114.

Helmer L., et al. 1983: *Astron. Astrophys. Suppl. Ser.*, **55**, 223.

Kirian T.R., Pinigin G.I., Timashkova G.M., 1982: *Izvestia GAO*, **199**, 43.

Yoshizawa M. et al. 1982: *Ann. Tokyo Astron. Observ.*, **18**, 205.

Sukharev L.A., Timashkova G.M., Pinigin G.I. et al., 1982: *Izvestia GAO*, **200**, 118.

EQUATORIAL COORDINATES AND PROPER MOTIONS OF COMPONENTS OF TRIPLE STARS FROM INPUT CATALOGUE OF HIPPARCOS ASTROMETRIC SATELLITE

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SUMMARY: Astrometrical observations were carried out for 66 triple stars of the declination zone (+30°, +50°) from the Input Catalogue of EAS HIPPARCOS. The equatorial coordinates $(\alpha, \delta)_{1988}$ of components of these systems were obtained with rms errors $\sigma_\alpha = \pm$ (0.010^s – 0.030^s) and σ_δ = (0.10"–0.30"). The proper motions of primary components were derived more accurately. Using the statistical treatment (with the exception of errqueous observations) of the data on positional observations from the Aitken Catalogue (ADS) the relative coordinates $(\rho, \theta)_{1988}$ and relative proper motions $(\dot\rho, \rho\dot\theta)$ were calculatied for 208 pairs in 170 triple systems. The uncertainties σ_ρ, $\rho\sigma_\theta$ are found to be ≤ 1.5".

INTRODUCTION

In order to demonstrate a physical connection between components in multiple stars, to reveal their dynamical states, and to study the dynamical evolutions (see Anosova 1984, Anosova and Orlov 1985), one must dispose of the set of highly–precise astrometrical and astrophysical observations for each particular component. Specially high requirements are claimed for the trigonometric parallaxes π and proper motions μ of objects, the mean uncertainties of which must be $\sigma_\pi \lesssim$ (0.001 – 0.002)" /yr and $\sigma_\mu \lesssim$ (0.001 – 0.002)"/yr. The highest accuracy of ground–based photographic observations that serve for derivation of these quantities can be achieved only by means of the long–focus instruments of type of the 26" refractor in Pulkovo (Kiselev and Kiyaeva, 1980), and by using the numerous systematic observations taken in the course of 15–20 years and the highly–precise reduction methods for photographic plates (e.g. the method of A.A.Kiselev, 1971). It is, however, expected to reach the accuracy level $\sigma_\pi \lesssim 0.002$"/yr and $\sigma_\mu \lesssim 0.002$"/yr by means of „an mass" observations of stars by the astrometric satellite HIPPARCOS (J.Dommanget 1985).

In the HIPPARCOS Input Catalogue there are nearly 3500 triple stars. To investigate the possibility of observation of these stars' components by HIPPARCOS it is necessary to know their equatorial coordinates (α, δ) at the epoch 1988 to within ± 1". The primary brightest components A of triple stars having the apparent magnitudes V $\lesssim 11.0^m$, are for the most part included in the Catalogues AGK 3 and SAO, so that their coordinates $(\alpha, \delta)_A$ and proper motions $(\mu_\alpha, \mu_\delta)_A$ are known with required accuracy – the mean errors of stellar coordinates in AGK 3 at the epoch 1990 are ± 0.4", and in SAO – ± 0.8" (Polozhentsev an;Potter 1983). The secondary components B are included in these catalogues only in ~ 50% of cases, while the faintest components C are practically absent.

ASTONOMICAL OBSERVATIONS OF COMPONENTS OF TRIPLE STAR SYSTEMS

According to the plan of the International Working Group „Double Stars HIPPARCOS Input Catalogue Consortium" on preparing the objects for observation by

Table I Astrometrical Observations of Triple Stars

Nº	ADS Index	$\alpha^h\alpha^m$	A α^s	B α^s	C α^s	$\delta^o\delta'$	A δ''	B δ''	C δ''	μ_α 0.ˢ0001	μ_δ .001	s
1	00085N3538	0ʰ 12ᵐ	69.ˢ423	68.ˢ286	58.ˢ395	36°06′	136.″66	152.″05	15.″18	30	−7	3
2	246	0 17	41.205	AB	44.174	43 57	18.73	AB	37.22	2666	414	1
3	585	0 41	37.748	AB	38.863	40 11	6.63	AB	19.49	0	−2	3
4	918	1 06	28.287	AB	29.776	38 34	72.53	AB	15.12	30	−12	3
5	1227	1 33	48.094	AB	45.774	34 36	0.83	AB	64.84	−8	−33	3
6	01347N3350	1 39	44.213	41.878	47.783	34 15	103.84	137.14	56.13	38	−60	3
7	01533N3244	1 58	24.089	26.488	29.709	33 07	192.30	226.59	54.98	206	−341	1
8	1961	2 34	42.392	43.667	40.049	39 36	46.99	50.05	80.13	28	−37	3
9	2730	3 43	48.722	AB	49.866	32 07	35.02	AB	53.28	−2	−13	3
10	2736	3 44	29.634	AB	26.916	49 49	31.04	AB	45.39	27	−22	1
11	2758	3 46	05.024	AB	3.850	30 46	23.38	AB	20.07	4	−13	2
12	2771	3 46	60.840	58.968	BC	34 58	57.42	29.33	BC	2	−4	2
13	2866	3 55	09.153	AB	12.963	32 07	16.77	AB	47.03	10	−9	3
14	2990	4 06	09.439	AB	11.966	33 24	56.28	AB	39.39	9	−4	2
15	3185	4 23	37.778	39.205	35.970	34 15	138.87	148.92	33.64	18	−39	2
16	3447	4 46	53.171	AB	54.403	40 12	46.45	AB	77.78	−1	0	1
17	4083	5 29	22.177	AB	23.930	41 16	30.02	AB	38.77	0	3	1
18	4456	5 51	40.188	AB	53.946	40 08	52.48	AB	161.72	–	–	1
19	4638	6 03	14.828	AB	15.425	31 37	63.27	AB	55.40	−2	−6	2
20	06044N3304	6 10	11.469	9.644	10.163	33 02	55.95	54.40	34.09	–	–	3
21	4779	6 10	33.063	34.635	BC	30 40	40.00	99.74	BC	1	−2	2
22	4905	6 18	17.690	AB	15.416	39 46	52.77	AB	45.94	−5	−4	1
23	5151	6 30	49.745	AB	48.963	32 10	35.28	AB	21.99	−2	−23	2
24	5403	6 44	23.774	AB	25.219	30 50	24.11	AB	20.32	−11	−14	2
25	5420	6 45	25.951	26.950	26.724	34 18	35.79	32.43	39.09	1	0	2
26	5532	6 51	59.954	56.117	59.129	33 57	98.92	164.04	0.00	2	−65	2
27	5555	6 54	30.828	AB	20.285	48 33	113.68	AB	0.73	−4	10	1
28	5680	7 00	30.348	30.199	28.082	32 25	59.51	42.54	72.64	−11	−22	2
29	5831	7 09	24.157	AB	32.294	38 08	66.34	AB	18.05	0	−10	3
30	5846	7 10	22.608	AB	21.547	30 15	59.67	AB	117.70	−28	−61	2
31	5879	7 12	58.628	AB	50.057	48 31	15.86	AB	115.42	−1	−4	1
32	5954	7 17	18.107	16.680	10.208	34 58	29.71	36.75	36.28	6	−40	3
33	5999	7 20	34.826	AB	40.848	34 02	63.59	AB	17.15	−5	−16	2
34	6137	7 30	09.310	AB	15.732	30 35	62.34	AB	26.52	−3	−23	2
35	6364	7 46	44.085	43.217	41.885	33 26	48.21	32.04	75.99	−14	−29	2
36	08054N3246	8 10	53.743	53.712	73.593	32 29	46.24	132.14	145.09	−333	−748	2
37	6866	8 32	25.346	27.506	21.646	33 28	24.05	29.26	0.68	14	−18	2
38	09247N3406	9 29	59.983	63.979	55.476	33 41	93.88	54.83	15.81	−18	−59	2
39	7438	9 34	37.857	38.947	31.696	40 00	64.13	42.51	157.12	−2	17	1
40	10053N4958	10 10	19.591	46.282	16.446	49 27	218.35	106.57	23.36	−1395	−519	1
41	7788	10 28	17.494	AB	14.142	34 55	30.93	AB	22.79	−17	−54	3
42	8031	11 02	16.757	6.994	BC	35 44	30.27	61.16	BC	−4	−20	3
43	8355	11 55	40.289	AB	42.200	35 30	53.06	AB	67.45	−84	2	3
44	8570	12 28	54.297	AB	54.199	29 33	103.12	AB	29.15	−1	−16	2
45	8697	12 53	01.320	0.971	0.848	38 02	14.35	28.15	92.54	49	−18	3
46	8805	13 09	30.297	9.040	BC	38 33	44.10	170.54	BC	−49	38	3
47	8958	13 34	02.000	AB	2.078	33 11	48.41	AB	84.49	43	−67	2
48	9037	13 50	49.841	AB	53.563	34 44	35.70	AB	46.92	12	−58	3
49	9935	16 07	36.687	–	–	45 24	41.16	–	–	−10	23	1
50	10630	17 32	30.300	32.384	30.142	47 53	45.99	42.41	111.69	−5	10	1
51	11028	18 02	49.974	52.145	41.168	48 27	46.78	30.62	86.46	13	17	1
52	11174	18 12	16.103	AB	12.242	41 22	54.15	AB	111.31	10	38	1
53	11624	18 43	14.484	16.013	11.552	30 22	90.58	100.22	15.17	−8	35	2
54	12240	19 14	60.283	AB	43.268	50 01	116.96	AB	27.67	−16	4	1
55	12427	19 24	43.078	AB	44.071	37 05	57.17	AB	110.40	−4	34	3
56	12446	19 25	40.951	AB	43.180	38 47	19.11	AB	28.81	18	−12	3
57	19365N3108	19 39	53.442	AB	53.377	31 19	42.74	AB	61.90	0	7	2
58	12913	19 45	58.133	60.095	65.484	33 40	114.88	124.53	41.11	15	−446	2
59	20029N3058	20 06	23.594	25.765	21.132	31 12	53.97	69.51	42.33	−29	−34	2
60	13463	20 10	07.096	10.343	BC	33 35	51.23	38.79	BC	−12	−14	2
61	14345	20 49	14.888	17.617	BC	50 04	54.68	154.11	BC	−11	14	1
62	14705	21 09	38.193	38.465	BC	43 54	24.86	3.15	BC	−3	5	1
63	15938	22 25	57.130	AB	54.343	43 27	57.25	AB	88.51	3	−4	1
64	16561	23 09	42.340	AB	46.739	32 25	18.11	AB	31.42	26	0	3
65	102N3524	23 14	24.058	22.592	21.077	35 51	57.97	46.46	32.77	5	−37	3
66	17019	23 47	58.920	AB	60.518	36 12	27.90	AB	31.15	7	−15	3

this satellite, we have carried out the photographic observations for 66 triple stars of the declination zone (+30°, +50°), in order to obtain the precise coordinates for their components. The observations have been made during 1984–1985 by means of: 1) the normal astrograph of Pulkovo Observatory – the responsible observer was N.M.Bronnikova; 2) the zone astrograph of Nicolaev Division of the Pulkovo Observatory – F.F.Kalikhevich; 3) the double astrograph of Goloseevo Observatory – A.I.Yatsenko. Measurements and reductions were performed according to the method of A.A.Kiselev (see Bronnikova and Kiselev 1973). There have also been used the observations acquired in Nicolaev during 1978–1983, but for these plates reduction a method of six constants has been applied.

The obtained results reduced to the epoch 1988 are given in Table 1, in which there are: the identification numbers of triple stars from the Catalogues of double and multiple stars by Aitken (ADS) or Index–Catalogue (IDS), the equatorial coordinates $(\alpha, \delta)_{1988}$ for components A, B, and C of triple stars, the proper motions of primary components A whose occuracy has been improved by using the Catalogues AGK 2 and AGK 3 (the mean uncertainties being $\sigma_\mu = \pm 0.005''/\mathrm{yr}$), and the numbers denoting where the particular observation has been made (1 – Pulkovo, 2 – Nicolaev, 3 – Goloseevo). The mean uncertainties in equatorial coordinates are $\sigma_\alpha = \pm (0.010 - 0.030)^s$, $\sigma_\delta = \pm (0.10 - 0.30)''$. The derived proper motions were used to reduce the positions at the epoch 1988.

RESULTS OF STATISTICAL STUDIES OF THE AITKEN CATALOGUE DATA FOR TRIPLE STAR SYSTEMS

It is obvious that the possibilities for ground–based astrometric observations of triple stars intended to obtain their components' equatorial coordinates are strongly limited due to short time spans, insufficient observational time, etc. At the same time, the large volume of information on the relative positions of components in doubles and triples can be found in the Aitken Catalogue (ADS); often the epoch difference for these stars amounts to as much as 60–100 years. However, the data included in this Catalogue are heterogeneous, obtained with various instruments and different accuracy, so that, therefore, some statistical analysis is necessary to obtain the veliable relative coordinates and proper motions.

In the present paper the statistical study is performed of the Aitken Catalogue 113 triple stars of AO LSU program, and 296 triple stars belonging to the Uccle Zone of HIPPARCOS Input Catalogue with $\delta\epsilon$ (+30°, +50°). The principal purpose of this investigation is to improve the accuracy of the relative positions – angular separations ρ and positional angels θ – and proper motions $\dot{\rho}$, $\rho\dot{\theta}$ of components B and C, and to estimate the uncertainties of these values:

$$(\rho \pm \sigma_\rho,\ \rho\theta \pm \rho\sigma_\theta,\ \dot{\rho} \pm \sigma_{\dot{\rho}},\ \rho\dot{\theta} \pm \rho\sigma_{\dot{\theta}})_{B,C} \tag{1}$$

Using the data $(\alpha, \delta)_A$, $(\mu_\alpha, \mu_\delta)_A$) for primary components of triple stars from the Catalogues AGK 3 (or SAO), and calculated quantities (x) one has a possibility to supply the equatorial coordinates ($\alpha \pm \sigma_\alpha$, $\delta \pm \sigma_\delta$) for secondary components B, C in triple stars at any epoch T_o.

The relative coordinates ρ and θ, and the relative velocities $\dot{\rho}$ and $\rho\dot{\theta}$ for components of triples are obtained in the following way: the positional angles $\theta(T_i)$ quoted in ADS at the epochs T_i of observations are reduced to a required epoch T_o by correcting for precession and proper motion of primary component A; the time functions $\rho\ (T_i)$ and $\theta(T_i)$ are fitted as the straight lines by the least–square method:

$$\rho(T) = \dot{\rho} \cdot (T - T_o) + \rho_o, \quad \theta(T) = \dot{\theta} \cdot (T - T_o) + \theta_o, \tag{2}$$

where ρ_o and θ_o are the unknown coordinates at the epoch T_o. In some cases, if it was necessary (remarkably curvilinear orbital motions for nearby stars), the quadratic terms are included. The erroneous observations are excluded at the confidence level $P = 0.95$ ($|\rho_i - \rho(T_i)| > q\sigma_\rho$ or $|\theta_i - \theta(T_i)| > q\sigma_\theta$). In order to apply this method the minimum number of observations for triple star components must be equal to 3.

The results for 208 pairs of components having σ_ρ, $\rho\sigma_\theta \leqslant 1.5''$ belonging to 170 triple stars are shown in the Table 2, in which there are the numbers in the Catalogue ADS, coordinates $(\alpha,\delta)_{1988}$ for components A obtained using the data from the Catalogues AGK 3 or SAO, then identifications of the components B and C of triple stars, coordinates and proper motions (x) of components B and C with respect to component A and their rms errors.

The above results are compared with corresponding data obtained by astrometric observations: 1) the data from Catalogues AGK 3 and SAO for 29 components B and C in 23 triple stars; 2) the observations of 66 triple stars whose results are given in the first section of this paper; 3) the observations for 14 triple stars made by means of the 26" refractor of Pulkovo Observatory, that were carried out by the colleagues of this Observatory (see Anosova 1984). It is clear that the mean differences $\overline{\Delta\rho} = (0.05 \pm 0.30)''$, $\overline{\rho\Delta\theta} = (0.11 \pm 0.41)''$ between above data and our results evidence on their satisfactory agreement, at least for triple stars under consideration (see Polozhentsev and Potter 1983).

Table 2 Data from Aitken Catalogue (ADS)

N	ADS	$(\alpha_A)_{1988}$	$(\delta_A)_{1988}$	c	ρ"	σ_ρ 0".01	$\dot{\rho}$ 0".001	$\sigma_{\dot{\rho}}$ 0".001	θ^o	$\rho\sigma_{\dot{\theta}}$ 0".01	$\rho\dot{\theta}$ 0".001	$\rho\sigma_{\dot{\theta}}$ 0".001
1	51	$00^h04^m51^s.78$	34°02'20".9	C	25".79	82	51	10	162°.2	24	−25	3
2	137	00 10 33.56	44 14 56.8	B	10.55	73	12	9	330.8	102	−4	2
3	246	00 17 41.19	43 57 18.6	B	37.42	45	−19	5	62.4	54	50	6
4	513	00 36 14.00	33 39 13.0	B	35.61	57	−2	7	172.1	32	−11	4
5	548	00 38 40.67	30 47 44.2	B	29.37	79	15	9	298.7	145	−104	17
6	627	00 44 48.15	43 20 07.6	B	1.54	32	2	4	193.7	6	−1	1
7	818	00 58 46.28	00 42 53.1	B	25.85	19	50	2	341.2	32	119	4
8	918	01 06 30.30	38 35 12.3	C	59.19	120	−34	15	162.9	64	45	8
9	1459	01 50 23.40	64 47 47.9	B	34.76	16	−1	2	36.4	25	11	2
10	1630	02 03 09.20	42 16 23.3	BC	9.78	11	−4	1	63.4	11	1	1
11	1727	02 15 03.53	10 42 58.2	B	14.65	29	1	3	238.2	8	−1	1
12	2052	02 41 26.32	42 38 57.8	B	1.48	28	−1	3	53.2	5	−1	1
13	2064	02 42 12.85	48 12 55.2	B	5.76	9	−1	1	148.8	13	−5	2
14	2081	02 43 22.08	49 10 45.4	B	20.05	12	30	1	305.6	18	24	2
				C	86.11	70	150	8	246.3	80	393	9
15	2117	02 46 18.88	35 30 20.9	B	2.01	12	4	2	192.0	91	94	12
16	2242	02 56 41.21	−25 01 20.0	B	1.67	59	9	7	207.7	26	153	3
17	2458	03 18 26.32	45 56 38.5	B	8.28	21	6	2	289.6	58	−2	1
18	2514	03 23 44.32	33 29 41.8	B	4.29	38	5	4	152.5	23	−1	2
19	2620	03 34 25.11	42 33 08.3	B	2.27	20	−5	2	302.8	109	−1	14
				C	34.15	83	−2	10	82.9	40	4	5
20	2643	03 36 51.25	48 04 46.3	B	2.26	33	9	4	55.6	59	−2	7
21	2677	03 40 02.31	39 04 48.0	B	19.99	24	1	2	342.2	18	3	2
22	2681	03 39 49.83	05 05 18.6	B	25.95	25	−4	3	56.2	30	2	3
				C	35.06	12	−28	1	300.2	9	−7	1
23	2717	03 43 11.25	38 20 14.2	B	32.93	14	29	2	82.8	12	−2	1
24	2736	3 44 29.51	49 49 31.7	B	1.62	13	9	2	201.6	7	−2	1
25	2730	03 43 48.73	32 07 34.2	B	1.01	13	6	2	16.5	1	4	1
				C	24.00	19	6	2	39.1	12	2	1
26	2758	03 46 04.99	30 46 22.3	B	1.73	21	−4	3	147.3	17	−4	2
27	2771	03 47 00.81	34 58 57.8	BC	2.85	57	6	7	278.8	71	1	9
28	2866	03 55 09.20	32 07 16.4	B	1.17	34	−1	4	313.5	35	−3	4
29	2888	03 57 02.44	39 58 39.2	B	9.02	15	2	2	9.5	2	1	1
30	2926	04 00 10.12	23 09 42.3	B	7.08	21	−2	2	126.4	6	−1	1
				C	58.38	18	2	2	241.7	31	7	3
31	2992	04 06 34.91	37 59 35.9	B	1.13	9	1	1	301.5	3	−2	3
				C	226.31	16	−98	2	34.8	72	276	8
32	3040	04 10 29.28	26 28 06.6	B	11.76	138	−69	19	253.8	63	−81	8
				B–C	10.17	103	−10	14	298.0	134	−10	4
33	3185	04 23 37.74	34 17 19.8	B	19.66	10	1	1	61.2	3	2	1
34	3414	04 44 29.52	43 45 55.6	B	4.68	5	−149	1	210.0	3	−7	1
35	3438	04 46 37.52	43 22 50.7	C	0.48	5	4	1	5.0	1	−31	1
36	3468	04 50 12.47	44 57 01.1	B	10.11	6	−1	1	337.0	5	2	1
37	3579	04 58 18.41	14 31 35.4	B	40.19	36	8	4	305.1	25	2	2
				C	54.42	73	−3	8	88.8	45	4	5
38	3954	05 21 16.59	−24 47 00.3	B	3.12	18	1	2	91.0	61	−63	1
39	4083	05 29 22.08	41 16 29.3	B	1.00	10	1	1	194.6	3	−1	1
40	4119	05 31 24.85	49 23 13.2	B	7.76	16	−1	2	74.4	2	1	1
41	4189	05 40 19.96	79 19 46.2	B–C	2.34	14	2	1	175.1	9	1	1
42	4329	05 44 05.41	03 49 39.7	B	8.19	31	7	2	91.7	22	3	2
43	4398	05 48 20.60	39 10 46.1	B	40.75	58	16	7	358.6	130	54	16
				C	52.05	118	40	15	37.0	43	35	5
44	4420	05 49 13.12	39 34 28.4	B	4.89	10	1	1	92.1	8	1	1
45	4556	05 58 40.64	44 56 55.0	B	193.64	133	118	14	41.8	15	98	3
46	4576	05 59 26.18	44 35 35.7	C	36.00	67	29	7	336.9	112	59	12
47	4779	06 10 33.06	30 40 40.2	BC	62.64	13	29	1	20.2	17	37	2
				B–C	1.75	13	1	1	318.5	2	1	1
48	5088	06 28 03.51	40 07 45.6	B	1.98	34	1	3	134.8	4	3	1
				C	151.25	80	−2	9	149.0	25	35	25
49	5151	06 30 49.74	32 10 35.2	B	0.89	18	−1	2	164.5	32	5	4
				C	17.72	92	−7	10	214.5	31	1	1
50	5177	06 33 11.53	56 39 26.5	B	9.69	38	4	4	258.1	15	3	1
51	5191	06 33 52.32	38 33 05.2	B	3.36	9	−2	1	133.0	12	−1	1
52	5403	06 44 23.81	30 50 25.1	B	3.65	18	2	2	90.9	11	−1	1

Table 2 (continued)

N	ADS	$(\alpha_A)_{1988}$	$(\delta_A)_{1988}$	c	ρ''	σ_ρ 0".01	$\dot\rho$ 0".001	$\sigma_{\dot\rho}$ 0".001	θ°	$\rho\sigma_\theta$ 0".01	$\rho\dot\theta$ 0".001	$\rho\sigma_{\dot\theta}$ 0".001
53	5509	06h 51m 14s.15	40°25'13".9	B	8".82	20	1	3	66°.2	51	−5	3
54	5534	06 52 11.92	38 53 07.5	B	22.86	84	3	8	225.0	46	6	5
55	5555	06 54 30.84	48 34 53.1	B	2.19	9	3	1	128.2	1	−1	1
56	5831	07 09 24.13	38 09 06.4	B	1.29	20	−1	2	315.2	2	1	1
57	5879	07 12 58.60	48 31 16.0	B	2.58	21	0	2	114.7	9	3	1
58	5948	07 17 21.30	63 34 19.8	B	3.37	16	3	2	205.7	4	−1	1
59	5954	07 17 18.01	34 58 30.9	B	18.72	2	1	1	291.1	33	−1	4
60	5999	07 20 34.86	34 03 03.6	B	1.83	4	−1	1	324.1	8	1	1
61	6009	07 21 14.64	36 47 06.0	B	11.98	36	13	4	8.5	81	1	10
62	6073	07 25 45.48	18 32 32.9	B	60.43	49	−4	5	97.8	39	1	4
				B−C	20.95	32	8	3	325.8	23	15	2
63	6336	07 45 54.84	64 05 01.4	B	5.55	21	2	2	339.6	9	−1	1
				C	11.57	20	2	2	175.7	8	1	1
64	6364	07 46 44.06	33 26 47.7	B	20.04	11	−16	1	213.6	16	4	1
65	6777	08 22 06.5	−10 38 44	B	2.50	28	8	3	162.2	8	−3	1
66	6811	08 25 57.13	24 34 29.9	B	5.79	7	−1	1	50.0	6	8	8
67	6866	08 32 25.35	33 28 23.8	B	27.74	5	36	1	80.6	29	22	2
68	7029	08 49 52.30	49 25 30.7	B	8.86	21	3	2	124.5	3	−1	1
69	7057	08 51 50.38	32 31 13.5	C	77.70	76	−27	7	23.2	78	−1	8
70	7071	08 53 30.87	30 37 34.9	B	1.51	9	1	1	316.5	4	−2	1
71	7092	08 55 19.44	43 45 29.4	B	1.62	19	1	2	358.6	8	2	1
72	7114	08 58 25.23	48 07 32.5	B	5.02	27	−39	3	12.8	8	16	1
73	7271	09 16 06.45	37 05 23.1	B	5.21	36	10	4	148.8	15	1	19
				C	28.00	1	−1	1	97.5	28	−5	2
74	7307	09 20 18.23	38 14 25.4	B	1.31	8	−3	1	228.2	3	17	1
75	7324	09 21 43.82	49 35 49.7	B	6.35	11	1	1	318.1	5	1	1
76	7425	09 33 21.34	66 50 59.8	B	10.55	13	1	2	248.3	4	1	1
				B−C	122.49	78	7	8	213.0	16	38	2
77	7438	09 34 37.91	40 01 03.4	B	24.75	13	0	1	149.2	12	4	1
				C	116.92	67	−10	7	323.0	21	−31	2
78	7503	09 44 15.78	43 16 09.9	B	5.24	34	1	4	308.1	12	−1	1
79	7541	09 50 26.41	36 32 46.7	B	0.22	27	−1	3	198.3	1	1	2
80	7705	10 16 54.65	71 07 17.9	B	16.85	8	1	1	167.4	10	1	1
81	7995	10 57 45.68	37 05 36.0	B	10.74	28	5	3	332.0	1	2	1
82	8031	11 02 16.76	35 44 29.9	B	121.75	29	16	4	284.7	16	−32	2
				B−C	1.47	85	9	10	164.0	1	55	1
83	8098	11 13 52.26	05 19 43.7	B	107.35	18	44	2	258.7	87	49	11
84	8368	11 57 30.38	32 20 27.7	B	7.61	41	2	5	229.6	16	−2	2
85	8470	12 13 30.39	32 51 03.2	B	26.83	13	−1	1	87.2	8	−1	1
86	8477	12 14 31.75	−7 11 20.5	B	6.79	14	−7	2	270.7	5	−11	1
				C	93.91	81	−69	11	167.2	44	−205	6
87	8530	12 21 54.18	25 54 44.6	B	34.22	72	−9	9	56.8	145	20	18
				C	64.79	81	−6	10	165.9	33	−18	5
88	8541	12 23 57.94	37 47 29.8	B	14.96	17	56	2	14.4	60	−60	9
89	8570	12 28 54.22	29 34 43.2	B	2.25	55	−4	7	215.4	96	−28	6
90	8690	12 51 19.52	19 14 13.1	B	16.10	13	1	1	202.0	8	1	1
91	8697	12 53 01.29	38 02 14.7	B	14.86	32	5	4	343.8	31	−1	1
92	8735	13 00 03.40	18 26 13.1	B−C	2.43	39	6	5	297.5	3	2	1
93	8805	13 09 30.24	38 33 44.7	C	280.05	33	−65	3	296.9	127	−15	15
94	8919	13 28 23.64	50 59 22.8	B	183.21	54	10	6	110.2	28	−16	3
				B−C	1.56	12	−4	1	131.5	5	−3	1
95	8958	13 34 01.94	33 11 48.3	B	3.18	51	11	6	25.0	5	−2	1
96	8974	13 36 55.67	36 21 19.5	B	2.03	15	10	2	140.8	42	6	5
97	8975	13 37 07.31	02 26 33.4	B	15.85	29	−2	3	31.2	12	−1	1
98	9037	13 50 49.76	34 44 35.3	B	0.80	8	1	1	141.4	1	−2	2
				C	45.72	42	−32	5	78.0	61	−40	7
99	9312	14 33 07.56	35 38 11.6	B	3.24	8	6	1	38.5	4	1	1
100	9338	14 40 09.74	16 28 07.2	B	5.79	13	−1	2	108.5	4	6	1
101	9461	14 57 55.79	44 05 28.2	B	2.60	66	−7	5	278.3	7	−2	1
102	9514	15 08 05.71	−0 56 08.1	B	0.94	14	−6	2	278.9	1	1	1
103	9573	15 16 57.53	43 50 12.0	B	3.88	7	23	1	9.6	22	−35	2
104	9626	15 24 02.10	37 25 06.0	BC	108.29	22	−1	3	171.0	45	−10	5
				B−C	2.47	20	17	2	73.6	55	−70	7

Table 2 (continued)

N	ADS	$(\alpha_A)_{1988}$	$(\delta_A)_{1988}$	c	ρ''	σ_ρ 0".01	$\dot\rho$ 0".001	$\sigma_{\dot\rho}$ 0".001	θ°	$\rho\sigma_\theta$ 0".01	$\rho\dot\theta$ 0".001	$\rho\sigma_{\dot\theta}$ 0".001
		h m s										
105	9719	15 35 59.18	37°24′55".2	B	4".17	30	6	4	124°.8	79	−5	11
106	9778	15 45 37.92	15 27 29.4	B	30.65	49	−2	5	264.4	24	−2	2
107	9865	15 58 21.83	21 49 27.0	B–C	4.40	46	3	5	26.7	6	−1	1
108	9909	16 03 42 29	−11 20 29.7	C	7.61	25	2	3	51.7	22	−17	3
109	9935	16 07 36.67	45 24 39.9	B	0.37	19	1	2	271.2	6	−1	1
110	10193	16 44 21.09	35 45 31.8	B	2.19	21	1	2	79.7	5	−21	1
111	10216	16 47.1	25 35	B	4.60	56	−2	6	314.7	3	−2	3
112	10288	16 57 33.12	47 23 00.2	B	2.75	1	−2	1	52.8	95	1	12
				C	112.85	57	−1	5	262.1	22	−16	2
113	10360	17 07 36.53	35 57 00.0	C	20.44	93	9	13	135.7	78	−23	10
114	10410	17 12 50.86	54 09 08.2	B	3.03	36	2	3	224.3	2	−1	1
115	10488	17 20 12.46	32 28 54.9	B	291.06	67	954	7	342.4	141	559	15
116	10526	17 23 16.18	37 09 20.8	B	4.12	19	2	2	317.4	8	4	1
117	10715	17 40 35.80	24 31 04.2	B	16.41	19	2	2	6.8	18	−4	1
118	10746	17 42 59.09	43 45 07.9	B	20.79	27	9	2	210.3	14	−3	1
				B–C	1.46	57	1	5	155.1	9	2	1
119	10781	17 46 02.04	−1 12 40.5	B	10.74	29	7	3	116.4	17	1	2
120	10998	17 59 45.90	33 18 36.0	B	14.65	125	11	14	205.7	19	6	2
121	11028	18 02 50.00	48 27 46.3	B	26.39	22	−8	2	125.8	18	23	17
122	11174	18 12 16.06	41 22 52.6	B	1.94	5	−3	1	173.4	7	−2	1
				C	74.13	79	−38	10	40.4	84	6	10
123	11328	18 23 28.12	51 38 28.0	B	3.30	99	10	13	201.7	55	1	7
124	11621	18 42 56.02	35 31 56.4	B	11.69	40	3	4	189.7	25	−3	3
125	11624	18 43 14.51	30 23 29.4	B	22.29	26	−1	3	63.8	11	1	1
126	11655	18 44 45.82	39 12 44.3	B	3.51	28	5	3	312.3	9	−5	1
				C	23.87	26	3	2	173.1	51	−14	5
127	11656	18 44 46.28	38 18 05.8	B	18.98	31	68	4	25.7	88	11	13
128	11950	19 01 50.93	−29 53 57.6	B	0.01	28	−7	4	358.1	68	−20	9
129	12029	19 05 12.58	06 31 38.4	B	9.40	32	−4	3	153.0	20	−1	1
130	12162	19 11 55.59	30 19 35.3	B	10.10	13	3	2	315.7	14	−3	2
				C	71.50	32	2	4	236.1	251	−7	66
131	12197	19 13 20.95	39 07 27.6	B	28.44	24	4	3	80.5	22	−5	1
132	12328	19 19 26.43	35 30 52.3	B	10.61	42	4	5	315.1	8	1	1
133	12397	19 22 53.96	47 10 18.2	B–C	4.29	84	6	8	295.5	1	1	1
134	12446	19 25 25.91	38 49 22.1	B	0.89	39	1	5	258.9	13	−2	2
135	12695	19 36 07.53	50 11 23.7	C	65.26	8	261	1	178.2	21	−66	2
136	12851	19 43 21.48	38 17 32.4	B	1.15	9	1	1	191.7	2	−1	1
137	12849	19 43 01.08	47 12 55.1	C	66.64	96	−9	10	316.1	22	−3	2
138	12913	19 45 58.17	33 41 55.3	B	26.09	7	2	1	68.4	10	−14	2
				C	113.60	81	−352	10	130.8	71	−228	8
139	12986	19 48 37.86	44 20 53.0	BC	9.76	2	1	1	158.6	15	−2	4
				B–C	0.31	1	1	1	26.1	8	−2	1
140	12992	19 49 02.14	38 40 44.3	B	10.48	125	−17	16	146.0	85	−61	23
141	13405	20 06 56.56	35 40 56.7	B	1.04	7	1	1	76.0	3	−1	1
142	13463	20 10 07.17	33 35 52.2	B	41.38	42	−1	4	107.0	20	−20	2
				C	1.83	37	1	5	178.7	6	−3	1
143	13464	20 09 35.17	56 55 02.8	B	5.97	20	6	3	80.0	91	−3	12
144	13524	20 09 19.50	77 40 34.4	B	7,59	20	1	2	120.9	11	−2	1
145	13572	20 13 56.65	42 04 00.2	B	0.94	10	2	1	170.3	67	−1	1
				C	11.29	55	−4	6	34.0	27	1	3
146	13628	20 16 13.64	39 35 25.7	B	3.29	90	2	12	217.6	11	9	2
				C	27.45	8	13	1	90.6	85	38	11
147	13640	20 16 29.63	40 19 36.2	B	12.94	43	3	5	61.2	6	−11	1
148	13660	20 17 31.52	33 09 12.5	B	0.61	18	4	2	212.6	9	1	1
				C	3.25	6	1	1	260.8	5	2	1
149	13728	20 19 49.08	39 21 54.1	B	0.22	68	−1	1	153.7	4	5	1
150	13745	20 20 50.28	30 33 42.2	B	0.28	46	−2	1	165.7	6	−1	1
151	13847	20 25 04.95	40 03 27.8	B	2.83	6	1	1	157.0	5	−33	6
152	13932	20 29 41.01	48 54 38.9	B	19.37	112	20	14	332.8	146	−32	18
153	14102	20 37 33.18	60 42 47.5	B	2.10	9	0	1	261.0	6	−1	1
				C	43.01	102	−36	13	55.8	122	29	15
154	14184	20 41 59.35	12 41 02.9	B	8.66	29	2	3	86.6	9	−1	1
155	14296	20 46 56.30	36 26 44.9	B	0.75	105	1	1	348.1	4	−12	1

Table 2 (continued)

N	ADS	$(\alpha_A)_{1988}$	$(\delta_A)_{1988}$	c	ρ"	σ_{ρ} 0".01	$\dot{\rho}$ 0".001	$\sigma_{\dot{\rho}}$ 0".001	θ^o	$\rho\sigma_\theta$ 0".01	$\rho\dot{\theta}$ 0".001	$\rho\sigma_{\dot{\theta}}$ 0".001
156	14786	$21^h 14^m 44^s.82$	$-10°23'56".2$	B	83".89	67	−8	5	52°.1	89	11	7
				B−C	7.11	137	10	10	336.1	19	−4	1
157	14831	21 17 25.24	34 50 45.3	C	21.66	83	3	1	183.1	18	16	2
158	15645	22 06 30.68	36 02 05.4	B	1.30	125	−1	1	320.3	4	−2	1
159	15758	22 13 21.61	39 39 18.0	B	30.57	10	31	1	192.7	65	66	8
160	15785	22 14 41.90	49 48 55.7	B	9.61	32	4	1	10.3	6	−1	1
161	16214	22 42 32.95	47 06 19.2	B−C	0.53	34	1	1	317.7	2	−2	1
162	16252	22 44 35.98	68 03 56.6	B	3.92	19	4	2	203.9	8	1	1
				C	20.64	18	0	2	219.9	25	2	3
163	16381	22 55 50.42	41 32 21.8	C	61.85	118	−11	1	48.0	19	7	2
164	16561	23 09 42.31	32 25 17.9	B	0.49	1	1	1	90.6	7	−4	1
				C	58.06	28	0	4	76.6	4	−5	1
165	16702	23 21 19.30	31 44 46.9	B	0.31	131	−2	2	152.8	8	3	1
166	16720	23 22 54.09	45 43 38.2	B	26.26	37	6	4	131.2	9	−4	1
167	16916	23 39 48.17	44 16 03.7	B	47.01	53	3	1	201.5	23	97	2
168	16928	23 40 41.17	32 29 39.9	B	0.61	141	1	2	215.4	6	−6	1
169	17131	23 57 26.94	24 16 28.0	B	8.97	6	−2	1	310.9	27	−3	3
170	17149	23 58 52.28	33 39 27.6	B	0.58	94	−22	1	263.6	3	6	1

PROBABLY OPTICAL AND POSSIBLY PHYSICAL TRIPLE STAR SYSTEMS

In certain cases the values (α, σ) or (ρ, θ) of components and their proper motions (μ_α, μ_δ) or $(\dot{\rho}, \rho\dot{\theta})$ are obtained for each component separately, or for nearby pair and for distant component separately. Hence, one may apply to these systems the dynamical criterion of physical connection between components (Anosova 1969) and reveal the probably optical systems. Amongst triple stars under study the possibly optical systems are ADS 246, 2992, 3358, 6993, 8690, and 15600. The remaining triple stars under consideration may be physical systems, but to make this issue more certain one must acquire a more complete information of astronomic and astrophysical character.

REFERENCES

Anosova, J.P.: 1969, *Trudy GAO v Pulkovo,* **77**, 126.

Anosova, J.P.: 1984, *Problems of Astrophysics,* Saransk, 75.

Anosova, J.P., Orlov, V.V.: 1985.:, *Trudy Astron. Observ.* Leningrad Univ., **40**, 66.

Bronnikova, N.M., Kiselev, A.A.: 1973, *Izvestia GAO v Pulkovo,* **191**, 148.

Dommanget, J.: 1985, *Proc. of a Colloq. EAS HIPPARCOS,* 7p.

Kiselev, A.A.: 1971, *Izvestia GAO v Pulkovo,* **187**, 49.

Kiselev, A.A., Kiyaeva, O.V.: 1980, *Astron. Zh.* (USSR), **57**, 1227.

Polozhentsev, D.D., Potter, H.J.: 1983, *Astron. Circuliar* (USSR), **1288**, 7.

ON DIVISION ERRORS OF THE BELGRADE VERTICAL AND MERIDIAN CIRCLES

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SUMMARY: By using the spectral analysis method the corrections of the division for the Meridian Circle and for the Vertical Cricle of Belgrade Observatory are treated. A prominent term of a period of two degrees has been found for the former instrument, but not for the latter one. Both instruments were produced by „Askania".

1. INTRODUCTION

The corrections of the limb divisions, determined from visual measurements, for two instruments of Belgrade Astronomical Observatory: the Vertical Circle (VC) and the Meridian Circle (MC) are treated by means of the spectral analysis method. Since Dejaiffe (1970), and Trajkovska (1981), for the MC of Belgrade Observatory, found a prominent periodic error of two degrees, a similar error has been expected for the VC, which had also been produced by „Askania", and nearly at the same time.

The metallic declination circles of the two Belgrade instruments have the same general characteristics and construction (size, silver limb, etc). The circles have a fine division of two minutes of arc, the marks at each 10' being somewhat larger and the marks designating halves and whole degrees being labeled.

As for the initial quantities we used the averaged corrections of the two mutually perpendicular diameters.

2. DESCRIPTION OF THE METHOD

The examination of the frequency structure of the limb division corrections is done by using the Fourier transform of the corresponding autocorrelation function. As a correlation window Tukey's function is used

$$r(\tau) = \begin{cases} 0.5\,[1 + \cos(\frac{\pi\tau}{\tau_0})]\,, & \tau \leqslant \tau_0 \\ 0\,, & \tau > \tau_0 \end{cases},$$

where the argument τ is represented by "distances" within the set of data and τ_0 is the smoothing parameter.

In order to correctly establish whether some hidden periodicities exist in the data, the quantity τ_0 is altered. It is experimentaly found that for our case an optimal choice is $\tau_0 = T/2$, where T is the width of the data interval. In view of the fact that the corrections are those of the averaged circle diameters, here $T=90^{\circ}$.

Spectral densities (S) of the limb division corrections for the analysed cases are presented as functions of the frequency (f) in Figs. 1, 2 and 3.

3. RESULTS

A determination of the corrections of the ten–minute diameters for the VC limb was done in 1980 by means of the Nikolić's method and the results that we made use of in the present work were published by Bozhichkovich and Mijatov (1984). We have to mention here that in the course of this examination three marks are always measured (8', 10', 2'). This is due to the fact that the values of the corrections of the two-minute diameters are interpolated from the corrections of the ten–minute diameters taken in succession. The results of the spectral analysis applied to the set of 540 corrections of the ten–minute diameters of VC are presented in Fig. 1. As can be seen the limb division of VC has usual characteristics; a few foremost large periods (90°, 45°, 30°, $22^{\circ}\!.5$, ...) are dominating, and there are no significant smaller periodicities in the division errors.

We also analysed here the two previous examinations of the MC division as for a comparison with the results obtained for VC, as well as for checking of the applied spectral analysis method. Unlike for the VC examination for which three marks were measured, in the MC case, only usual two marks were measured (labeled one being considered as younger one, and the next mark of two minutes of arc as the elder one).

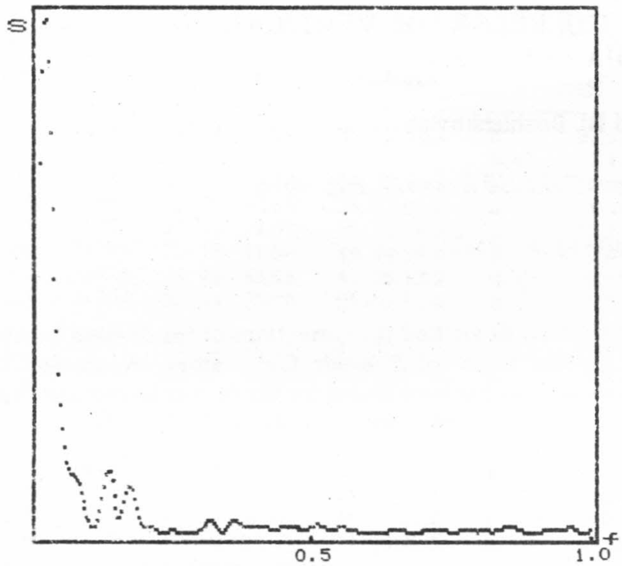

Fig. 1. VC, examination carried out in 1980 by using Nikolić's method

In 1966 a determination of the corrections of labeled MC diameters (every half a degree) was done by means of the Nikolić's method (Nikolić, 1968). The results of a spectral analysis applied to 180 averaged corrections of the two percendicular labeled diameters are presented in Fig. 2. An unusually high peak at higher frequencies corresponding to a period of two degrees is readily seen.

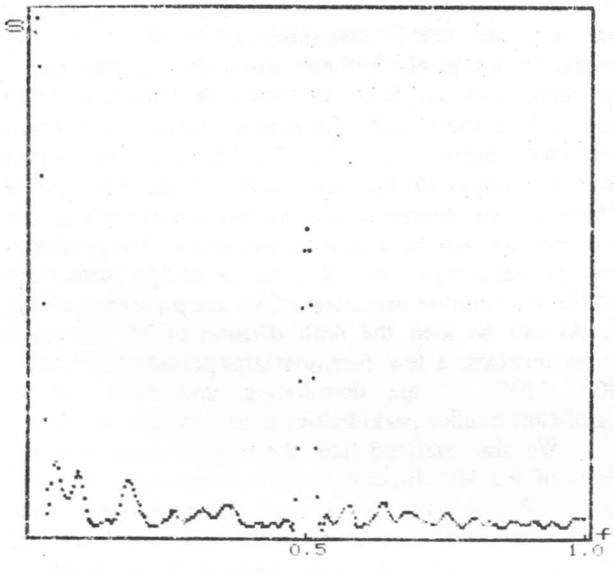

Fig. 2. MC, examination made in 1966 by using Nikolić's method

The second eximination of the MC division was done in 1968. This time the corrections of the same diameters labeled at each half a degree were determined, but now by using Bruns' method (Sadžakov, Šaletić, 1968). The results of a spectral analysis applied to 180 averaged corrections of the perpendicular labeled diameters are presented in Fig. 3. As easily seen, the prominent peak is present again. It is interesting to note that taking into consideration the corrections of all the two–minute diameters (Šaletić, Sadžakov, 1970) which are based on the half-a-degree division corrections (Sadžakov, Šaletić, 1968), Dejaiffe (1973.) did not discover the two degrees period, i.e. it disappeared.

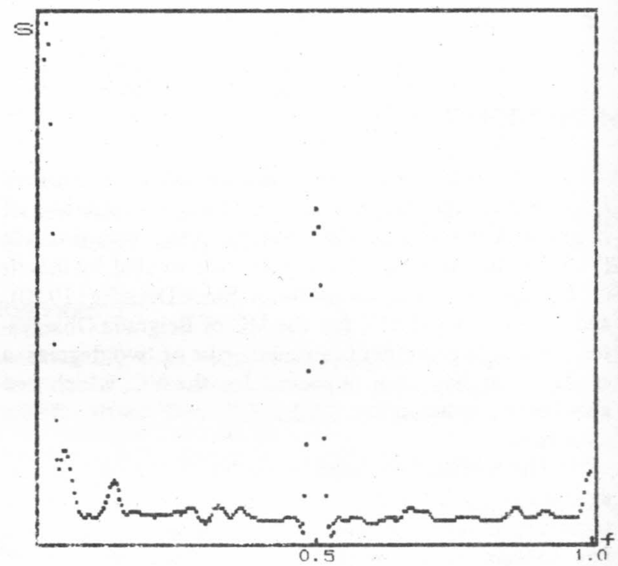

Fig. 3. MC, examination made in 1968 by using Bruns' method

4. CONCLUSIONS

In a view of all being said above and taking into account the results of the previous examination of circle divisions of our two instruments, one can derive the following conclusions:

1. A similarity in the general trend of the corrections of the examined diameters is evident for both circles. This is understandable in view of their common origin.

2. Differences existing between the two circles, as well as in the results of the repeated examination of one of them, are present, too.

3. If one assumes that existence of the periodic error of two degrees for Askania circles is due to their construction (Dejaiffe, 1969.), then the absence of this

error in the obtained corrections of the ten–minute diameters for the VC limb is difficult to explain.

In our opinion the question of the period of two degrees, as well as a number of others, regarding our circles (though being metallic) can be definitely answered only after determination of all the corrections, and by means of the more objective measurements like the photoelectric ones.

Until that time one should keep on changing, from time to time, the microscope–micrometer position covering uniformly the entire interval of two degres, this being no more a serious problem (Bozhichkovich, 1985).

REFERENCES

Bozhichkovich Dj., Mijatov M.: 1984, *Bull.Astron.Obs.Beograd,* **134**, 16.

Bozhichkovich Dj.: 1985, *Astron.Cirk.AN SSSR,* **1395**, 4.

Dejaiffe R.J.: 1969, *Ciel e Terre,* **4**, 193.

Dejaiffe R.J.: 1970, *Astron. Astrophys.,* **7**, 169.

Dejaiffe R.J.: 1973, *Publ.Dept. Astron. Beograd,* **4**, 40.

Nikolić Lj.: 1968, *Publ.Astron.Obs. Beograd,* **14**, 145.

Sadžakov S., Šaletić D.: 1968, *Publ.Astron.Obs.Beograd,* **14**, 159.

Šaletić D., Sadžakov S.: 1970, *Bull. Astron. Obs.Beograd,* **124**, 117.

Trajkovska V.: 1981, *Publ.Astron. Obs, Sarajevo,* **1**, 85.

UNSEEN COMPANIONS TO STARS

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SUMMARY: The existing data concerning 32 unseen companions are compiled and presented in Table I of the paper. The contribution of unseen companions to the local mass density is estimated. A value of 0.0044 $m_\odot$ pc^{-3} is found. Only one of the stars listed in Table I (Barnard's star) seems as a strong candidate to possess a planetary system, according to the accepted criteria.

The search for unseen companions to known stars is one of the main trends in contemporary double (multiple) star astronomy (Popović, 1981).

Some thirty unseen companions have been discovered as yet. Using the existing observational material we have compiled the data concerning the primary stars, as well as their unseen companions. The basic reference is that by Lippincott (1978). There were presented the completed data referring to the state of the problem by 1978. The new data concerning the investigations after that year, have been taken directly from observational references.

The compiled data are presented in Table I. For each primary are given the equatorial coordinates (1950.0), the visual apparent magnitude, the spectral type, when possible the apparent maximal separation from the unseen companion with its epoch, the heliocentric distance of the system(s), the mass of the primary and of the companion (also when possible) and the orbital period in years. In those cases when the primary is a member of a multiple system, the visual magnitudes, spectral types and masses (of course when possible) for other components are given too. Reference Lippincott (1978) in the last column means that the given star was also present in her list of astrometric binaries. Two stars from that list, μ Cas and PGC 372, are not given here, since in the meantime new data have appeared (e.g. Mc Carthy, 1984; Lippincott et al., 1983, respectively) which have confirmed existence of the companions on the basis of different technics, mainly of the infrared measurements. In such a way these stars are no more pure astrometric binaries, which is the only class of interest to the present work. For the same reason other stars present in the additional list of Lippincott (1978) are also not taken into account. There are some controversial cases, stars suspected to have substellar companions such as Proxima Cen, Krüger 60 A, 70 Ophiuchi (e.g. Aleksandrov, Zakhozhaj, 1983), Lalande 21185, ϵ Eridani, 61 Cygni (e.g. Gatewood, 1976; Black, 1980). Out of them only the latter one is included in the present list, since we have evaluated Dejch's results (1978) as worth. In those cases when two references appear in the last column, the data are due to both and the purpose of the more recent one is in data improving. For two stars, Barnard's one and ζ Aquarii, reference Lippincott, 1978 is not written, though these stars are present there, since all the data except the equatorial coordinates are taken from the references given in Table I.

The problem is, of course, in the very beginning of its history, the mass values for the unseen companions are very uncertain, so that any statistical examination can have no serious grounds. Nevertheless, there are some questions being of interest and worth of answering. About a decade ago van de Kamp (1976) tried to estimate the contribution of the unseen companions to the local mass density. In our opinion it is of interest to try the same thing once more, but at first some questions should be answered.

First of all, what is an unseen companion? It is clear that it is a companion to a star which has escaped to a detection by means of electromagnetic waves, but it does not represent a certain class of objects. Among the unseen companions listed in Table I are different kinds of objects: white dwarfs, red dwarfs, dark dwarfs, probably black dwarfs and even black holes. The statistics of all these objects is not quite well known, it is different, having different properties dependent of the kind of objects. Therefore, it is very difficult to estimate the true contribution of the unseen companions to the local mass density.

We assume, following van de Kamp (1976), that within a small heliocentric volume there are no alterations in the number density of unseen companions, otherwise that within a reasonably small heliocentric radius S, is valid $N(S) \propto S^3$, where N is the number of the unseen companions. As easily seen from Fig. 1, this is not the case. Within $S = 15$ pc we have approximately $N(S) \propto S$; further the increase of the number of the unseen companions is slower, approaching gradually a

Table I. List of unseen companions

N°	Star	α(1950)	δ(1950)	m_A m_B m_C	A Sp B C	estimated max ρ Epoch max. ρ	S(pc)	M_A	M_B	M_{uc}	P	Reference
1	BD + 66°34 A ADS 433	0^h 29.3	+ 66° 58'	10.5 12.4 –	d M2.5e d M4.2 –	~0.5 –	10.0	0.4	0.25	0.13	15.95	Lippincott, 1978
2	τ Ceti	1 41.7	–16 12	3.5 – –	G8 – –	– – –	3.5	?	–	0.03	~3.	Lippincott & Worth, 1980
3.	BD + 6°398 PGC 588	2 33.3	+ 6 39	5.84 – –	K3 V – –	2 1980± .5	7.8	?	–	0.11	60:	Lippincott, 1978
4.	Algol	3 4.9	+ 40 46	3 var. – –	B8 – –	~0.09 –	29.4	?	–	1.7	1.862	Lippincott, 1978
5.	Stein 2051A G 175–34 A	4 26.8	+ 58 53	11.1 12.4 –	M5 ? –	0.8 ~1985 ~1997	5.5	?	?	0.02	23	Lippincott, 1978
6.	G 96–45	5 29.6	+ 44 47	12.19 – –	md – –	⩾0.1 1979.8	15.9	0.27	–	0.10	7.2	Lippincott, 1978
7.	χ^1 Orionis	5 51.4	+ 20 16	4.41 – –	G0 V – –	0.6 1983 ±2	9.9	?	–	0.17	14.25	Lippincott, 1978
8.	γ Gem	6 34.8	+ 16 27	1.93 – –	A0IV – –	0.3 ~1980	32.2	3.	–	1.	12.6	Lippincott, 1978
9.	R Canis Maj.	7 17.2	–16 07	6.05–6.66	A9	?	?	?	?	0.54	?	Radhakrishnan et al., 1984
10	G 107–G9A	7 27.1	+ 48 18	?	M	–	11.0	0.17	?	0.08	0.94	Harrington et al., 1981
11	ζ Cancri C ADS 6650	8 9.3	+ 17 48	IDS: 5.6 6.0 6.3	IDS: F7 F7 G2	~0.4 – –	25.0	?	?	0.9	17.5	Lippincott, 1978
12	BD + 67°552 CC 475	8 31.9	+ 67 28	9.29 –	dM1 –	~0.6 ~1978	14.3	?	–	?	23.0	Lippincott, 1978
13	36 UMa A BD + 56°1459	10 27.4	+ 56 14	4.84 8.69	F8 V K7 V dK0		13.5	1.		0.07	18.	Lippincott, 1983a
14	G 146–72	10 52.2	+ 47 31	12.72 – –	md – –	~0.1 1984 ±1	33.0	0.35	–	0.16	6.7	Lippincott, 1978
15	ξ UMa A	11 15.5	+ 31 49	4.32 4.80	G0 V G0 V	~0.2 1979.8	7.7	?	?	?	1.832	Lippincott, 1978
16	U Cu B HD 136 175	15 16.1	+ 31 50	7.65 8.8	B6 F8III–IV –	0.06 – –	55.5	?	–	?	~30	Lippincott, 1983 b
17	CC 20, 986	16 22.7	+ 48 28	10.3 – –	M3	>0.3 1978.5	7.4	?	–	0.06–0.16	3.72	Lippincott, 1978
18.	G 139–29	17 15.4	+ 11 44	15.1 – –	(red)	~0.2 1981	12.5	?	–	⩾0.05	~10	Lippincott, 1978
19	α Ophiuchi	17 32.6	+ 12 36	2.07 – –	A5 III	~0.5 ~1974	16.7	~3.0	–	?	8.5	Lippincott, 1978
20	BD + 68°946 Ci 2354	17 36.7	+ 68 23	9.15 – –	M3.5 V	~1 1985	4.7	?	–	0.006–0.07	26.4	Lippincott, 1978
21	Barnard's Star	17 55.4	+ 4 33	9.5 – –	M5 V	0.0070 0.0064 –	1.8	0.14	–	0.0007 0.0005	12 20	Van de Kamp, 1983

Table 1 (continued)

No	Star	α(1950)	δ(1950)	m_A m_B m_C	A Sp B C	estimated max ρ Epoch max. ρ	S(pc)	M_A	M_B	M_u	P	Reference
22	Wolf 1062	19 9.6	+ 2 49	11.1 – –	M4	0.15 1979.9	10	?	?	0.06–0.15	2.4	Lippincott, 1978
23	δ Aquilae	19 23.0	+ 3 00	3.4	F0 IV	~0.2 1977	14.3	1.2	–	0.5	3.4	Lippincott, 1978
24	G 208–44/45	19 53.3	+ 44 , 17	13.4 14.0	me m	0.25 –	4.8	?	?	~0.01	>20	Circ. Cent. Bur. Ast. Tel. IAU, No 3989, 1
25	G 24–16	20 27.4	+ 9 31	13.05 – –	dM	~0.1 1980.0 ±0.3	8.7	?	–	0.07–0.11	1.49	Lippincott, 1978
26	CC 1228= AC +44°871–589 = = Furuhjelm 53	20 43.3	+ 44 19	10.82 – –	dM 3	0.3 ?	12.2	0.35	–	0.02	6.3	Lippincott, 1979
27	61 Cygni	21 04.7	+ 38 30	5.2 6.0 –	K5e K7 –	0.006	3.4			0.004	6	Dejch, 1978
28.	Wolf 922	21 28.6	–10° 1	11.95 – –	M4.5e	0.12 1979	8.2	0.25	–	0.13–0.20	1.93	Lippincott, 1979
29	BD +27°4120 CC 1299	21 35.8	+ 27 30	9.8 – –	M0	~0.7 ~1985	14.1 12.3	? 0.44–0.55	–	? 0.23–0.29	~40 85	Lippincott, 1978 Lippincott & Turner,
30	ζ Aquarii A	22 23.7	– 0 32	4.3 4.5 –	F2 IV F2 IV	0.12 –	27.8	1.5	1.5	0.4	25.7	Heintz, 1984
31	BD +43°4305 EV Lac	22 44.7	+ 44 5	10.2 – –	M4.5e	~1.3 1990 ±3	5.0	?	–	0.002–0.004	45	Lippincott, 1978, 1983c

constant value. Of course, such a situation is a consequence of the incompleteness of the sample. According to van de Kamp (1976) the sample is complete up to S = 0.29 pc, which is less than the distance to the nearest known star. But since inside the 0.29 pc sphere we know no stars, one cannot find any companion. Existence of a star nearer than Proxima Cen is quite possible, but the opposite case is possible too, since at small distances one cannot expect the statistical rules to be obeyed. Therefore, it is a matter of dispute how much such an extrapolation is justified and we propose choice of an arbitrary heliocentric distance S_r within which a reasonable number of the unseen companions is situated and to calculate the observed number of the unseen companions as a product of the simple division $N(S_r)/(4\pi/3)\ S_r^3$. Since the function N(S) has an apparent increase up to S = 15 pc, the latter value is chosen as S_r. In such a way one obtaines $n_{obs} = 1.5 \times 10^{-3}\ pc^{-3}$ as the observed local number density of the unseen compains. Taking into account the usual accuracy of a distance determination an estimate like the following, $\Delta n_{obs} = 0.1 \times 10^{-3}\ pc^{-3}$, for the number density error seems reasonable.

Now, one should take into account possible sources of observational selection preventing us to see the complete sample of the unseen companions. Firstly, there is no companion below the declination $\delta \approx -16°$ (Table I). This is probably due to the fact that the southern stars have been less examined. A simple calculation yields that the examined part of the sky ($-16° \leqslant \delta \leqslant +90°$) is 2/3 of the total solid angle, i.e. the obtained number density should be multiplied by 1.5 yielding thus $(2.25 \pm 0.1) \times 10^{-3}\ pc^{-3}$. The second correction takes into account that in all directions not all of the unseen companions have been found.

An inspection of Table I reveals that more than a half of the primaries are red dwarfs. The predominance of the red dwarfs among the primaries becomes especially apparent if one is halted at smaller heliocentric distances. For example, out of the six primaries nearer than 5 pc four are classified as red dwarfs. This seems to be an indication that in the vicinity of the red dwarfs new unseen companions may be found. Since among the nearby stars there are many red dwarfs, for example out of 63 stars, $S \leqslant 5$ pc, 42 are red dwarfs, or may be classified as red dwarfs according to Lippincott's (1978) catalogue. Thus it seems reasonable to suppose that the local number density of the unseen companions should be similar to that of the red dwarfs. An estimate based on the stars from Lippincott's catalogue yields that the local number density of the red dwarfs is about 0.1 pc^{-3}. If the same value is assumed for the local number density of the unseen companions, then it is 40–50 times as large as the corrected value of 2.25×10^{-3} pc^{-3}. By the way, by use of his own method van de Kamp (1976) found a value of (0.21 ± 0.06) pc^{-3}, which is not much different from ours, bearing in mind the low reliability.

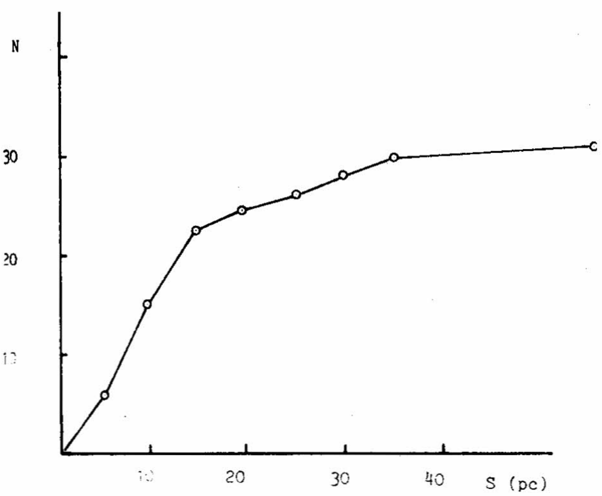

Fig. 1. Number of unseen companions versus heliocentric distance as derived from observations

It is difficult to comment the latter result, but a number density of 0.1–0.2 pc^{-3} means that in a volume of, say, 10 pc^3 are present 1–2 unseen companions. Such a volume has a heliocentric sphere, whose radius is approximately equal to the distance to the nearest known star. It cannot be excluded that there are more bodies within the system to which the latter star belongs (e.g. Lippincott, 1978; Aleksandrov, Zakhozhaj, 1983). Existence of a companion to the Sun has been also speculated (Hills, 1985). Thus the upper estimate of 1–2 unseen companions within the heliocentric sphere, of the volume of 10 pc^3, does not seem unrealistic and on the basis of van de Kamp's assumption that the number density of the unseen companions is constant at least up to S = 30 pc, also assumed here, we assume the value of 0.1 pc^{-3} as our final result.

To calculate the mass density one should know also the mean mass per unseen companion. The available data (Table I) yield a value of 0.243 $m_\odot$ with a standard deviation of 0.385 $m_\odot$. For a small sample like the present one the standard deviation is not meaningful, its purpose is merely to demonstrate the inhomogenuity of the sample. This fact is easy to be understood since the unseen companions are not well–defined category of celestial bodies.

Van de Kamp (1976) assumed 0.3 $m_\odot$ as the mean mass, having been a value yielded by the sample, which existed at that time. However, being aware of observational selection influence, one cannot assume such a value as a final one. In our opinion one should try to correct the obtained value for the observational selection effects. The assumption concerning the rate of the red dwarfs, mentioned above, suggests a calculation of the mean mass of only those unseen companions appearing as copanions to red dwarfs. In such a case we should have $m_{uc} = 0.08$ $m_\odot$ with a standard deviation of 0.072 $m_\odot$. A large standard deviation like the present one indicates that even this part of the sample is not homogenous enough; in the case of nearer red dwarfs it is possible to detect perturbations near the noise level, corresponding to very low mass companions, on the contrary in the case of more distant ones, it is more difficult. Thus, it seems that the obtained standard deviation suggests a correction downwards, probably for one half of its value, since a larger correction may yield a significant understimate in the mean mass. This means that we adopt $m_{ue} = 0.044$ $m_\odot$ as a final value for the mean mass of an unseen companion. Finally a simple multiplication of 0.1 pc^{-3} by 0.044 $m_\odot$ yields $\rho = 0.0044$ $m_\odot$ pc^{-3}, which should be the contribution of the unseen companions to the local mass density. This is an order of magnitude less than that what van de Kamp (1976) obtained. Nevertheless it seems real, since one cannot expect that the observational selection will bring only a slight change in the mean mass per unseen companion, leading to a somewhat strange result–a mean mass per unseen companion is nearly equal to, or even larger than the mean mass of a prevailing type star! Finally, since according to Oort (1965) the total local mass density should be about 0.1 $m_\odot$ pc^{-3}, it seems that the contribution of the unseen companions is not essential, or at least the unseen companions may given a nonnegligible contribution only together with the unseen primaries.

Our estimate is, of course, very uncertain and compared to van de Kamp's one it may seem too conservative. However, one should certainly bear in mind the negative results obtained in some infrared searches for new companions to nearby stars (e.g. Jameson et al., 1983).

Finally, the topic of the unseen companions certainly involves consideration of the possibility of other planetary systems. Though, it is often said that the fundamental characteristic of an object determining whether the object should be classified as a planet or as a star is its mass, one should also take into account, according to van de Kamp (1983b), the orbital eccentricity. If we accept such a point of view, then after analysing the material of Table I we reach a conclusion that there is only one star Barnard's one – which probably has a planetary system, since solely its companions seem to orbit their primary along low–eccentricity orbits. The case of Barnard's star has been already studied by van de Kamp (e.g. 1982; 1983b). This concept is in accordance with the well–known Kant–Laplace hypothesis. Perhaps, other planetary systems are now formed in such a way (Walgate, 1983).

Certainly, the negative results concerning the possibility that Barnard's star has a companion, obtained by Marcy (1983) and by Marcy, Lindsay (1985) by means of line–of–sight velocity analyses, should be mentioned. However, the latter two authors give a value of 470 m s^{-1} as their accuracy level, whereas one can easily calculate using the data given by van de Kamp (1982; 1983a, b) that the reflected motion of Barnard's star caused by the shift of the mass centre due to the suspected companions is only 55 m s^{-1}. Therefore, it lies well below the accuracy level of Marcy, i.e. Marcy and Lindsay.

It is very difficult to point out which stars are perspective candidates to possess unseen companions. There is a study concerning the latter question by Walbaum and Duvent (1983) according to which existence of a third body in the system of Sirius is highly probable.

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REFERENCES

Aleksandrov, Yu. V., Zakhozhaj, V.A.: 1983, *Astron. Vest.*, **17**, 131.
Black, D.C.: 1980, *Space Sci. Rev.*, **25**, 35.
Dejch, A.N.: 1978, *Pis'ma v Astron. Zh.*, **4**, 95.
Gatewood, G.: 1976, *Icarus*, **27**, 1.
Harrington, R.S., Christy, J.W., Strand, K.A.: 1981, *Astron, J.*, **86**, 909.
Heintz, W.D.: 1984, *Astrophys. J.*, **284**, 806.
Hills, J.G.: 1985, *Astron. J.*, **90**, 1876.
Jameson, R.F., Sherrington, M.R., Giles, A.B.: 1983, *Mon. Not. R. astr. Soc.*, **205**, P39.
Lippincott, S.L.: 1978, *Space Sci. Rev.*, **22**, 153.
Lippincott, S.L.: 1979, *Publ. astr. Soc. Pac.*, **91**, 784.
Lippincott, S.L.: 1983a, *Publ. astr. Soc. Pac.*, **95**, 775.
Lippincott, S.L.: 1983b, *Astron. J.*, **88**, 542.
Lippincott, S.L.: 1983c, *IAU Col. No 71*, D. Reidel, Dordrecht, 201.
Lippincott, S.L., Turner, A.: 1980, *Publ. astr. Soc. Pac.*, **92**, 531.
Lippincott, S.L., Worth, M.D.: 1980, *Astron. J.*, **85**, 171.
Lippincott, S.L., Braun, D., McCarthy, Jr., D.W.: 1983, *Publ. astr. Soc. Pac.*, **95**, 271.
Marcy, G.W.: 1983, *Bul. Am. astr. Soc.*, **15**, 947.
Marcy, G.W., Lindsay, V.: 1985, *Bull. Am. astr. Soc.*, **17**, 558.
MaCarthy, Jr., D.W.: 1984, *Astron. J.*, **89**, 433.
Oort, J.H.: 1965, *in Galactic Structure*, Volume V of *Stars and Stellar Systems*, ed. A. Blaauw, M. Schmidt, University of Chicago Press, Chicago & London, 455.
Popović, G.M.: 1981, *Publikacija Astronomske opservatorije u Sarajevu*, **1**, 269.
Radhakrishnan, K.R., Abhyankar, K.D., Sarma, M.B.K.: 1984, *Bull. astr. Soc. India*, **12**, 182.
van de Kamp, P.: 1976, *Roy. Green. Obs. Bull.*, **182**, 7.
van de Kamp, P.: 1982, *Vistas in Astronomy*, **26**, 141.
van de Kamp, P.: 1983a, *IAU Col. No 76*, ed. A.G. Davis Philip, A.R. Upgren, L. Davis Press, *Inc. Schenectady*, New York, USA, 15.
van de Kamp, P.: 1983b, *Astron. Nachr.*, **304**, 97.
Walbaum, M., Duvent, J.L.: 1983, *Astronomie*, **97**, 277.
Walgate, R.: 1983, *Nature*, **304**, 681.

OPTICAL POLARIZATION CHANGES OF 88 HER IN THE PERIOD 1974–1985

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SUMMARY Linear optical intrinsic polarization of 88 He (HD 162732) measured with the Belgrade:polarimeter in the period 1974–1985 has been presented. The polarization percentage changed from 0.15% (1976) to 0.56% (1979). Small values of polarization percentage corresponded to the period with negligible envelope effects. The maximum polarization has been found during the early period of a strong shell phase, about one year after brightness minimum. The polarization position angle varies between 58 and 83 degrees. An indication of the correlation between polarization percentage and H–alfa emission line intensities is demonstrated.

1. INTRODUCTION

During the last two decades, or so, 88 Her has been in the focus of interest of several authors. The star was spectroscopicaly observed in a rather wide spectral region and analysed by Doazan (1973), Harmanec et al. (1972, 1974), Doazan et al. (1982 a, b), Barylak and Doazan (1986). The long term variations of the envelope (emission of HI and metals, shell absorption lines etc.) have been found. The periodic radial velocity changes with the period of approximately 87 days has been found too. The photometric observations in UBV (Doazan et al.. 1982a, b; Harmanec et al. 1978) and in Far –UV spectral regions (Doazan et al. 1986; Barylak and Doazan, 1986) led to the discovery of long–term brightness and colour variations in the period 1972–1985. During the same period, fortunately, remarkable changes from quasi normal B phase to Be–shell phase with the luminosity changes took place. Doazan et al. (1986) have interpreted the observations from the new point of view associating the photospheric and envelope phenomena.

Almost stimultaneously with spectral and photometric observations elswhere, polarimetry of 88 Her in V colour was done at Belgrade. The intrinsic linear optical polarization was found for the period 1974–1985. The changes of the intrinsic polarization percentage are definitely present in the period of measuring. A graphic indication of the polarization percentage correlation with the corresponding V magnitude and emissive flux intensities of H–alfa lines were found. The interpretation of the complex nature of variable phenomena of this Be star starts to be now, with polarization data, more complicated than it was before.

2. THE OBSERVATIONAL FACTS ABOUT POLARIZATION CHANGES

In the period 1974–1985, the linear optical polarization parameters of 88 Her were measured with the Belgrade polarimeter and 65 cm refractor in V spectral region. Each measurement represents 8–minute continuously integrated stellar signal modified by a rotating analyser with the period of 1 minute (for full rotation). In the period 1974–1978 the integration was made by overlaping of eight one–minute records at the X–Y recorder and by visual estimation and measuring of the amplitudes and phases of the sine–wave signals. After 1978, the measurements were digitally registered and integrated by KRS 24–100 Data record system and after that processes „off–line". During the whole period a number of polarized and non–polarized standard stars were measured and instrumental system was checked. The detailed description of the measurement procedure and elaboration of the data will be published separately.

The interestellar polarization percentage in the direction of 88 Her was estimated as a mean value of average percentage of the nearby stars and the value of percentage estimated under the assumption of certain stellar extinction, taking into account Barylak and Doazan (1986) estimation, and Behr's (1959) relation between polarization and extinction in the region of 88 Her. The two nearest stars are HD 160762 and HD 156 110 with the polarization parameters p = 0.75%, p = 0.18% and θ = 148°, θ = 166° repectively. That gives the average value 0.46% for polarization percentage. The assumption E(B–V) = 0.03 of Barylak and Doazan (1986), A_V = 3E(B–V)taken from Doazan (1982) and P/A_V = 0.24 for the region of 88 Her, led to the interstellar polarization percentage amounting to 0.1%. These two estimated values of the interstellar polarization percentage component gave the mean value of P_i = 0.28%. The same value have been also found as a result of averaging the polarization percentage of five stars in the vicinity of 88 Her. The position angle value $\theta = 158^{\circ}$ has been found as a mean of the position angles of two nearest stars. Almost the same value could be derived as a weighted mean (if the weight is polarization percentage) of 15 stars in the neighborhood of 88 Her. We decided to take the values $P_i = 0.28\%$, $\theta = 158^{\circ}$ as the interstellar polarization parameters in the direction of 88 Her. We are not able to claim that these values are the best but we do not expect them to differ too much from the true ones. Besides, this value of polarization percentage seems real for the galactic latitude of about 30 degrees. The interstellar polarization was vectorially extracted from the observed polarization parameters.

The observed values of polarization percentage P_o, position angle θ_o and corresponding Stokes parameters Q_o, U_o, expressed in percents, are presented in the first part of Table 1. together with the dates and Julian days. In the second part of the same Table the corresponding intrinsic polarization parameters of the star P_s, θ_s, Q_s and U_s are shown. The typical r.m.s. error of the observed Stokes parameters for one 8–minute measurement is ± 0.07%.

We decided to present each 8–minute measurement in order to show the large disperssion of the data, greater than the triple error. The large dispersion is, by our oppinion, the result of real small changes of stellar polarization in shorter intervals of time. Some other short period changes are common for Be stars generally and could be expected in the case of 88 Her too. Namely, Doazan et al. (1982, b) have found a 86.7221 day period of radial velocities and H–alfa double emission V/R ratio variations. Moreover, some suspection of the presence of rapid variation in line intensities of NaI and H–alfa profiles was expressed by Harmanec et al. (1978) together with some indication of a sudden random photometric change. These different small amplitude and rapid changes might lead to the rapid changes of poarization parameters. For the moment, there are several reasons to expect the existence of some short–term periodicities in our sample of polarimetric data. This should be the subject of a study in the near future in spite the fact that the changes are small, may be smaller than our observational error.

The intrinsic polarization percentage P_s from the Table 1. is presented in the Figure 1. versus time. It is easily seen that the intrinsic polarization percentage does change with time in the period 1974–1985. The interval of the maximal percentage variation is 0.00%–0.67%. Small values are observed during the years 1975, 1976,

Table 1. 8–minute measurements of the observed (subscript o) and the intrinsic (subscript s) polarization parameters of 88 Her in V colour.

DATE	J.D. (2440000+)	P(%)	θ_o(°)	Q_o(%)	U_o(%)	P_s(%)	θ_s(°)	Q_s(%)	U_s(%)
740716	2244.5	0.12	109.9	-0.095	-0.08	0.31	79.5	-0.294	0.112
740917	2307.5	0.22	113.5	-0.155	-0.167	0.35	87.9	-0.354	0.024
750708	2601.5	0.12	17.8	0.103	0.073	0.28	54.8	-0.096	0.265
750709	2602.5	0.23	172.5	0.231	-0.062	0.13	37.8	0.033	0.13
750709	2602.5	0.22	163.7	0.192	-0.123	0.06	47.5	-0.007	0.068
750906	2661.5	0.08	16.1	0.067	0.043	0.26	59.5	-0.121	0.234
760620	2949.5	0.09	6	0.096	0.02	0.23	57.8	-0.103	0.212
760624	2953.5	0.17	158.4	0.127	-0.12	0.1	67.2	-0.072	0.072
760624	2953.5	0.16	109.6	-0.131	-0.108	0.33	82.8	-0.33	0.084
760624	2953.5	0.21	123.9	-0.008	-0.212	0.2	92.7	-0.207	-0.021
760720	2979.5	0.27	157.9	0.194	-0.139	00	73.2	-0.005	0.002
760720	2979.5	0.32	2.3	0.326	0.076	0.25	29.7	0.128	0.218
760827	3017.5	0.21	171.2	0.209	-0.066	0.12	42.5	0.01	0.125
760827	3017.5	0.21	133.3	-0.013	-0.212	0.21	92.6	-0.211	-0.02
770323	3225.5	0.34	172.1	0.336	-0.095	0.16	17.5	0.157	0.097
770323	3225.5	0.24	161.1	0.196	-0.152	0.03	46.4	-0.003	0.039
770417	3250.5	0.07	155.3	0.047	-0.056	0.2	68.9	-0.152	0.136
770417	3250.5	0.11	152	0.066	-0.099	0.16	72.3	-0.133	0.093
770612	3306.5	0.04	140.7	0.008	-0.04	0.24	70.7	-0.191	0.151
770613	3307.5	0.25	147.6	0.107	-0.226	0.09	100.2	-0.092	-0.035
770620	3314.5	0.05	162.5	0.049	-0.035	0.21	66.7	-0.15	0.157
770712	3336.5	0.13	127.2	-0.061	-0.127	0.26	82.8	-0.259	0.065
770712	3336.5	0.09	109.3	-0.075	-0.06	0.3	77.1	-0.273	0.131
770712	3336.5	0.07	149.6	0.035	-0.064	0.2	70.9	-0.163	0.127
770713	3337.5	0.05	119.1	-0.03	-0.048	0.26	73.7	-0.228	0.144
770713	3337.5	0.11	132.9	-0.009	-0.111	0.22	79.2	-0.207	0.081
770713	3337.5	0.04	156.3	0.031	-0.035	0.22	68.3	-0.167	0.157
770719	3343.5	0.11	147.9	0.052	-0.108	0.16	75	-0.146	0.083
770719	3343.5	0.21	104.4	-0.18	-0.117	0.38	38.3	-0.379	0.075
780601	3660.5	0.23	134.3	-0.085	-0.218	0.28	72.5	-0.284	0.026

Table 1 (continued)

DATE	J.D. (2440000+)	P(%)	θ_o(°)	Q_o(%)	U_o(%)	P_S(%)	θ_S(°)	Q_S(%)	U_S(%)
780601	3660.5	0.27	118.6	-0.148	-0.23	0.34	93.1	-0.346	-0.038
780602	3661.5	0.15	99.9	-0.15	-0.055	0.37	79.2	-0.348	0.137
780602	3661.5	0.14	135.8	0.004	-0.146	0.19	83.2	-0.195	0.046
780602	3661.5	0.14	133.9	-0.006	-0.15	0.2	84.1	-0.205	0.042
780602	3661.5	0.28	114.6	-0.188	-0.218	0.38	91.8	-0.386	-0.026
780703	3692.5	0.16	139.1	0.024	-0.167	0.17	85.9	-0.175	0.024
780703	3692.5	0.14	131.7	-0.017	-0.148	0.21	84.2	-0.216	0.043
780703	3692.5	0.14	138.4	0.017	-0.144	0.18	82.5	-0.182	0.048
780731	3720.5	0.18	88.8	-0.187	0.007	0.43	76.3	-0.386	0.199
780801	3721.5	0.21	96.3	-0.207	-0.047	0.43	80.1	-0.406	0.145
780801	3721.5	0.24	107.3	-0.202	-0.14	0.4	86.2	-0.401	0.052
780802	3722.5	0.11	110.7	-0.09	-0.079	0.3	79.2	-0.288	0.113
780802	3722.5	0.07	111.2	-0.053	-0.049	0.28	75.1	-0.252	0.143
780806	3726.5	0.07	93.3	-0.076	-0.009	0.32	73.1	-0.274	0.182
780908	3759.5	0.03	93.8	-0.037	-0.005	0.29	70.7	-0.235	0.186
780908	3759.5	0.1	106.5	-0.089	-0.058	0.31	77.4	-0.287	0.134
790529	4022.5	0.29	52.5	-0.078	0.284	0.55	60	-0.276	0.476
790625	4049.5	0.15	68.2	-0.115	0.108	0.43	68.1	-0.313	0.299
790626	4050.5	0.19	60.3	-0.099	0.165	0.46	64.8	-0.297	0.356
790626	4050.5	0.36	63.7	-0.222	0.288	0.63	65.5	-0.42	0.48
790626	4050.5	0.31	55.2	-0.112	0.296	0.57	61.1	-0.31	0.488
790626	4050.5	0.38	67.3	-0.272	0.274	0.66	67.6	-0.471	0.466
790725	4079.5	0.24	66.7	-0.171	0.18	0.52	67.3	-0.37	0.372
790827	4112.5	0.36	64.9	-0.232	0.278	0.63	66.2	-0.431	0.47
790827	4112.5	0.35	68.8	-0.266	0.241	0.63	68.4	-0.464	0.433
790827	4112.5	0.31	49	-0.044	0.308	0.55	57.9	-0.243	0.499
790918	4134.5	0.34	57	-0.14	0.313	0.6	61.9	-0.339	0.504
790918	4134.5	0.35	62.8	-0.207	0.287	0.62	65	-0.405	0.479
790919	4135.5	0.29	55.6	-0.108	0.275	0.55	61.6	-0.307	0.466
790919	4135.5	0.33	54.9	-0.115	0.315	0.59	60.8	-0.313	0.507
790921	4137.5	0.31	58	-0.141	0.287	0.58	62.6	-0.34	0.479
790921	4137.5	0.37	61.5	-0.206	0.314	0.64	64.2	-0.404	0.506
800611	4401.5	0.25	67.9	-0.186	0.179	0.53	67.9	-0.385	0.371
800611	4401.5	0.34	70.2	-0.268	0.22	0.62	69.2	-0.467	0.412
800612	4402.5	0.33	80.3	-0.319	0.111	0.59	74.7	-0.517	0.303
800612	4402.5	0.34	64.5	-0.219	0.269	0.62	66	-0.418	0.461
800613	4403.5	0.34	61.3	-0.186	0.289	0.61	64.2	-0.385	0.481
800613	4403.5	0.17	55.6	-0.065	0.166	0.44	63.1	-0.264	0.358
800614	4404.5	0.3	46.8	-0.02	0.309	0.54	56.7	-0.219	0.501
800614	4404.5	0.16	80.4	-0.152	0.052	0.42	72.5	-0.35	0.244
800616	4406.5	0.29	73.9	-0.254	0.159	0.57	71	-0.452	0.35
800616	4406.5	0.21	69.5	-0.162	0.14	0.49	68.6	-0.361	0.332
800808	4459.5	0.22	64.5	-0.144	0.176	0.5	66.4	-0.342	0.368
800905	4487.5	0.24	72.1	-0.197	0.14	0.51	69.9	-0.395	0.332
800909	4491.5	0.35	64.1	-0.223	0.282	0.63	65.8	-0.421	0.473
810531	4755.5	0.28	59.5	-0.141	0.252	0.55	63.6	-0.34	0.444
810531	4755.5	0.2	60.3	-0.103	0.173	0.47	64.7	-0.302	0.364
810627	4782.5	0.33	69.2	-0.254	0.223	0.61	68.7	-0.453	0.415
810629	4784.5	0.18	39.2	0.036	0.18	0.4	56.7	-0.162	0.372
810701	4786.5	0.21	56	-0.081	0.198	0.47	62.7	-0.279	0.39
810702	4787.5	0.19	53.8	-0.061	0.19	0.46	62	-0.26	0.382
810702	4787.5	0.29	68.6	-0.214	0.197	0.56	68.3	-0.413	0.389
810802	4818.5	0.22	54.6	-0.074	0.208	0.48	62	-0.272	0.4
810802	4818.5	0.28	60.2	-0.146	0.246	0.55	64	-0.344	0.438
810819	4835.5	0.2	49.3	-0.032	0.205	0.45	60	-0.23	0.396
820518	5107.5	0.32	40.2	0.054	0.323	0.53	52.7	-0.144	0.515
820522	5111.5	0.29	49.4	-0.045	0.287	0.53	58.4	-0.244	0.478
820715	5165.5	0.12	51.9	-0.031	0.123	0.38	63	-0.23	0.315
820716	5166.5	0.28	39.3	0.056	0.281	0.49	53.3	-0.143	0.473
820716	5166.5	0.29	60.2	-0.152	0.258	0.57	63.9	-0.351	0.449
820716	5166.5	0.25	67.2	-0.182	0.185	0.53	67.6	-0.381	0.377
820716	5166.5	0.26	47.6	-0.025	0.266	0.5	57.9	-0.224	0.458
820717	5167.5	0.36	52.1	-0.09	0.355	0.61	58.9	-0.289	0.546
820717	5167.5	0.16	42.5	0.014	0.166	0.4	58.5	-0.185	0.358
820717	5167.5	0.21	50.1	-0.039	0.215	0.47	60.1	-0.238	0.406
820718	5168.5	0.25	60.6	-0.132	0.216	0.52	64.4	-0.331	0.408
820718	5168.5	0.33	48.9	-0.047	0.333	0.57	57.5	-0.246	0.524
820721	5171.5	0.35	45.2	-0.004	0.356	0.58	55.1	-0.202	0.548
820721	5171.5	0.39	38.8	0.084	0.385	0.58	50.5	-0.114	0.577

Table 1 (continued)

DATE	J.D. (2440000+)	P(%)	θ_o(°)	Q_o(%)	U_o(%)	P_s(%)	θ_s(°)	Q_s(%)	U_s(%)
820813	5194.5	0.13	53.5	-0.039	0.126	0.39	63.3	-0.238	0.317
820813	5194.5	0.24	52.5	-0.063	0.232	0.49	60.8	-0.261	0.423
820815	5196.5	0.25	37	0.071	0.249	0.45	53	-0.127	0.441
820815	5196.5	0.24	41.5	0.029	0.244	0.46	55.5	-0.169	0.435
820815	5196.5	0.23	39.1	0.048	0.23	0.44	54.7	-0.151	0.422
820816	5197.5	0.29	56.3	-0.113	0.271	0.55	61.9	-0.312	0.462
820816	5197.5	0.38	33	0.154	0.349	0.54	47.3	-0.044	0.54
820819	5200.5	0.28	33.6	0.11	0.264	0.46	50.4	-0.089	0.456
820823	5204.5	0.11	49.7	-0.02	0.114	0.37	62.6	-0.218	0.306
820825	5206.5	0.13	37.4	0.036	0.134	0.36	58.2	-0.163	0.325
830507	5461.5	0.13	84.7	-0.135	0.025	0.39	73.4	-0.333	0.216
830510	5464.5	0.32	35.2	0.108	0.307	0.5	50.1	-0.091	0.499
830514	5468.5	0.31	34.6	0.111	0.295	0.49	50	-0.088	0.486
830514	5468.5	0.25	30.3	0.125	0.224	0.42	49.9	-0.073	0.416
830515	5469.5	0.19	33.6	0.073	0.175	0.38	54.3	-0.125	0.367
830515	5469.5	0.22	44	0.007	0.226	0.45	57.2	-0.191	0.418
830515	5469.5	0.22	46.2	-0.01	0.225	0.46	58.2	-0.209	0.417
830516	5470.5	0.28	29	0.148	0.238	0.43	48.2	-0.05	0.43
830516	5470.5	0.37	30	0.186	0.325	0.51	45.6	-0.012	0.517
830518	5472.5	0.3	51.5	-0.07	0.295	0.55	59.3	-0.268	0.487
830518	5472.5	0.19	53.8	-0.059	0.183	0.45	62.2	-0.257	0.374
830518	5472.5	0.22	42.9	0.016	0.226	0.45	56.7	-0.183	0.418
830705	5520.5	0.28	50.7	-0.057	0.275	0.53	59.3	-0.255	0.466
830708	5523.5	0.14	26.1	0.089	0.115	0.32	54.7	-0.11	0.307
830708	5523.5	0.26	56.9	-0.108	0.243	0.53	62.5	-0.306	0.434
830709	5524.5	0.07	69.2	-0.056	0.049	0.35	68.2	-0.255	0.241
830709	5524.5	0.09	24.8	0.062	0.074	0.29	58.5	-0.136	0.265
830715	5530.5	0.12	81.6	-0.12	0.035	0.39	72.1	-0.318	0.227
830715	5530.5	0.23	53.1	-0.066	0.223	0.49	61.2	-0.264	0.415
830804	5550.5	0.27	47.1	-0.021	0.269	0.51	57.6	-0.219	0.461
830804	5550.5	0.34	52.6	-0.092	0.335	0.6	59.4	-0.291	0.527
830805	5551.5	0.28	33	0.114	0.256	0.45	50.3	-0.085	0.448
830806	5552.5	0.42	21.3	0.311	0.286	0.49	38.3	0.112	0.478
830806	5552.5	0.29	27.5	0.166	0.239	0.43	47.1	-0.033	0.43
830806	5552.5	0.14	102.7	-0.135	-0.065	0.35	79.5	-0.333	0.127
830812	5558.5	0.46	42.8	0.034	0.465	0.67	52	-0.165	0.657
830902	5579.5	0.13	38.4	0.03	0.133	0.36	58.6	-0.168	0.325
830902	5579.5	0.21	47.8	-0.021	0.209	0.45	59.3	-0.22	0.401
840506	5826.5	0.26	37.9	0.064	0.254	0.46	53.3	-0.135	0.446
840530	5850.5	0.18	34.5	0.068	0.177	0.39	54.7	-0.131	0.369
840530	5850.5	0.2	42.8	0.014	0.199	0.43	57.5	-0.184	0.391
840530	5850.5	0.26	42.9	0.018	0.261	0.48	55.8	-0.181	0.452
840530	5850.5	0.19	27	0.116	0.161	0.36	51.5	-0.082	0.352
840603	5854.5	0.31	36.2	0.095	0.301	0.5	50.9	-0.104	0.492
840603	5854.5	0.14	26.4	0.089	0.118	0.32	54.6	-0.109	0.309
840603	5854.5	0.25	28	0.14	0.208	0.4	49.1	-0.059	0.4
840603	5854.5	0.18	10.9	0.17	0.068	0.26	48	-0.028	0.26
840603	5854.5	0.05	42.4	0.005	0.059	0.31	63.7	-0.194	0.251
840604	5855.5	0.23	63.5	-0.142	0.186	0.5	65.9	-0.34	0.378
840604	5855.5	0.2	57.1	-0.085	0.186	0.47	63.3	-0.284	0.378
840604	5855.5	0.14	66.7	-00.1	0.105	0.42	67.5	-0.299	0.297
840604	5855.5	0.34	37.3	0.091	0.334	0.53	50.7	-0.108	0.526
840628	5879.5	0.32	43.4	0.018	0.328	0.55	54.5	-0.181	0.52
840628	5879.5	0.2	42.8	0.015	0.204	0.43	57.3	-0.184	0.396
840828	5940.5	0.15	38.5	0.033	0.149	0.37	57.8	-0.165	0.341
840828	5940.5	0.23	30.2	0.116	0.207	0.4	50.7	-0.082	0.398
840829	5941.5	0.29	27.9	0.165	0.244	0.43	47.1	-0.034	0.436
840829	5941.5	0.29	22	0.21	0.204	0.39	44.1	0.012	0.395
840829	5941.5	0.26	176.9	0.258	-0.028	0.17	34.9	0.06	0.164
840722	5903.5	0.24	34.4	0.087	0.227	0.43	52.3	-0.111	0.419
840722	5903.5	0.12	51.2	-0.027	0.118	0.38	62.9	-0.225	0.309
840722	5903.5	0.16	63.2	-0.101	0.134	0.44	66.2	-0.299	0.326
840731	5912.5	0.15	90.4	-0.155	-0.003	0.4	75.9	-0.354	0.189
84073.	5912.5	0.02	65.1	-0.018	0.02	0.3	67.7	-0.216	0.211
840801	5913.5	0.05	159.5	0.039	-0.035	0.22	67.6	-0.159	0.157
840801	5913.5	0.14	42.1	0.014	0.143	0.38	59.4	-0.185	0.335
840801	5913.5	0.07	95	-0.074	-0.014	0.32	73.3	-0.273	0.178
840801	5913.5	0.15	86.7	-0.156	0.017	0.41	74.7	-0.355	0.209
840803	5915.5	0.34	165.6	0.306	-0.169	0.11	6.1	0.108	0.023
840803	5915.5	0.38	147.6	0.165	-0.35	0.16	129.1	-0.033	-0.158

Table 1 (continued)

DATE	J.D. (2440000+)	P(%)	θ_o(°)	Q_o(%)	U_o(%)	P_s(%)	θ_s(°)	Q_s(%)	U_s(%)
840804	5916.5	0.14	162.7	0.121	-0.084	0.13	62.7	-0.077	0.107
840804	5916.5	0.09	135.7	0.002	-00.1	0.21	77.4	-0.197	0.091
840804	5916.5	0.21	168.9	0.199	-0.081	0.11	44.7	00	0.111
840804	5916.5	0.22	154.6	0.142	-0.175	0.05	81.4	-0.057	0.017
840805	5917.5	0.33	139.6	0.054	-0.335	0.2	112.3	-0.145	-0.143
840805	5917.5	0.23	150	0.116	-0.201	0.08	93.2	-0.082	-0.01
840805	5917.5	0.11	162.1	0.094	-0.069	0.16	64.9	-0.104	0.123
840822	5934.5	0.22	58.2	-0.102	0.202	0.49	63.6	-0.3	0.394
840822	5934.5	0.41	45.9	-0.014	0.41	0.63	54.7	-0.213	0.602
840822	5934.5	0.23	51.5	-0.053	0.226	0.48	60.4	-0.251	0.418
840823	5935.5	0.22	65.6	-0.148	0.168	0.49	66.9	-0.347	0.36
840823	5935.5	0.24	52.4	-0.063	0.234	0.5	60.7	-0.262	0.426
840823	5935.5	0.03	26.2	0.022	0.029	0.28	64.2	-0.176	0.221
840823	5935.5	0.14	67.1	-00.1	0.102	0.41	67.7	-0.299	0.293
840823	5935.5	0.14	41.7	0.016	0.147	0.38	59	-0.182	0.339
840823	5935.5	0.19	10.4	0.18	0.069	0.26	46.9	-0.018	0.26
840823	5935.5	0.05	91.8	-0.059	-0.004	0.31	71.9	-0.257	0.187
840823	5935.5	0.13	89.4	-0.139	0.002	0.38	75	-0.338	0.194
840823	5935.5	0.25	29.8	0.13	0.224	0.42	49.6	-0.068	0.415
840823	5935.5	0.11	54.2	-0.036	0.104	0.37	64.1	-0.234	0.296
840823	5935.5	0.13	52.1	-0.034	0.129	0.39	62.8	-0.232	0.321
850525	6210.5	0.33	53	-0.093	0.323	0.59	59.7	-0.292	0.515
850525	6210.5	0.31	39	0.064	0.309	0.51	52.4	-0.134	0.5
850714	6260.5	0.21	34.7	0.075	0.201	0.41	53.7	-0.124	0.393
850715	6261.5	0.13	45.7	-0.004	0.132	0.38	60.9	-0.203	0.324
850715	6261.5	0.25	36.2	0.076	0.239	0.44	52.9	-0.123	0.431
850715	6261.5	0.25	35.9	0.079	0.242	0.44	52.6	-0.12	0.433
850716	6262.5	0.16	10.6	0.151	0.059	0.25	50.2	-0.047	0.25
850716	6262.5	0.15	36.9	0.042	0.145	0.37	57.4	-0.157	0.337
850716	6262.5	0.19	53.1	-0.055	0.187	0.45	61.8	-0.254	0.379

1977 and 1978. The minimal values were observed at the end of the year 1976 and during the first part of 1977, and the maximal values during 1979. After 1979, polarization percentage decreases slowly approaching the values of 1975–77. There is a definite tendency of polarization percentage to decrease after 1979. but, we can not say whether it is going back to the level observed in the year 1976 and begining of 1977, or will it stay at somewhat higher values for a long period of time. It is important to conclude that the polarization percentage experienced relatively high and well seen variations of the amplitude of more than 0.5%. The increasing period was several times shorter than the decreasing period.

The position angle of the intrinsic polarization θ_S, illustrated in the Figure 2, have the decreasing tendency during the whole interval of time, changing approximately for about 1.5° per year. During the year 1974 it amounted to about 83 degrees and in the year 1985 about 58 degrees. The largest deviations of the position angle from the general trend were found in the period of small measured values of polarization percentage, 1975–1977, what is the normal consequence of the nature of the measurements.

It the Figure 3. the Stokes parameters of the intrinsic polarization Q_S and U_S are presented. At the first sight, the Stokes parameters look randomly distributed. Deeper inspection could demonstrate some regularities which we shall analyse further in the text.

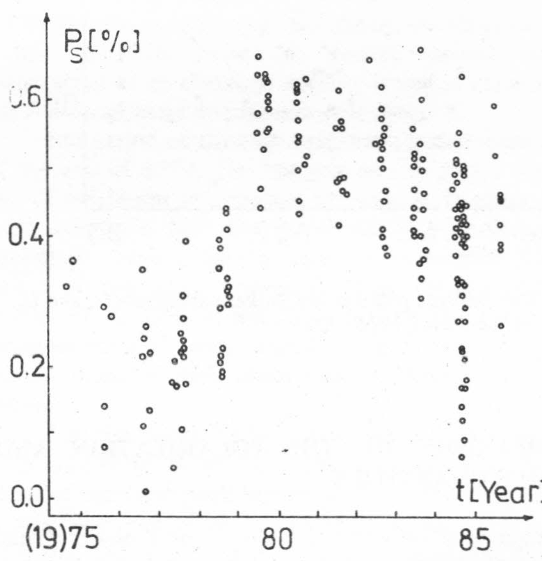

Fig. 1. The intrinsic polarization percentage of 88 Her in V colour in the period 1974–1985.

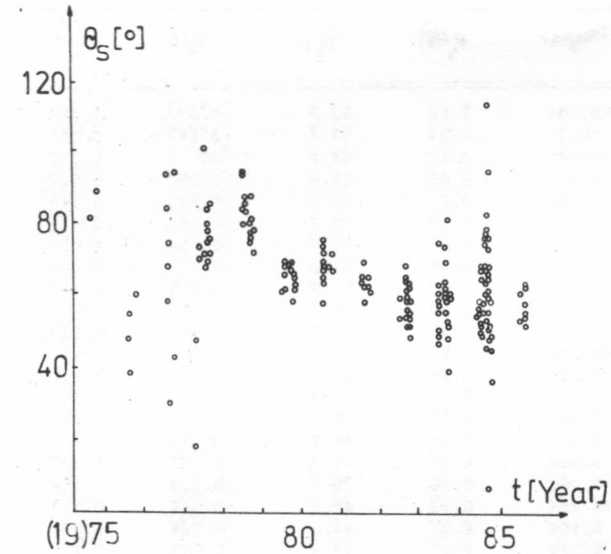

Fig. 2. The position angle of intrinsic polarization of 88 Her in V colour versus time in the period 1974–1985.

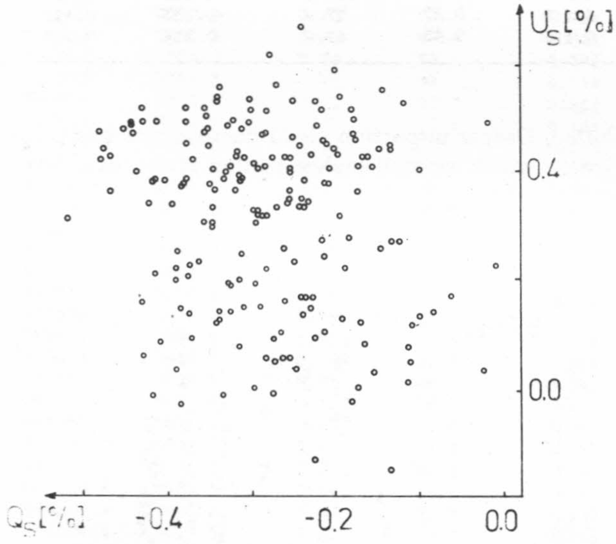

Fig. 3. The intrinsic polarization Stokes parameters Q_S and U_S 88 Her, in the period 1974–1985.

3. COMPARISON OF THE POLARIZATION AND OTHER QUANTITIES

The main goal of our very long–lasted observational tracking of 88 Her was to find long–term changes of polarization parameters. One of the ways to represent them is to average the intrinsic values in the intervals of „one year" (one observational season lasting not more than 6 months). So defined annaul mean values of the polarization parameters are presented in Table 2. with the corresponding r.m.s. errors of the mean and the number of observations. These values are ilustrated in Figures 4, 5, 6. The long–term changes of polarization percentage are very well seen in the Figure 4. The minimum of the annual mean values of polarization percentage was in the year 1976 and it reached the maximum value of 0.56% in the year 1979.

Table 2. Annual mean values of the intrinsic polarization parameters of 88 Her in V colour.

Year	Q_S(%)	σ_q	U_S(%)	σ_u	P_S(%)	θ_S(o)	n
1974	–.323 ±	.030	.069 ±	.044	.334	83.8	2
1975	–.050	.038	.175	.046	.188	50.0	4
1976	–.098	.052	.085	.034	.185	67.4	8
1977	–.160	.031	.101	.014	.212	70.3	15
1978	–.286	.019	.083	.019	.306	82.1	16
1979	–.356	.017	.456	.015	.581	64.0	16
1980	–.382	.022	.384	.021	.548	67.4	13
1981	–.305	.027	.400	.008	.506	63.0	10
1982	–.212	.017	.441	.016	.497	58.0	24
1983	–.175	.021	.402	.021	.458	57.3	28
1984	–.165	.015	.287	.022	.360	61.8	53
1985	–.161	.025	.396	.028	.432	55.8	9

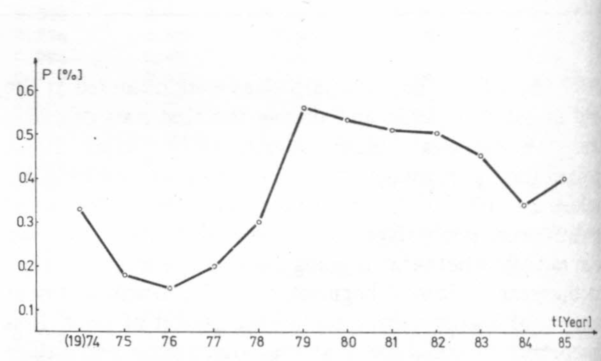

Fig. 4. Annual mean values of the intrinsic polarization percentage of 88 Her, in the period 1974–1985.

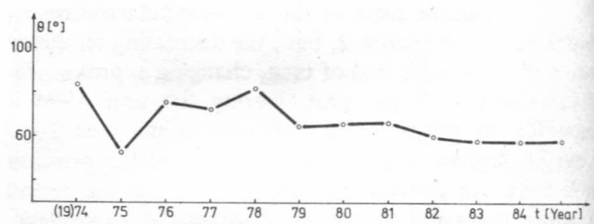

Fig. 5. Annual mean values of the intrinsic position angle of 88 Her.

In Figure 6. annual mean values of the Stokes parameters are presented. In the Q_SU_S plane two regions are apparent: the region of small values U_s ($U_s < 0.2\%$) in the period 1974–1978 and the region of higher U_s values ($U_s > 0.3\%$), in the period 1979–1985. The smallest simultaneous values of both parameters was measured in the year 1976. The highest annual jamp of Stokes parameters was between 1978 and 1979. During the period 1982–1984 both parameters are decreasing.

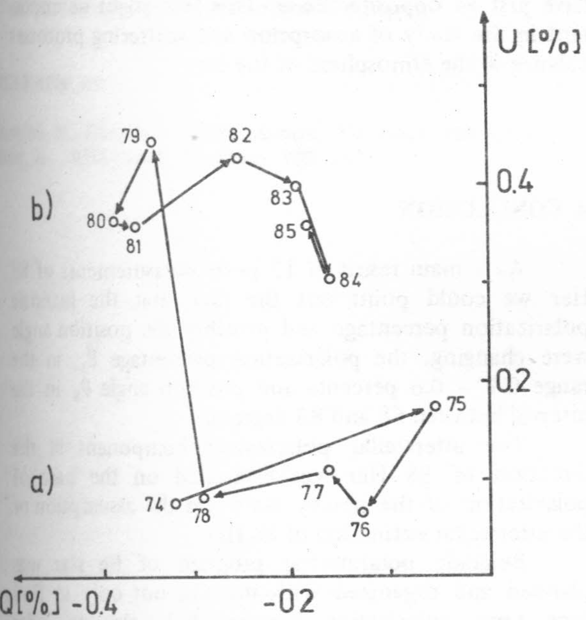

Fig. 6. Annual mean values of the intrinsic Stokes parameters of 88 Her, in the period 1974–1985.

Fortunately, during the period of our observations there are certain brightness observations made on several observatoires. For this occasion we used the data which have been published by Harmanec et al. (1978), Doazan et al. (1982, b) and Barylak and Doazan (1986). These data for V spectral region were averaged within the period of each year in order to compare them with the polarization parameters. The annual mean values of V magnitude of 88 Her are shown in Figure 7. This light curve could be easily anticorrelated with the polarization percentage curve, Figure 4, after translation for one year later. In other words, the polarization percentage reached the maximum value about one year after the brightness minimum happend. All values of polarization percentagees after rhe 1978 brightness minimum, namely, in the period 1979–1983, were grater than the values belonging to the period before 1979. According to Barylak and Doazan (1986) that was the period of an increasing Be–shall phase. This does not mean that the polarization correlated with the shell absorption. In agreement with the presently accepted explanations of Be stars phenomena we could claim that the polarization in those stars is an envelope phenomenon. It originates in electron scattering by a nonsymetrical envelope of the star. On the other hand, Doazan et al. (1986) have interpreted the brightness drop as the photospheric thermal energy decrease, and mass outflow and envelope activity increase as a consequences. If this is correct, the delay of polarization increase as an envelope event, in regard to the light decrease as the photospheric event, seems logical. In other words, we may say that the polarization increasing was the consequence of the brightness drop. Namely, the polarization maximum in 1979 was the consequence of brightness minimum in 1978. For the precise estimation of time delay it would be necessary to study the data in more detail.

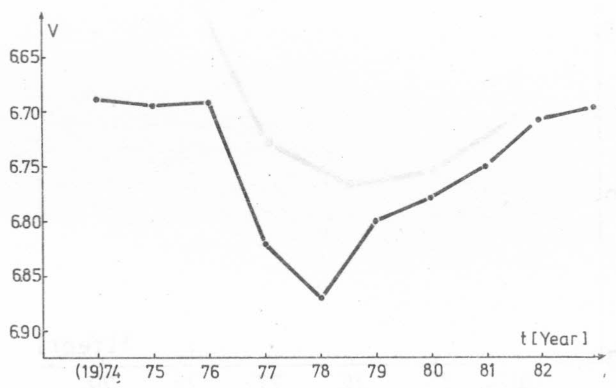

Fig. 7. Annual mean values of the V magnitudes for 88 Her in the period 1974–1983.

Slow brightness increase after 1979. is followed by polarization decrease till the year 1983. Since then, no data about light changes are found published. The 88 Her brightness in 1983. reached almost the same value as it had in 1976, before its decline started. Higher polarization as an envelope activity lasted in spite of the fact that brightness disturbance was over.

The period of the high brightness lasted from 1973 till the end of 1976. The last year of this period was the year of minimum polarization percentage. In general, we could conclude that the small values of polarization percentage, very close to zero, corresponded to the period of the quasi normal B phase (terminology of Doazan et al. 1986a), with very low envelope activities (disappearence of shell metallic lines, weakening of Balmer lines of shell absorption as well as of their emission).

For the years 1974–1979, we have found very good indicators of an envelope activities, namely, the values of emission peak intensities ($E = (E_V + E_T)/2$) of H–alfa line published by Doazan et al. (1982). We calculated the annual mean values and represent them in the Figure 8. Comparing these values with the annual mean values of the polarization percentage, Figure 4. we can find very good correlation with the correlation coefficinet of 0,92. This correlation could be interpretated as a result of certain electron density changes in the envelope.

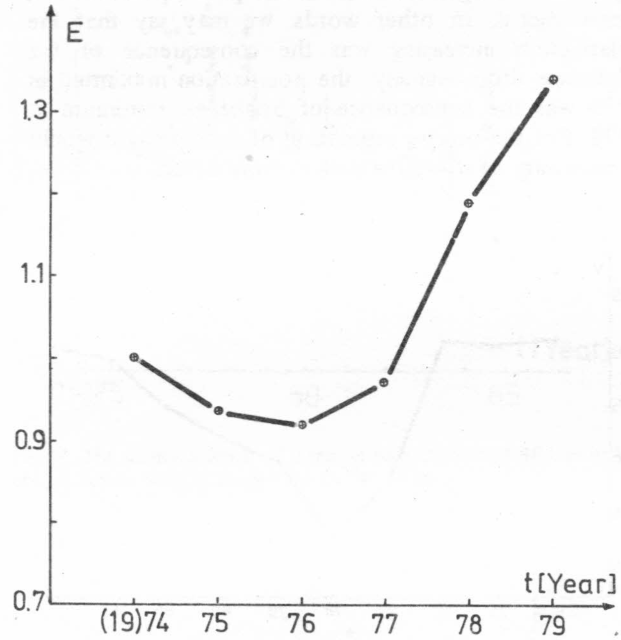

Fig. 8. Annual mean values of the emission peak intensities of H–alfa lines for 88 Her in the period 1974–1979.

The position angle, as we can see in the Figure 5. and the Table 2. varies in the interval of only about 25 degrees. Nevertheless, we would like to comment three phases in its decreasing trend. In the period of low polarization percentage (1974–1978) and high errors, the average position angle was about 77 degrees. During the period 1979–1981 the position angle was about 10 degrees lower and stable. The next period, 1982–1985, was also with the stable position angle but somewhat lower, not more then 7 degrees. If these phases in position angle changes are real, it might be that the brightness drop has led to changes not only of the polarization percentage but of the position angle too. After the end of the episode of the brightness drop (photospheric temperature and energy drop too) position angle was disturbed and it stayed in new, disturbed stage, for a long period of time. This could mean that not only the physical (electron density) but also the geometrical changes of the envelope had happened.

The relations between our polarization parameters and other parameters as central H–alfa absorption Ic, for example, is not so easily seen or the data do not exist for the whole period of time. According to Barylak and Doazan (1986) the shell absorption was low in 1979, during maximum of polarization percentage. But, during the period 1981–1983, when the polarization percentage was still high, the shell absorption was high too. This could mean that the shell absorption is not dominant in the formation of polarization percentage. Some colour indices of far UV spectral region of 88 Her (Barylak and Doazan, 1986) exhibit changes very similar to polarization percentage variation but some of them have just an opposite phase. This fact might be important in the study of absorption and scattering processes balance in the atmosphere of the star.

4 CONCLUSION

As a main result of 12 years measurements of 88 Her we could point out the fact that the intrinsic polarization percentage and possibly the position angle were changing; the polarization percentage P_s, in the range 0.1 – 0.6 percents and position angle θ_s in the interval between 58 and 83 degrees.

The interstellar polarization component in the direction of 88 Her was estimated on the base of polarization of the nearby stars and the assumption of the interstellar extinction of 88 Her.

Belgrade polarimetric program of Be star was planned and organized with the aim not only to find long term polarization changes but, also to offer long–term polarization parameters for a more complex study of these stars which are under photometric and spectral observational watch at other observatories. In the case of 88 Her that was the fruitful work, polarization was measured almost simultaneously with many other parameters as brightness, emission and absorption caracteristics of many spectral lines, energy distribution in large spectral region, and so on.

We have found that the polarization percentage variation with time and V–colour light curve anticorrelate very well after phase translation of polarization curve for about on year earlier. This delay of polarization percentage change in regard to light variation is qualitatively in agreement with Doazan et al. (1986) interpretation of the brightness decrease as a lowering of temperature.

In accordance with the same idea is an excellent correlation between polarization percentage and H–alfa emission peak internsities we have found in the period 1974–1979.

According to the published data, the correlation between polarization percentage and central intensities of H–alfa shell cores, I_c, does not exist. This might lead to the conclusion that the maximum of the shell phase does not mean the maximum of polarization percentage, the chell absorption and polarization originate in the different parts of the envelope.

There are indications of the exsistence of some other correlations of polarization percentage and different physical parameters what may call for new investigations.

Acknowledgment

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REFERENCES

Barylak, M., Doazan, V.: 1986, *Astron. Astrophys.* **159**, 64.
Behr, A.: 1959, *Veroff. Gotingen,* **126**, 185.
Doazan, V.: 1973, *Astron. Astrophys.* **27**, 395.
Doazan, V.: 1982, *The B Stars With and Without Emission Lines*, Eds. Underhill, A.B., Doazan, V., NASA–SP 456.
Doazan, V., Haramanec, P., Koubsky, P., Krpata, J., Zdarsky, F.: 1982a, *Astron. Astrophys. Suppl. Ser.* **50**, 481 (Paper 7A).
Doazan, V., Harmanec, P., Koubsky, P., Krpata, J., Zdarsky, F.: 1982b, *Astron. Astrophys.*, **115**, 138.
Doazan, V., Thomas, R.N., Barylak, M.: 1986, *Astron. Astrophys.*, **159**, 75.
Haramanec, P., Koubsky, P., Krpata, J.: 1972, *Bull. Astron. Inst. Czech.*, **23**, 218.
Harmanec, P., Koubsky, P., Krpata, J.: 1974, *Astron. Astrophys.*, **33**, 117.
Harmanec, P., Horn, J., Koubsky, P., Križ, S., Zdarsky, F., Papousek, J., Doazan, V., Bourdonneau, B., Baldinelli, L., Ghedini, S., Pavlovski, K.: 1978, *Bull. Astron. Inst. Czech.*, **29**, 278.

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PARAMETERS CHARACTERIZING NON–LTE LINE RADIATIVE TRANSFER IN SOME ASTROPHYSICAL CONDITIONS

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SUMMARY: In this paper, the values of three dimensionless parameters: ϵ, ζ and η, characterizing non–LTE line formation, and measuring, respectively, the importance of inelastic collisions, elastic collisions and streaming of excited atoms, are estimated for different astrophysical conditions. The estimation is performed for the atmospheres of main sequence stars, those of white dwarfs and gaseous nebulae and for the resonance lines formed therein. It is shown that in all cases except for the Lyman α line, for which kinetic non–local effects can be significant, local „classical" partial redistribution theory should be used.

1. INTRODUCTION

In difference to the complete redistribution description of non–LTE line transfer problem, characterized by only one parameter ϵ, describing the deviations from LTE, general, kinetic description of non–LTE problem (Borsenberger et al., 1986a), taking into account local (partial redistribution) and non–local (convective transport of excited atoms due to non–LTE effects) kinetic effects, is characterized by three dimensionaless parameters ϵ, ζ and η, measuring respectively, inelastic, elastic collisions and streaming of excited atoms.

In the paper of Atanacković–Vukmanović and Simonneau (1987), henceforth referred to as Paper I, for the analysis of the kinetic processes, these parameters were taken as the constants in the constant property (unparametrized) medium and relatively wide diapason of their values has been used.

As it is interesting to determine the importance of particular process in real conditions, we shall estimate these parameters for some typical plasmas of the astrophysical interest. Therefore, we can decide about the possibility of applying some approximations or the necessity for the exact solution.

2. EVALUATION OF PARAMETERS ϵ, ζ AND η

The three dimensionless parameters are defined as follows. If we denote with A_{21} and C_{21}' respectively, the probabilities of spontaneous (radiative) and collisional de–excitation of an atom from the excited level 2 to the ground level 1, the mean lifetime of the excited atomic level is:

$$t_2 = 1/(A_{21} + n_e C_{21})$$

where n_e is electron density.

Parameters, measuring, respectively, the importance of inelastic collisions (deviations from LTE), elastic collisions and streaming of excited atoms during that lifetime, have the following form:

$$\epsilon = n_e C_{21} t_2$$

$$\zeta = \gamma^{el} t_2 \tag{1}$$

$$\eta = k\, w\, t_2$$

where: γ^{el} is the frequency of elastic, velocity–changing collisions of the excited atoms, k – mean absorption coefficient in the line and w – the thermal velocity of the two–level atoms.

Recall that $\epsilon = 1$ for an inelastic collision–dominated LTE gas, while $\epsilon \ll 1$ for non–LTE gases.

As discussed in Paper I, in non–LTE gases ($\epsilon \ll 1$) with the increasing number of elastic collisions, velocity distribution function of excited atoms tends to Maxwellian, ie. it thermalizes, and the emission profile takes the same form as the absorption one (complete redistribution – C.R.). One can take that C.R. approximation is valid over the entire line profile, throughout the gas layer, for elastic collision parameter $\zeta > 10$.

In the paper of Borsenberger et al. (1987) it is shown that the streaming of excited atoms with $\eta > 1$ can cause great changes in the emergent line intensity or in the shape (asymmetry) of the line profile. For $\eta < 1$ streaming effects can be considered as negligeable.

According to the equation (1), parameters are determined by the characteristics of an atom and a medium, ie. of the supposed physical model.

Atomic data are taken from the tables of Wiese et al. (1966). The rate (the probability per an atom per second) of deexcitation by electronic collisions C_{21} is calculated by the formula of Park (1971) for hydrogen, helium and sodium, and for the other elements by the formula of van Regemorter (1962). The values of C_{21} for the considered transitions at different temperatures are given in Table 1.

The number of the non–excited atoms (absorbers) of element i in the ionization state j, $n_{i_1}^{j}$, necessary for the evaluation of line mean absorption coefficient k, is calculated according to the relation:

$$n_{i_1}{}^{j} = n_H \cdot \frac{n_i}{n_H} \cdot \frac{n_i^j}{n_i} \cdot \frac{n_{i_1}{}^{j}}{n_i} = n_H \cdot \frac{n_i}{n_H} \cdot S_i \cdot B_i\ ,$$

where : n_H – hydrogen number density ($n_H \sim 0.89 \cdot n_a$); n_i/n_H – the abundance of element i relative to hydrogen, and the last term – $S_i \cdot B_i$ is the ratio of number of the non–excited atoms of element i in a given state of ionization j to the total number of atoms of that element, calculated by means of Saha (S_i) and Boltzmann (B_i) formula. The term S_i is evaluated by algorithm and tables for partition functions given in the paper of Traving et al. (1966).

Elastic collisions frequency of the excited atoms (ions) with other particles in the non–excited state is given by the expression:

$$\gamma^{el} = \Sigma n_s \cdot w\ Q,$$

where : n_s is the density of scattering particles, Q – average cross section for elastic collisions, and the sumation is over all the relevant collisions with different kinds of particles. We used the following relations (Oxenius, 1979) for:

– atom–atom collisions
$Q_{nn} \sim 10^{-16}$

– atom–ion collisions
$Q_{nq} \sim 10^{-15}$

–ion–ion collisions
$Q_{qq} \sim 2\pi\, (Z_i Z_s e^2/\, kT)^2 \ln \Lambda,$

and Λ is given by:

$$\Lambda = \frac{3}{2\, e^3\, Z_i\, Z_s} \sqrt{(k^3 T^3/\pi n_e)}\ .$$

Using the tables of the characteristic conditions in the stellar atmospheres (Allen, 1973), we prepared Table 2 in order to find the dominant sources of scattering. For neutrals as the scattering particles, we choose hydrogen atoms because of their greatest abundance. Since $n_p \sim n_e$ in the early–type stars and $n_{ion} \sim n_e$ in the later–type ones, as the number density of scattering ions we used the electron concentration n_e. Therefore, for neutrals :

$$\gamma_n = n_H\ w\ Q_{nn} + n_e\ w\ Q_{nq},$$

and for ions :

$$\gamma_q = n_H\ w\ Q_{nq} + n_e\ w\ Q_{qq}.$$

The choice of the lines and media is directly conditioned by the assumptions of the physical model (Paper I). Refering to the assumed atomic model (two infinitely sharp atomic levels), we have chosen strong resonance lines formed in various types of atmospheric

Table 1. Rates of collisional deexcitation $C_{21}(T)$ for several temperatures and for given lines, calculated by the formula of Park (*) and of van Regemorter. (λ – wavelength of the line)

atom	λ(nm)	$C_{21}(T)$ $[m^3 . s^{-1}]$ T = 5000K	10000K	15000K	20000K	30000K
H I(*)	121.567	3.99E–15	4.34E–15	4.56E–15	4.72E–15	4.96E–15
He I(*)	58.4334	4.61E–16	4.98E–16	5.21E–16	5.37E–16	5.62E–16
C I	156.1	2.56E–15	2.96E–15	3.26E–15	3.18E–15	3.44E–15
Na I(*)	589.18	1.92E–13	2.16E–13	2.32E–13	2.43E–13	2.61E–13
Si I	221.47	3.19E–15	4.05E–15	3.93E–15	4.23E–15	4.34E–15
C II	133.53	8.32E–14	5.89E–14	4.81E–14	4.16E–14	3.40E–14
C III	97.7026	1.03E–13	7.30E–14	5.96E–14	5.16E–14	4.22E–14
C IV	154.91	5.74E–14	4.06E–14	3.31E–14	2.87E–14	2.35E–14
Mg II	279.553	3.41E–13	2.41E–13	1.97E–13	1.71E–13	1.43E–13
Al III	185.74	2.11E–13	1.49E–13	1.22E–13	1.05E–13	8.63E–14
Si III	120.651	2.65E–13	1.87E–13	1.53E–13	1.33E–13	1.08E–13
Si IV	139.67	1.45E–13	1.03E–13	8.39E–14	7.26E–14	5.94E–14
Ca II	393.366	5.32E–13	3.76E–13	3.08E–13	2.70E–13	2.29E–13

conditions and the forbidden lines, arising in very rarified media such as gaseous nebulae. The main criterium ni the choice of media was the low temperature limit, in that $h\nu/kT > 4-5$. Therefore, the maximum considered value of effective temperature is $T_{eff} \sim 30000$ K.

Table 2. Characteristics of stellar atmospheres of different spectral classes: T – temperature, n_H – density of H atoms, n_p – proton density, n_e – electron density, n_{ion} – density of heavy ions.

spectral class	T (K)	n_H (m^{-3})	n_p (m^{-3})	n_e (m^{-3})	n_{ions} (m^{-3})
BO	25760	–	3.1E20	3.1E20	–
B5	15170	–	2.6E20	2.6E20	–
AO	10020	2.5E20	2.5E20	2.5E20	–
A5	8340	3.5E21	2.7E19	1.9E20	1.6E20
FO	7260	1.2E22	9.0E18	8.7E19	7.8E19
F5	6470	4.5E22	–	3.1E19	3.1E19
GO	6040	8.0E22	–	1.3E19	1.3E19
G5	5500	1.0E23	–	7.2E18	7.2E18

3. RESULTS AND DISCUSSION

a) Stellar atmospheres (6000K < T_{eff} < 30000K) and resonant lines

For an ilustration of the values of parameters in typical atmospheric conditions, four models (Kurucz, 1979) are used, having the effective temperatures T_{eff} = 6000K, 11000K, 20000K, 30000K, and the acceleration of gravity at the surface of the star as in the Sun (log g = 4.5). Parameters were calculated in five representative points, obtained by interpolation of the given values for each model. Data, corresponding to the lines used are presented in Table 3.

In Fig.1., we plotted the values of parameter ϵ throughout the atmospheric models. The maximum (LTE) value of ϵ (=1) is presented by the dashed line. As we can see, ϵ is in the line fomation region, in all models and for all lines less than 10^{-2}. For lines λ 121.567 nm HI and λ 58.43334 nm HeI, ϵ has extremely small value of 10^{-5}, as a consequence of much larger probability of the radiative de–excitation than of the collisional one for the lines. For the lines of metals (NaI, MgII, CaII and others), LTE is reached not before $\tau \sim 10$

The parameter η as a measure of the importance of the excited atoms streaming is represented in Fig. 2. In all the considered cases except for the lines of HI and HeI (at lower temperatures, $T_{eff} \sim 6000$K), η is less than 10^{-2} and, hence, streaming effects can be taken as completely negligeable. For Lyman α line, η can be significant, growing up from $\eta \sim 2$ at $\tau = 0$ to $\eta \sim 40$ at $\tau = 1$.

In order to find out if there is some possibility of using some of the approximations developed in Chapters 6. and 7. of the Paper I, (local partial redistribution with the effect of elastic collisions and the diffusion approximation), it is interesting to estimate the value of elastic collision parameter ζ. As we can see from Fig. 3., ζ is for all the lines and media less than 1. Eventually for the lines of metals, it could be useful to investigate the possibility of making C.R. approximation. The situation is clear for the lines of HI and HeI, for which $\zeta \ll 1$. Since the elastic collisions are completely negligeable, distribution function of the excited atoms does not thermalize and the source function will be frequency dependent for these resonant lines.

b) The atmospheres of white dwarfs and the Lyman α line

According to the previous analysis, the largest non–local kinetic effects, as well as partial noncoherency is met in the case of the Lyman α line. Let us see,

Table 3. Atomic data for the considered resonant lines: λ – wavelength of the line, $E_{1,2}$ – energy of lower (1) and upper (2) atomic level, $g_{1,2}$ – statistical weight of levels 1, 2; A_{21} – Einstein spontaneous emission probability for transition 2 → 1.

atom	λ(nm)	E_1(cm^{-1})	E_2(cm^{-1})	g_1	g_2	A_{21}(10^8 s^{-1})
H I	121.567	0	82259	2	8	4.699
He I	58.4334	0	171135	1	3	17.99
C I	156.1	30	64091	9	15	1.5
Na I	589.18	0	16968	2	6	0.629
Si I	221.47	150	45303	9	15	0.55
C II	133.53	43	74932	6	10	6.0
C III	97.7026	0	102351	1	3	19.0
C IV	154.91	0	64555	2	6	2.65
Mg II	279.553	0	35761	2	4	2.68
Al III	185.74	0	53839	2	6	5.64
Si III	120.651	0	82884	1	3	25.9
Si IV	139.67	0	71595	2	6	9.15
Ca II	393.366	0	25414	2	4	1.5

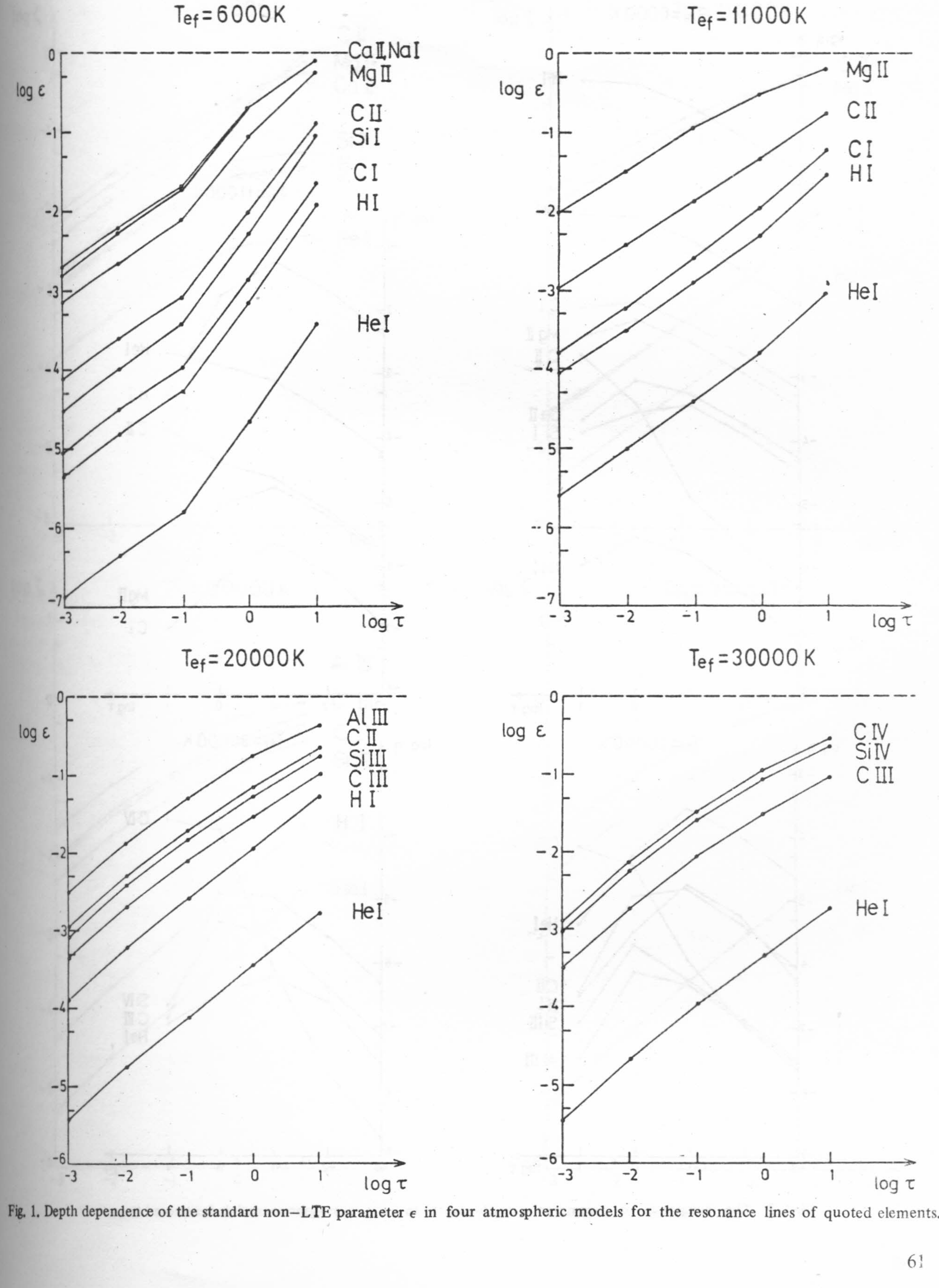

Fig. 1. Depth dependence of the standard non-LTE parameter ϵ in four atmospheric models for the resonance lines of quoted elements.

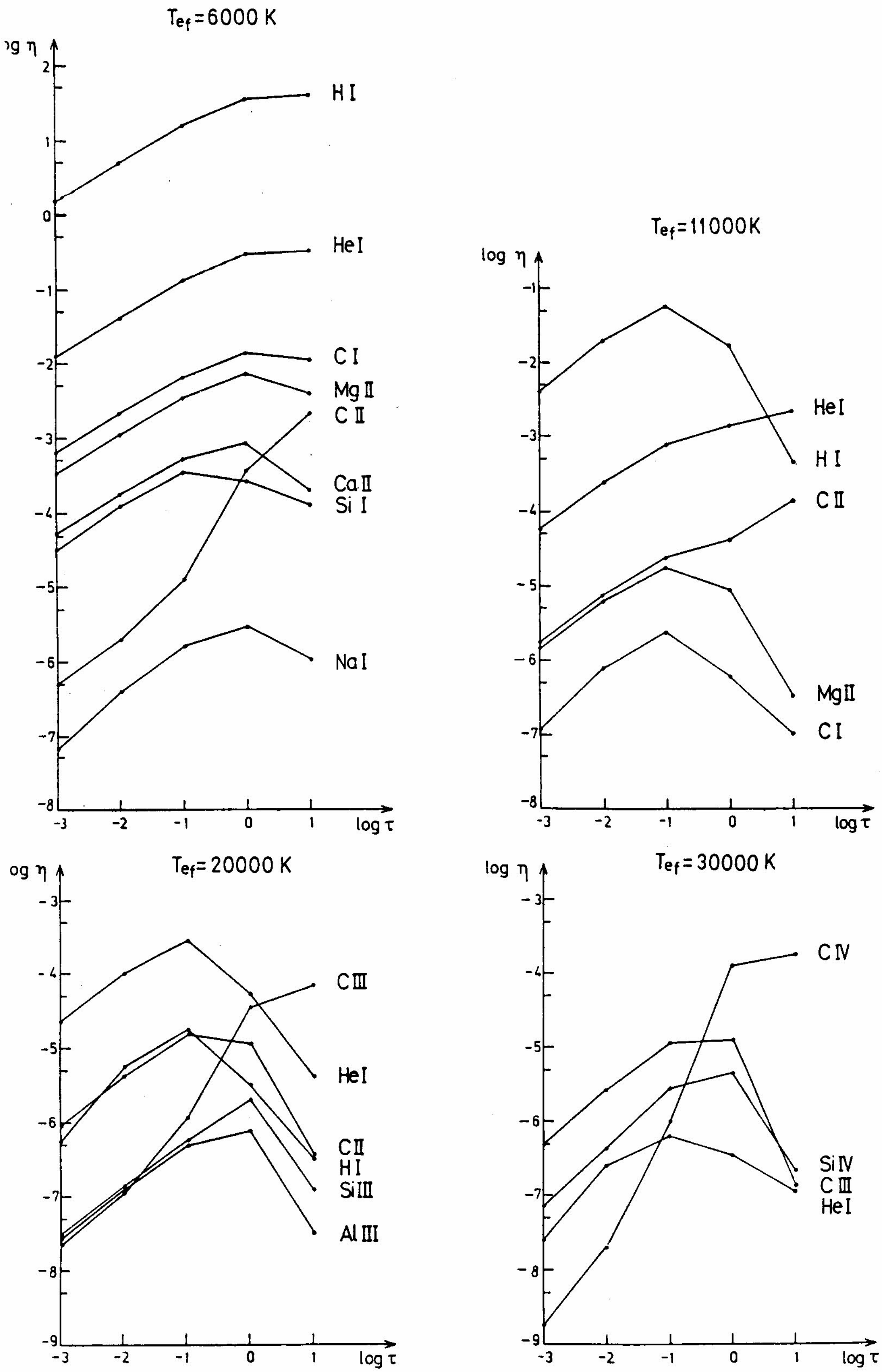

Fig. 2. The behaviour of parameter η with depth in four atmospheric models for quoted lines.

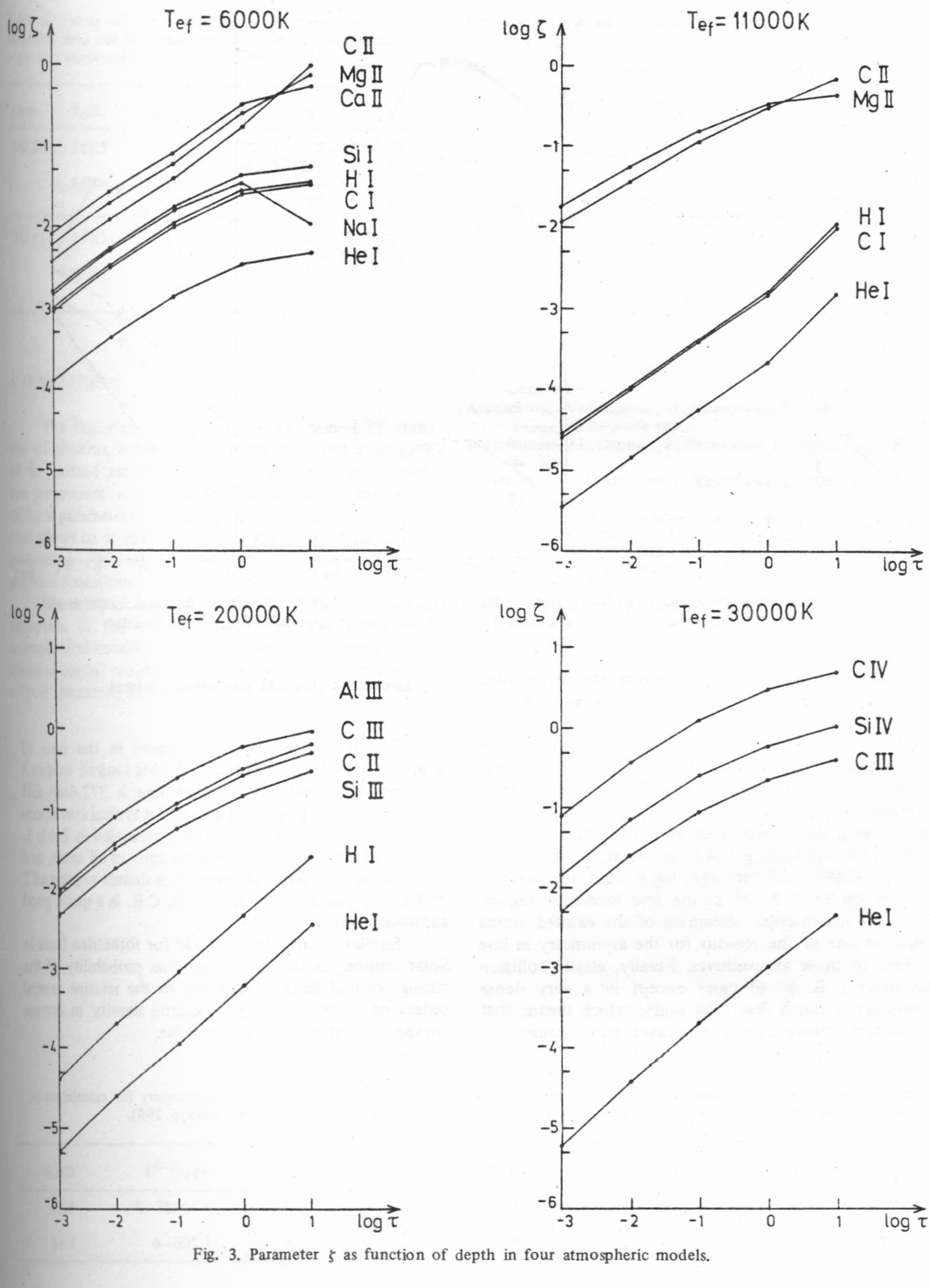

Fig. 3. Parameter ζ as function of depth in four atmospheric models.

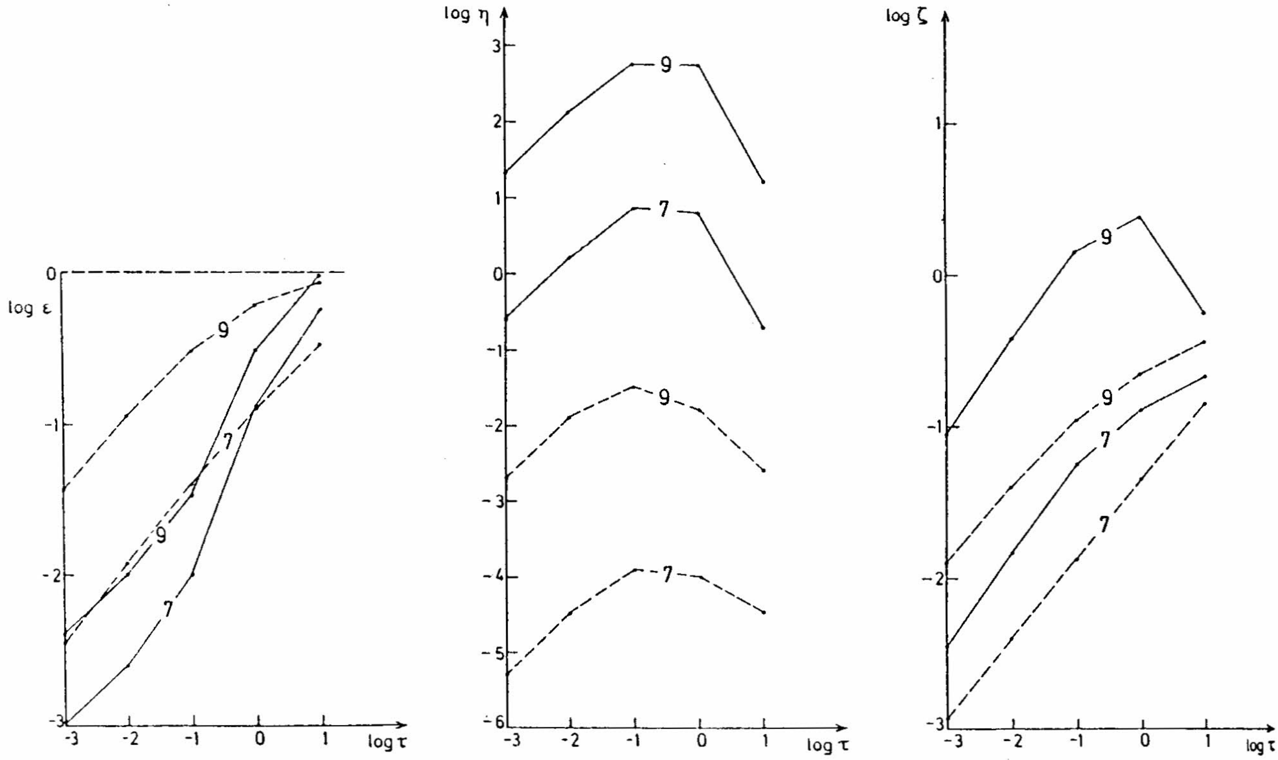

Fig. 4. Depth dependence of parameters ϵ, η and ζ in DA white dwarfs atmospheric models (dashed lines – models with $T_{eff} = 2 \cdot 10^4$ K, solid lines – models with $T_{eff} = 10^4$ K; 7 and 9 are values of log g of a model).

now, these effects in very dense astrophysical plasma such as the atmospheres of white dwarfs for this resonant line.

In Fig. 4. we represent the behaviour of the parameters ϵ η and ζ with depth in four atmospheric models of DA white dwarfs. As a consequence of larger electron density, the value of parameter ϵ approaches unity, being about two orders of magnitude larger than in the case when log g = 4.5. In the atmospheres with $T_{eff} \sim 10000$K and for larger log g value, parameter η increase up to $\sim 5 \cdot 10^2$ in the line formation region. Thus, the macroscopic streaming of the excited atoms could be one of the reasons for the asymmetry in line profiles of those atmospheres. Finally, elastic collision parameter ζ is, in all cases except in a very dense atmospheres, much less than unity, which means that partial non–coherency has to be taken into account.

c) Gaseous nebulae and the forbidden lines

Let us see now what happens in the case of intensive forbidden lines N_2 of double ionized oxigen λ 495.9nm OIII and UV doublet line λ 372.6nm OII (atomic data are given in Table 4) for typical conditions in gaseous nebulae. The results are presented in Table 5. As we can see, η is very near to zero in all cases, and since elastic collision parameter ζ in denser regions of T $\sim$ 5000 K can reach value of 50, C.R. is a quite good approximation.

Similar results will be valid for forbidden lines in Solar corona, as the larger transition probability of the strong coronal lines corresponds to the relative several orders of magnitude larger electron density in corona compared to that density in nebulae.

Table 4. Data for forbidden lines. Ω (i, j) is dimensionless cross–section for collisional excitation, necessary for calculation of collisional de–excitation rate for forbidden transitions ($C_{ji} = 8.54 \cdot 10^{-6}\ \Omega(i,j)/(\sqrt{T_e} \cdot g_j)$; Sobolev, 1985, p. 298).

atom	λ(nm)	$E_1(cm^{-1})$	$E_2(cm^{-1})$	g_1	g_2	$A_{21}(s^{-1})$	Ω(i,j)
0 III	495.891	113.4	20271	3	5	7.1062E–3	1.73
0 II	372.616	0	26830.5	4	4	1.70E–4	1.44

Table 5. Values of the parameters ϵ, η and ζ for the two forbidden lines and for some conditions in gaseous nebulae (T_e – electron temperature, n_e – electron density).

λ(nm)	T_e(K)	$n_e(m^{-3})$	ϵ	η	ζ
495.891	5.0E3	1.0E8	6E–4	1E–32	2E–1
		1.0E10	6E–2	1E–32	1E+1
	1.0E4	1.0E8	4E–4	2E–16	6E–2
		1.0E10	4E–2	1E–14	5E+0
372.616	5.0E3	1.0E8	2E–2	8E–17	2E+0
		1.0E10	7E–1	2E–15	5E+1
	1.0E4	1.0E8	2E–2	7E–19	7E–1
		1.0E10	6E–1	1E–15	2E+1

4. CONCLUSION

The following physical processes: non–LTE transfer of photons, collisional redistribution and streaming of the excited atoms are characterized by three respective parameters: ϵ, ζ and η. We have evaluated the values of these parameters in different astrophysical conditions, that allows us to have an idea of the importance of the preceeding physical processes in these systems and physical conditions.

The analyses has shown that in all cases, with the exception of the Lyman α line, radiative transfer in astrophysical conditions can be described in terms of the classical partial redistribution theory. Non–local kinetic effects (streaming of excited atoms) can be significant in the case of Lyman α line and for very dense atmospheres of white dwarfs, and could be one of the reasons for the asymmetry of line profiles in these atmospheres.

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REFERENCES

Allen, C.: 1973, *Astrophysical Quantities,* **3ed** ed., Athlone Press London.

Atanacković–Vukmanović, O., Simonneau, E.: 1987, *Bull. Obs. Astron. de Belgrade* **137.**

Borsenberger, J., Oxenius, J., Simonneau, E.: 1986a, *J.Q.S.R.T.* **35,** 303.

Borsenberger, J., Oxenius, J., Simonneau, E.: 1987, *J.Q.S.R.T.* **37,** 331.

Kurucz, R.L.: 1979, *Astrophys. J. Suppl.* **40,** 1.

Oxenius, J.: 1979, *Astron. Astrophys.* **76**, 312.

Park, C.: 1971. *J.Q.S.R.T.* **11,** 7.

Sobolev, V.V.: 1985, *Kurs teoreticheskoj astrofiziki,* Nauka, Moskva.

Traving, G., Baschek, B., Holweger, H.: 1966, *Abh. Hamburger Sternw.* **8,** 3.

Van Regemorter, H.: 1962. *Astrophys. J.* **136,** 906.

Wiese, W. L., Smith, M.W., Glennon, B. M.: 1966, *Atomic Transition Probabilities,* Vol. I, NSRDS – NBS4, Washington.

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KINETIC EFFECTS IN NON–LTE LINE TRANSFER IN STELLAR ATMOSPHERIC CONDITIONS

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SUMMARY: A survey of the main stages in the development of radiative transfer theory is given. Special attention is dedicated to an analysis of kinetic (local and non–local) effects of the transport of the excited atoms in two approximations of the general, selfconsistent solution. In both cases, emission profile coefficient is coherently derived proceeding from the velocity distribution function of the excited atoms.

1. INTRODUCTION

The principal aim of the theory of stellar atmospheres is the determination of the physical state of atmospheric gas, ie. of the radiation field and distribution of atomic states throughout the atmosphere.

The development of radiative transfer theory is a necessary step in solving this problem. Using this theory, the frequency distribution of the radiation field emerging from a gas of a given structure can be computed and compared with the observations. Postulated model of gas and applied radiative transfer theory have to be modified till the required agreement between the computed and observed spectra achieved. Therefore, it is obvious that the radiative transfer presents one of the fundamental problems in the astrophysical spectroscopic diagnostics and it appears also as necessary step in the iterative process of the model construction.

This problem has been solved for more than six decades, and by including various phenomena and physical processes in gases, it was getting more and more complex.

Stellar atmospheres themselves are very complex physical systems whose macroscopic characteristics are determined by the simultaneous action of numerous microprocesses among different kinds of particles. Taking into account all of these processes makes the problem extremelly difficult and, from the mathematical point of view, practically unsoluble. Hence, it is necessary to make some approximations in order to simplify the mathematical solution of the problem without loosing its physical essence and generality. In order to investigate the importance of some effect, we choose simple models where other less relevant features or processes can be taken as negligeable. In this paper we use a few gross simplifications in order to analyse the importance of some kinetic effects in the non–LTE line transfer in stellar atmospheric conditions. Firstly, stellar atmospheres are considered as systems of two–level atoms, electrons and photons. Here, the atomic structure is described by a very simple model which, nevertheless, can explain well many features of the line transfer, especially for the resonant lines, making this model very useful and often applied in literature.

The state of each constituent of the atmosphere can be described by some distribution function. Radiative transfer problem is said to be solved if all the distribution functions are known throughout the atmosphere.

The simplest possible case is realized when all of the particles are in equilibrium. Then the microreversibility (detailed balance) of both the collisional and radiative processes exists. As a consequence, there is no energetic flux, and the frequency distribution of radiation has a continual Planckian form. The excitation and ionization follow the Boltzmann–Saha formula, and velocity distribution of atoms and electrons is the Maxwellian one. This state of thermodynamic equilibrium (TE) can never be realized in real, non–isolated systems such as stars. In stellar spectra, the distribution of radiation shows many discontinuities and absorption and emission lines. The interpretation of these spectral features is the main interest of stellar atmosphere theory.

2. SOME STAGES IN THE PROCESS OF SOLVING THE LINE TRANSFER PROBLEM IN STELLAR ATMOSPHERES

Stars have boundaries through which photons can freely escape, and we receive them as an information of the existence and of the properties of the star. Consequently, among other particles it is certain that at least the gas of photons is no more in equilibrium. Its distribution must be obtained from the equation of radiative transfer. The intensity of radiation $I_\nu(\vec{n}, \vec{r})$ of frequency ν propagating in the direction defined by unit vector $\vec{n}$ through a stationary atmosphere is a solution of time-independent radiative transfer equation:

$$\vec{n} \cdot \vec{\nabla} I_\nu (\vec{n}, \vec{r}) = - k_\nu (\vec{n}, \vec{r}) I_\nu (\vec{n}, \vec{r}) + \epsilon_\nu (\vec{n}, \vec{r})$$

$$= - k_\nu (\vec{n}, \vec{r}) \cdot [I_\nu (\vec{n}, \vec{r}) - S_\nu (\vec{n}, \vec{r})], \quad (1)$$

where $\vec{\nabla} \equiv \partial / \partial \vec{r}$, k_ν and ϵ_ν are the line opacity and emissivity or macroscopic absorption and emission coefficients, respectively, which contain the details of interactions between radiation and gas. For our two-level atom model:

$$k_\nu = (h\nu_0 / 4\pi) [n_1 B_{12} \phi_\nu (\vec{n}) - n_2 B_{21} \psi^*_\nu (\vec{n})] \quad (2)$$

$$\epsilon_\nu = (h\nu_0 / 4\pi) n_2 A_{21} \psi_\nu (\vec{n}) \quad (2')$$

Here: ν_0 is the line central frequency, h – Planck's constant; B_{12}, B_{21} and A_{21} – Einstein coefficients for absorption, stimulated and spontaneous emission, respectively; n_1 and n_2 are the number densities of atoms at ground and excited level; $\phi_\nu (\vec{n})$, $\psi^*_\nu (\vec{n})$ and $\psi_\nu (\vec{n})$ are the so-called laboratory profiles for absorption, stimulated and spontaneous emission describing the frequency dependence of the corresponding coefficients.

Stimulated emission is usually treated as negative absorption with the same profile ϕ_ν or is neglected. The exact calculation (Oxenius, 1965) showed that the profiles of stimulated and spontaneous emission are identical ($\psi^*_\nu = \psi_\nu$).

The source function $S_\nu (\vec{n}, \vec{r})$, defined as the ratio of emissivity to opacity

$$S_\nu (\vec{n}, \vec{r}) = \frac{\epsilon_\nu (\vec{n}, \vec{r})}{k_\nu (\vec{n}, \vec{r})}, \quad (3)$$

represents the main quantity in radiative transfer problems, as it contains physics of all the relevant processes. The form of the source function depends on the mutual interactions and the state of all kinds of particles. See equations (2) and (2').

As we have already seen, the radiation field always deviates from its equilibrium form. Whether other particles remain in equilibrium, it depends on the importance of the particular type of interactions: matter – matter or matter – radiation. If the former (elastic and inelastic collisions among atoms and electrons) prevails, the particles rest in equilibrium at the local electronic temperature (*local thermodynamic equilibrium* – LTE). In that case, level populations are described by Boltzmann formula, and the velocity distribution functions of differently excited atoms are described by Maxwell formula. As a consequence, the equality of the absorption and emission profiles is here automatically satisfied. Hence, LTE source function has a Planckian form.

If the interactions radiation – matter are important, as is the case in the rarefied media such as the atmospheres are, the interactions with radiation field generate non-equilibrial phenomena among the particles too. As a consequence of the importance of radiative transitions, both the number densities of atoms in the excited levels and their velocity distribution functions depend on the radiation field. More general approach in stellar atmospheres theory which takes both types of interactions (collisional and radiative ones) into consideration is known as *non*–LTE theory of radiative transfer. The LTE approximation appears as its limiting case when collisional processes dominate over the radiative ones. In non–LTE theory, number densities of particular atomic levels have to be determined from the so-called statistical equilibrium equation. For two-level atom, it has the form:

$$n_1 (B_{12} \int \phi_\nu J_\nu d\nu + n_e C_{12}) = n_2 (A_{21} + n_e C_{21} + B_{21} \int \psi_\nu J_\nu d\nu). \quad (4)$$

It remains to find the frequency dependence of the source function, described by the ratio ψ_ν / ϕ_ν. The absorption profile ϕ_ν is supposed to be known and determined by various broadening processes. However, emission profile ψ_ν, depending on the radiation field (Hummer, 1965) cannot be taken as known a priori. A great practical advantage is provided if one makes the approximation of the two profiles being identical. This case in the transfer theory is known as the *standard non–LTE problem or complete redistribution approximation.* Here, only level populations have to be found from the statistical equilibrium condition, and the source function is frequency independent, having the following form:

$$S = \epsilon B + (1 - \epsilon) \int \phi_\nu J_\nu d\nu. \quad (5)$$

ϵ is a standard non–LTE parameter, defined as:

$$\epsilon = \frac{n_e C_{21}}{n_e C_{21} + A_{21} (1 - \exp(- h\nu_0 / kT_e))^{-1}} \quad (6)$$

which measures the probability that a photon is thermalized by collisional deexcitation (ie. its energy is transformed into the kinetic energy of the gas). When ϵ has its maximum value $\epsilon = 1$ ($n_e C_{21} >> A_{21}$), a photon is thermalized inside its mean free path l from the point it was created (the case of LTE). In the stellar atmospheres, however, ϵ is usually much less than unity ($A_{21} >> n_e C_{21}$) implying that a photon can undergo many scatterings and can travel some characteristic length L greater than l, before being destructed by collisions. Moreover, a photon will have some chance of escaping through the atmospheric boundary, thus diminishing the radiation intensity and the source function value in respect to the Plackian one. The depth in the atmosphere at which the source function is approaching the Planck's value B_ν is called thermalization length Λ, thus representing the deepest region from which the photons have a chance of leaving the atmosphere. This length depends on the way of the photon redistribution over the line in the scattering process.

The equality of the two profiles is realized when there is no correlation between the absorbed and the emitted frequency, ie. when the emission at any frequency can follow the absorption at a given frequency ν'. Such a case occurs if there are many elastic, velocity changing, collisions during the lifetime of an excited atom.

Two important results of the standard non–LTE problem for two–level atom and constant property medium (Avrett and Hummer, 1965) are:

– line source function at the boundary of the semi–infinite atmosphere is:

$$S(\tau = 0) = \sqrt{\epsilon} \cdot B \tag{7}$$

– thermalization depth for Doppler profile is $\Lambda \sim 1/\epsilon$, which, with the increasing role of the line wings, where photon diffusion is efficient, grows up to $\Lambda \sim 1/\epsilon^2$ for the profile of Lorentz.

Generally speaking, one cannot assure the equality of the emission and absorption profiles, especially not if absorptions dominate over the collisional excitations. Due to Doppler effect, the absorption process is selective to the frequency and angular dependence of the radiation field. As a consequence, the emission profile is some function of the radiation field. This dependence can be expressed through the action of the operator of redistribution $\hat{R}$ as follows:

$$\psi_\nu^s(\vec{n}) = \hat{R} \oplus I_\nu(\vec{n}), \tag{8}$$

or, the total emission profile as:

$$\psi_\nu(\vec{n}) = (1 - \epsilon) \int d\nu' \frac{d\Omega'}{4\pi} R(\nu', \vec{n}', \nu, \vec{n}) I_{\nu'}(\vec{n}') + \epsilon\phi_\nu, \tag{9}$$

where $R(\nu', \vec{n}', \nu, \vec{n})$ is the redistribution function which includes all the physics of the scattering process (absorption of photon (ν', $\vec{n}'$) followed by reemission of the photon (ν, $\vec{n}$)).

The first right–hand side term in eq. (9) describes the contribution of scattering and the second that of collisional excitation to the emission profile. In that expression, there is no explicit dependence either on the number density or on the velocity distribution of emiters (excited atoms). However, it shows clearly that the emission profile depends on the type of excitation (by absorption or by collisions), and accordingly, on the previous history of the atom.

Since the main aspect of the redistribution in the theory of line formation is a small change in frequency, isotropic and angle averaged restribution function $R(\nu', \nu)$ is usually employed. A limiting, but in reality non existing case of no changes between the absorbing and emiting frequency during the scattering process, is the one of coherent scattering:

$$R(\nu', \nu) = \phi(\nu')\ \delta(\nu - \nu'),$$

where $\delta(\nu - \nu')$ is the Dirac δ–function.

The second extreme case already mentioned is the one of complete redistribution or complete non–coherence, where:

$$R(\nu', \nu) = \phi(\nu')\, \phi(\nu)$$

the redistribution function is a product of two independent events.

Generally, a form of redistribution function in every particular case has to be found, ie. one has to solve the so–called *partial redistribution problem.* The form of the redistribution function depends on the assumed atomic model (Hummer, 1962).

In this more general problem related to the standard one, the source function is frequency dependent:

$$S_\nu = \epsilon B + (1 - \epsilon) \frac{1}{\phi_\nu} \int d\nu' \frac{d\Omega'}{4\pi} R(\nu', \vec{n}', \nu, \vec{n})\, I_{\nu'}(\vec{n}'). \tag{10}$$

The theory of partial redistribution was widely developed by Hummer (1962), Hubeny (1984), Mihalas (1978) and others.

3. KINETIC APPROACH TO THE PARTIAL REDISTRIBUTION PROBLEM

A more general, the so–called kinetic description (and a more fundamental one) of the partial redistribution problem was introduced by Oxenius (1965). He was the first to present the laboratory absorption $\phi(\nu)$ and emission $\psi(\nu)$ profiles as a convolution of the corresponding atomic profiles (in the atomic rest frame) $a(\xi)$ and $\eta(\xi)$ with velocity distribution functions of the non–excited and excited atoms, respectively:

$$\phi(\nu) = \iiint d^3v \cdot f_1(\vec{v}) \cdot a(\xi, \xi_0) \tag{11}$$

$$\psi(\nu) = \iiint d^3v \cdot f_2(\vec{v}) \cdot \eta(\xi, \xi_0). \tag{11'}$$

Here, ξ denotes frequency in the atomic reference frame, relating to frequency ν in laboratory frame in the following way:

$$\xi = \nu - \frac{\nu_0}{c} \vec{n}\,\vec{v}\,.$$

Generally, $f_1(\vec{v}) \neq f_2(\vec{v})$, accordingly one can see that no additional assumption on the form of these distribution functions is made.

This approach has many advantages compared with the „classical" one, especially in those problems where the explicit expressions for the velocity distribution functions of the atoms in particular states are necessary. Let's see briefly some of these advantages. As we have seen from eq. (9), redistribution processes describe emission profile coefficient in a function of the radiation field intensity. This can be described in two steps. Firstly, the emission profile coefficient is an image of the velocity distribution function of the excited atoms, eq. (11'):

$$\psi_\nu(\vec{n}) = \hat{A} \oplus f_2(\vec{v}, \xi), \tag{12}$$

where the details of atomic structure are contained in the operator $\hat{A}$. The velocity distribution of the atoms excited by collisions is given by the Maxwellian, but that of the atoms excited by radiation depends on the radiation field intensity. Hence,

$$f_2(\vec{v}) = \hat{B} \oplus I_{\nu'}(\vec{n}')\,. \tag{13}$$

Regardless of the possible evolution of $f_2(\vec{v})$ between the moments of excitation and emission, the two expressions can be connected in one:

$$\psi_\nu(\vec{n}) = \hat{O} \oplus I_{\nu'}(\vec{n}'), \tag{14}$$

which describes $\psi_\nu(\vec{n})$ as a direct image of the radiation field intensity $I_{\nu'}$, $(\vec{n}')$. If there is no evolution of $f_2(\vec{v})$ during the lifetime of an excited atom, $\hat{O}$ is the operator of redistribution $\hat{R}$ already mentioned in „classical" partial redistribution problem. With our choice of the atomic model, there is no redistribution in the atomic rest frame. Therefore, the only evolution of $f_2(\vec{v})$ can be realized in the kinetic sense. This occurs either through the action of elastic, velocity changing, collisions or as the macroscopic transfer of the excited atoms. The both, the local and non–local kinetic effects, respectively, can be described by some kinetic operator $\hat{C}$. Hence,

$$\hat{O} = \hat{C} \oplus \hat{R}.$$

For the studying of the kinetic effects, ie. of the evolution of the function $f_2(\vec{v})$, it is necessary to introduce the kinetic equation, instead of the statistical equilibrium one. Its direct application in the analysis of the line transfer with transport of the excited atoms taken into account, is described in details in the next chapter.

4. DIFFUSION OF EXCITED ATOMS

The transport of the excited atoms as a consequence of non–LTE line transfer had been disregarded before the paper of Düchs and Oxenius (1977) appeared. Since the radiation field intensity, contributing significantly to the level populations in non–LTE line transfer, decreases towards the surface of the star, so does the density of the excited atoms to the same extent, making their gradient much steeper than the natural gradient of the non–excited atoms density. The streaming of the excited atoms, arising due to this gradient, can significantly change their concentration and velocity distribution, finally modifying line shape and intensity. This effect was analysed for the first time in the papers of Düchs and Oxenius (1977) and Düchs et al. (1978) in terms of the diffusion model with the complete redistribution approximation. Oxenius (1979) reanalysed this problem in the frame of the kinetic theory of particles and photons, through the relations between the characteristic lengths for photons and excited atoms. It was shown that the streaming must not be a priori neglected, at least not for the resonance lines of the most abundant elements.

The first self–consistent solution of line transfer problem obtained by simultaneous solution of radiative transfer equation and kinetic equation for the excited atoms is presented in the paper of Simonneau (1984) and described in more details in the papers of Borsenberger et al. (1986 a,b), hereinafter denoted as BOS I and BOS II.

A brief survey of the physical model and equations is given here, since they serve as the basic point for further approximative solutions.

5. PHYSICAL MODEL AND EQUATIONS

In all the analysis, plane–paralel, stationary, homogeneous and isothermal gas layer of large optical depth is considered. The gas consists of two-level atoms and electrons with given densities n and n_e, respectively. There are no external fields.

As the particular form of the atomic profile coefficients for the absorption and emission is not important for the description of the problem and for the interpretation of the results, we can simplify the atomic model by choosing two perfectly sharp states:

$$\alpha(\xi,\xi_0) = \eta(\xi,\xi_0) = \delta(\xi - \xi_0). \tag{15}$$

where ξ_0 is the central line frequency in the atomic rest frame.

For the resonant transitions in the stellar atmospheric conditions, one can suppose that the kinetic temperature of gas T is much lower than the temperature of excitation ($h\nu_0/k >> T$). Thus, the excited atoms density is much smaller than that of the non–excited ones, $n_1 >> n_2$, and the stimulated emission can be neglected. Under these conditions, collisions among non–excited atoms lead to Maxwellian velocity distribution function. As the collisions between the electrons are much more probable than the inelastic atom–electron ones, the electron velocity distribution function can also be represented by the Maxwellian one. Therefore,

$$f_1(\vec{v}) \doteq f_e(\vec{v}) = f^m(v). \tag{16}$$

The situation is more complicated with the distribution function of the excited atoms. As we could see from discussion in the chapter 3., the introduction of the kinetic equation, describing the distribution of excited atoms $F_2(\vec{v}) = n_2 f_2(\vec{v})$ is necessary. As the intensity of radiation field depends – via the emission coefficient – on the distribution of the excited atoms, two equations: for $I_\nu(\vec{n})$ and for $F_2(\vec{v})$ have to be solved simultaneously.

In the absence of the external forces, the excited atoms distribution function $F_2(\vec{v})$ is defined by time independent kinetic equation of the form (Oxenius, 1979):

$$\vec{v}\,\nabla F_2(\vec{v}) = \left(\frac{\delta F_2}{\delta t}\right)_{el} + \left(\frac{\delta F_2}{\delta t}\right)_{inel} + \left(\frac{\delta F_2}{\delta t}\right)_{rad}. \tag{17}$$

Term on the left–hand side describes the streaming of the excited atoms, and collisional terms on the right–hand side, expressed as follows (BOS I):

$$\left(\frac{\delta F_2}{\delta t}\right)_{el} = \gamma^{el} \cdot n_2 \cdot (f^m(v) - f_2(\vec{v})) \tag{18a}$$

$$\left(\frac{\delta F_2}{\delta t}\right)_{inel} = n_e C_{12} F_1(\vec{v}) - n_e C_{21} F_2(\vec{v}) \tag{18b}$$

$$\left(\frac{\delta F_2}{\delta t}\right)_{rad} = B_{12} I_{12}(\vec{v}) F_1(\vec{v}) - A_{21} F_2(\vec{v}) \tag{18c}$$

present the source and sink terms: radiative and inelastic (electronic) excitations and deexcitations and elastic collisions of the excited atoms with other particles, namely the non–excited atoms. In the above expressions, γ^{el} is frequency of elastic collisions, and

$$I_{12}(\vec{v}) = \int \oint d\nu' (d\Omega'/4\pi) I_{\nu'}(\vec{n}') \, \delta((\nu' - \xi_0) - \xi_0 \vec{n}\vec{v}/c). \tag{19}$$

It is much more convinient to express the equations in the dimensionless form. Substituting corresponding terms, ie. eqs. (18a, b, c) in the eq. (17) and expressing all the quantities in terms of their corresponding thermal equilibrium values (denoted by tilde ~), one obtains the following kinetic equation for the excited atoms in plane- paralel atmosphere:

$$\eta y \mu \frac{d}{d\tau}[\tilde{n}_2(\tau) f_2(y,\mu,\tau)] = [\tilde{n}_2(\tau) f_2(y,\mu,\tau)] - [\epsilon + (1-\epsilon)\tilde{I}_{12}(y,\mu,\tau)] f^m(y) - \zeta \tilde{n}_2(\tau)[f^m(y) - f_2(y,\mu,\tau)]. \tag{20}$$

Here: μ is the cosine of angle between the direction of propagation and the outward normal to the surface, τ is the mean optical depth in the line:

$$\tau = -\int_0^z k(z)\,dz,$$

where

$$k(z) = \int k_\nu(z)\,d\nu = \frac{h\nu_0}{4\pi\Delta\nu_D} n_1(z) B_{12} \tag{21}$$

is the mean line opacity, and z is the geometrical depth. x is frequency displacement from line center, $\nu_0 \equiv \xi_0$, in Doppler units ($x = (\nu - \nu_0)/\Delta\nu_D$) and $\vec{y}$ is velocity $\vec{v}$ expressed in terms of the thermal velocity w of two–level atoms.

Besides a parameter ϵ, introduced in standard non–LTE problem, kinetic equation contains two new parameters: η which measures the importance of streaming and ζ – the importance of elastic collisions during the lifetime of an excited atom. In the absence of stimulated emission, they are given by the following expressions:

$$\epsilon = n_e C_{21}/(A_{21} + n_e C_{21}) \tag{22a}$$

$$\eta = k\,w/(A_{21} + n_e C_{21}) \tag{22b}$$

$$\zeta = \gamma^{el}/(A_{21} + n_e C_{21}) \tag{22c}$$

Radiative transfer equation for plan–paralel atmosphere in the dimensionless form is:

$$\mu \frac{d}{d\tau} \widetilde{I}_x(\mu, \tau) = \phi_x [\widetilde{I}_x(\mu, \tau) - \widetilde{S}_x(\mu, \tau)], \tag{23}$$

where, according to the eqs. (11), (15) and (16)

$$\phi_x = \frac{1}{\sqrt{\pi}} e^{-x^2},$$

the absorption profile is the Gaussian one, and the source function is:

$$\phi_x \widetilde{S}_x(\mu, \tau) = \widetilde{n}_2(\tau)\, \psi_x(\mu, \tau)$$

$$= \iiint F_2(y, \mu, \tau)\; \delta(x - \vec{n} \cdot \vec{y})\, d^3 y. \tag{24}$$

To solve the system of equations (20), (23) and (24), it is necessary to define boundary conditions for two distributions: $\widetilde{I}_x(\vec{n})$ and $F_2(\vec{y})$. In the frame of the "two–fluid model" (BOS I and BOS II), these functions can be separated in outward:

$$\widetilde{I}_x^{+}(\mu, \tau), \qquad F_2^{+}(y, \mu, \tau) \qquad \mu > 0,$$

and inward part:

$$\widetilde{I}_x^{-}(\mu, \tau), \qquad F_2^{-}(y, \mu, \tau) \qquad \mu < 0,$$

so, the boundary conditions for a "semi–infinite" layer can be written:

– for the intensity of radiation:

$$\tau = 0 \qquad \widetilde{I}_x^{-}(\mu, \tau = 0) = 0, \tag{25}$$

$$\lim_{\tau \to \infty} e^{-\tau/\mu} \cdot \widetilde{I}_x^{+}(\mu, \tau) = 0. \tag{25'}$$

– for the excited atoms:

$$\tau = 0 \qquad F_2^{-}(y, \mu, \tau = 0) = \begin{cases} 0, \text{ destruction} \\ F_2^{+}(y, \mu, \tau = 0), \text{ reflection} \end{cases} \tag{26}$$

$$\lim_{\tau \to \infty} e^{-\tau/\mu} \cdot F_2^{+}(y, \mu, \tau) = 0. \tag{26'}$$

The method of solution and the results obtained are presented in the papers of Simonneau (1984) and BOS II (1986) for the case $\zeta = 0$. It is shown that the streaming of excited atoms for $\eta > 1$ can cause great changes in the emergent line intensity in the case of reflection boundary conditions, and asymmetry in the line profile in the case of destruction.

It should be noted that even though the kinetic non–local effects, ie. streaming of the excited atoms is not appreciable and therefore can be neglected, the kinetic local effects (the shape of the emission coefficient – redistribution theory) can be studied in terms of the same kinetic description. In the following chapters, we shall make short analysis of the two extreme cases:

1. If there is no streaming of the excited atoms, however, the influence of elastic collisions is taken into consideration (local case);
2. Elastic collisions dominate, so the streaming of excited atoms can be analysed in terms of the diffusion approximation (non–local case).

Some results of these approximative solutions are described in the paper of Atanacković et al. (1987).

6. LOCAL CLASSICAL THEORY OF REDISTRIBUTION WITH THE EFFECTS OF ELASTIC COLLISIONS

In the absence of streaming of the excited atoms ($\eta = 0$), kinetic equation becomes a simple statistical equilibrium equation for the excited atoms with the velocities between $\vec{y}$ and $\vec{y} + d\vec{y}$. Substituting $\eta = 0$ in eq. (20), it follows the expression for $F_2(\vec{y}, \tau)$:

$$F_2(y, \mu, \tau) = \frac{1}{1+\zeta} [\epsilon + (1-\epsilon)\, \widetilde{I}_{12}(y, \mu, \tau)]\, f^m(y) + \frac{\zeta}{1+\zeta} \widetilde{n}_2(\tau)\, f^m(y). \tag{27}$$

The influence of elastic collisions is clearly visible from this equation. If there are no elastic collisions, $\zeta = 0$, $F_2(\vec{y}, \tau)$ recovers its known "classical" form, deviating from the Maxwellian only due to the selectivity of the absorption process. $F_2(\vec{y}, \tau)$ thermalizes, ie. it tends to $\widetilde{n}_2 f^m(y)$ with the increasing number of elastic collisions, $\zeta \gg 1$.

Using the equations (24) and (27), the source function becomes:

$$\widetilde{S}_x(\vec{n}) = \frac{1}{1+\zeta} [\epsilon + (1-\epsilon) \frac{1}{\phi_x} \oint dx\, (d\Omega/4\pi)\; R_I(x', \vec{n}', x, \vec{n})\, \widetilde{I}_{x'}(\vec{n}')] + \frac{\zeta}{1+\zeta} \widetilde{n}_2(\tau). \tag{28}$$

Again, we find that the classical partial redistribution expression (10) is recovered when there are no elastic collisions, and that the thermalization ($f_2(\vec{y}) = f^m(y)$) or complete redistribution ($\tilde{\psi}_x = 1$, ie. $\tilde{S}_x(n) = \tilde{n}_2(\tau)$) is realized if $\zeta \gg 1$. Comparing the expressions (27) and (28) for $F_2(\vec{y}, \tau)$ and $\tilde{S}_x(\mu, \tau)$, respectively, one can see that the deviations of the excited atoms velocity distribution function from the Maxwellian lead to the partial redistribution effects, ie. to frequency dependent source function.

The effects of different values of parameter ζ on the behaviour of some characteristic quantities of radiative transfer are shown in the paper of Atanacković and Simonneau (1985) as well. We present them here as an ilustration of the previous discussion, together with some new figures.

These results have been obtained by solving the transfer equation (23) with the source function in equation (24). We have used the method as in BOS II, with the peculiarity that now the velocity distribution function $F_2(y, \mu, \tau)$ is given by the algebraic (local) equation (27), contrary to the general case ($\eta \neq 0$) where $F_2(y, \mu, \tau)$ was given by another transport differential equation.

In Figures 1a) and 1b) we plotted the reduced velocity distribution of the excited atoms $\tilde{f}_2(y, \mu, \tau) = f_2/f^m$ as the function of velocity $\vec{y}$, and the reduced emission profile coefficient $\tilde{\psi}_x(\mu) = \psi_x(\mu)/\phi_x$ as function of frequency x, at various optical depths τ of the layer with $\epsilon = 10^{-4}$, for two directions μ and four values of elastic collision parameter ζ. Corresponding complete redistribution (C.R.) values for which $\zeta = \infty$ are presented by dashed lines.

One can see that in our choice of the atomic model, $\tilde{\psi}_x$ is direct image of $\tilde{f}_2(\vec{y})$. With the increasing number of elastic collisions, both of the functions tend

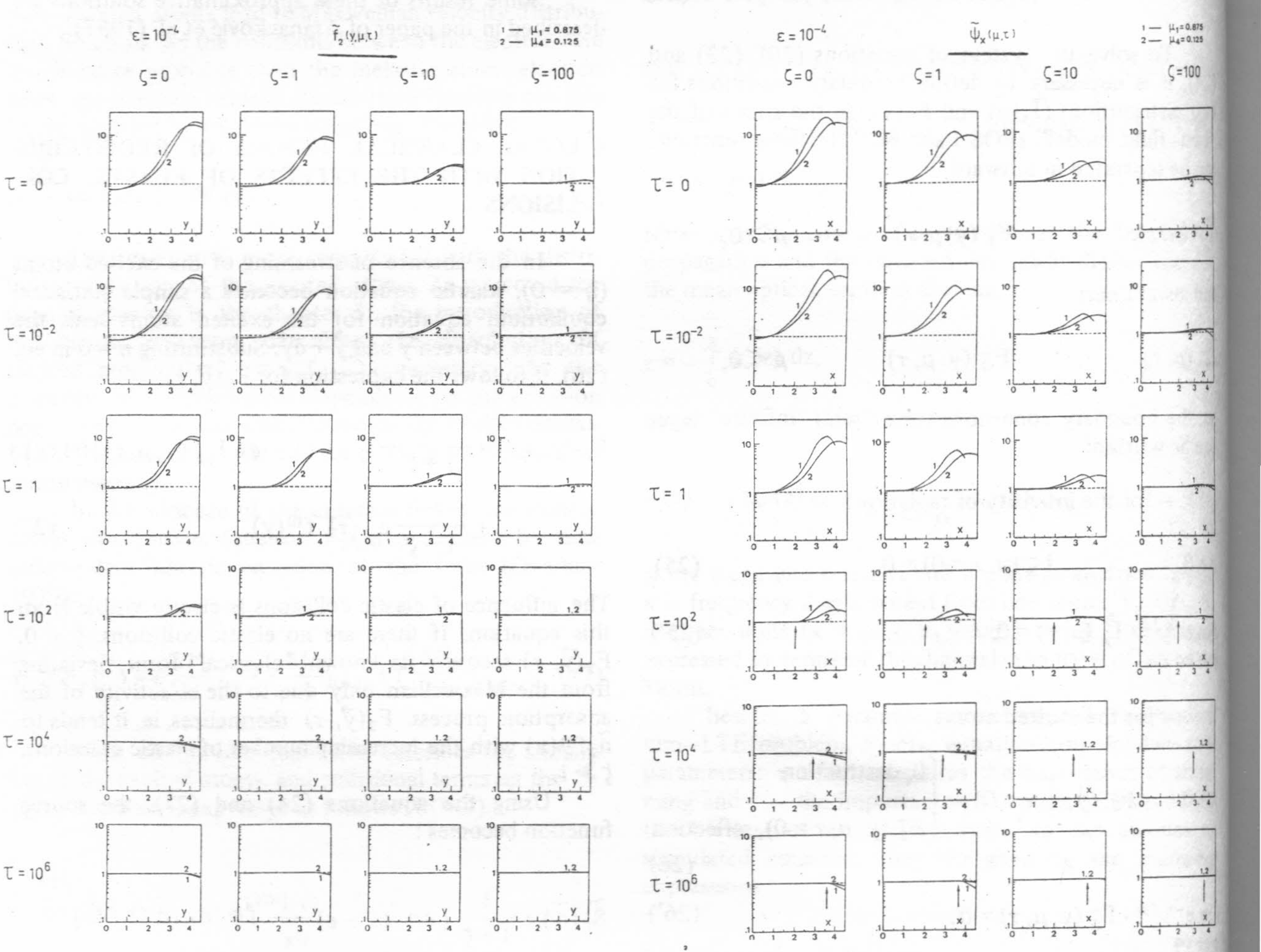

Fig. 1. a) Reduced velocity distribution function $\tilde{f}_2(y, \mu, \tau) = f_2/f^m$ of the excited atoms in a gas layer of finite optical depth $T = 10^6$ as the function of velocity y at various optical depths, for $\epsilon = 10^{-4}$ and quoted values of ζ. b) Reduced emission profile coefficient $\tilde{\psi}_x(\mu, \tau) = \psi_x/\phi_x$ as the function of frequency x.

to unity, ie. $f_2(y, \mu, \tau)$ and $\psi_x(\mu, \tau)$ tend to their equilibrium values. For $\zeta = 100$, thermalization is reached even at the boundary of the layer. Depth dependence is evident as well. The two functions approach unity at all frequencies at large (thermalization) depth $\tau \sim 1/\epsilon$ $(=10^4)$.

Vertical arrows indicate the frequency at which the monochromatic optical depth τ_x $(= \phi_x \tau)$ is unity. For all the frequencies where $\tau_x > 1$, the values of $\tilde{f}_2$ and $\tilde{\psi}_x$ are closely equal to unity. This region of line where one can suppose complete redistribution increases with the increasing value of ζ.

From Fig. 2, we can conclude that there are no great differencies between the curves of specific intensities corresponding to the two extreme cases of parameter ζ($\zeta = 0$ and $\zeta = \infty$), ie. that the effects of redistribution are not so much evident on the line intensity. The relation of the shapes of $\tilde{\psi}_x$ and $\tilde{I}_x$ as a consequence of partial coherency in the redistribution processes is evident.

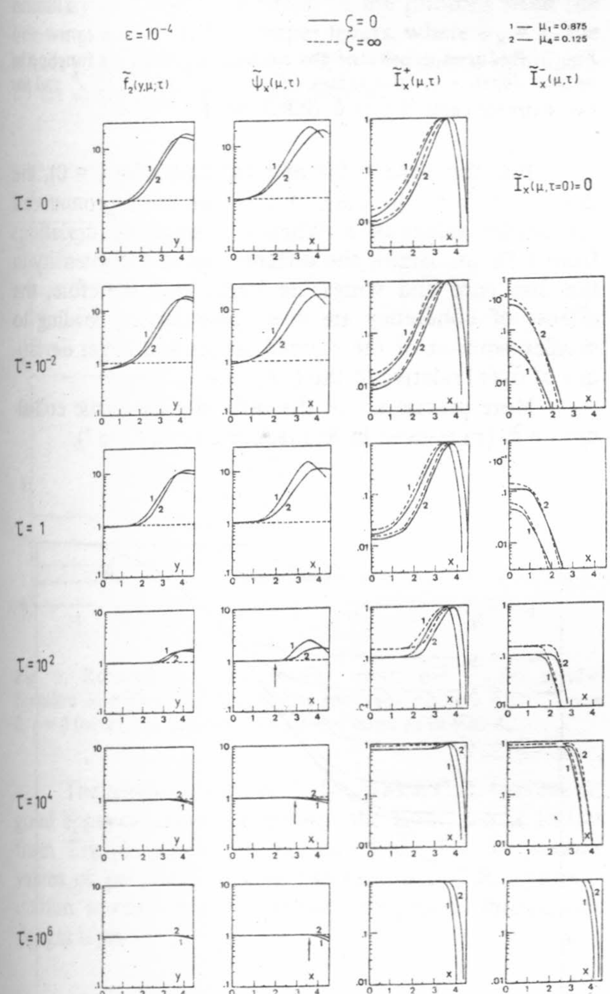

Fig. 2. Reduced velocity distribution function $\tilde{f}_2$, reduced emission profile coefficient $\tilde{\psi}_x$, and outgoing $\tilde{I}_x^+(\mu, \tau)$ and incoming $\tilde{I}_x^-(\mu, \tau)$ intensities at different optical depths of a gas layer ($\epsilon = 10^{-4}$) for two directions and two extreme values of parameter ζ($\zeta = 0$ (P.R.) – solid curves and $\zeta = \infty$ (C.R.) – dashed curves).

In order to have the first good numerical description for other relevant quantities, we can compute the densities for the excited atoms distribution and for the radiation field, by using the Eddington approximation for the transfer equation.

As the intensity of this radiation field $\tilde{I}_x(\mu, \tau)$ is, in the absence of streaming ($\eta = 0$) a symmetrical one, the velocity distribution function $F_2(y, \mu, \tau)$ and the emission profile coefficient $\psi_x(\mu, \tau)$ will be pair in μ. (Equations (19), (24) and (27)). Therefore, the corresponding redistribution function $R_I(x', \vec{n}', x, \vec{n})$ will also be pair in direction. We can see from Figs 1. and 2. that, for the functions F_2 and $\tilde{\psi}$, μ dependence (at least of the second order) is not very pronounced and, therefore, it is correct to use the angle averaged redistribution function $R_I(x', x)$ instead of the general one. This is even more fulfilled as we use the Eddington approximation for the transfer equation. Then, we can rewrite the expression for the source function:

$$\tilde{S}_x(\tau) = \frac{1}{1+\zeta}\left[\epsilon + (1-\epsilon)\frac{1}{\phi_x}\int dx'\, R_I(x', x)\, \tilde{J}_{x'}(\tau)\right] + \frac{\zeta}{1+\zeta}\,\tilde{n}_2(\tau) \tag{29}$$

where the density of excited atoms $\tilde{n}_2(\tau)$ is obtained by integration of (27) over all velocities:

$$\tilde{n}_2(\tau) = \epsilon + (1-\epsilon)\,\tilde{J}_\phi(\tau), \tag{30}$$

and

$$\tilde{J}_\phi(\tau) = \iiint \tilde{I}_{12}(\vec{y}, \tau)\, f^m(y)\, d^3y = \int \tilde{J}_x(\tau)\, \phi_x\, dx. \tag{31}$$

For any value of ζ from the interval $(0, \infty)$ one has to solve radiative transfer equation, written in the Eddington approximation:

$$\frac{1}{3}\frac{d^2\tilde{J}_x(\tau)}{d\tau^2} = \phi_x^2\,\tilde{J}_x(\tau) - \phi_x^2\,\tilde{S}_x(\tau) \tag{32}$$

with the source function (29), ie. to solve one integro–differential equation.

The discrete ordinate method is used. Since the weightened function ϕ_x has the Gaussian form, we used zeros and weights of the Hermite polynomials. Finally, the system of NF linear differential equations (for NF chosen frequency points) of the second order

$$\frac{1}{3}\frac{d^2 \widetilde{J}_{x_i}(\tau)}{d\tau^2} = \phi_{x_i}^2 \widetilde{J}_{x_i}(\tau) - \phi_{x_i}^2$$

$$\{\widetilde{n}_2(\tau) + \frac{(1-\epsilon)}{(1+\zeta)} \sum_{j=1}^{NF} (R_{ij} - w_j) \widetilde{J}_{x_j}(\tau)\} \qquad (33)$$

with boundary condition:

$$\frac{1}{\sqrt{3}}\left(\frac{d\widetilde{J}_{x_i}(\tau)}{d\tau}\right)_{\tau=0} = \phi_{x_i} \widetilde{J}_{x_i}(0) \qquad (34)$$

has been solved.

We supposed the solutions in the form:

$$\widetilde{n}_2(\tau) = 1 - \sum_{l=1}^{NF} N_\ell \exp(-\lambda_\ell \tau)$$

$$\widetilde{J}_{x_i}(\tau) = 1 - \sum_{l=1}^{NF} N_\ell \, g_{il} \exp(-\lambda_\ell \tau).$$

Substituting them into equation (30) for $\widetilde{n}_2(\tau)$, the so-called characteristic equation is obtained:

$$1 = (1-\epsilon) \sum_{j=1}^{NF} w_j g_{jl},$$

where g_{jl} is given by the expression:

$$g_{il} - \frac{(1-\epsilon)}{(1+\zeta)} Q_i \sum_{j=1}^{NF} (R_{ij} - w_j)\, g_{jl} = Q_i,$$

obtained from the equation (33), and

$$Q_i(\lambda_\ell) = \frac{\phi_{x_i}^2}{\phi_{x_i}^2 - \lambda_\ell^2/3}.$$

The unknown constants λ_ℓ and $g_{il}(\lambda_\ell)$ are determined by the iterative procedure. Coefficients N_l are obtained from the boundary condition (34).

The effects of partial redistribution on the excited atoms density $\widetilde{n}_2(\tau)$ are presented in Fig. 3. The density distribution $\widetilde{n}_2$ is given for three values of parameter ϵ (10^{-2}, 10^{-4}, 10^{-6}) and two extreme values of parameter ζ ($\zeta = 0$, P.R. – solid line and $\zeta = \infty$, C.R. – dashed line). The solution which corresponds to C.R. satisfies the expression at the boundary of the layer:

$$\widetilde{n}_2(\tau = 0) = \sqrt{\epsilon}$$

and is thermalized ($\widetilde{n}_2(\tau) \to 1$) at $\tau = 1/\epsilon$.

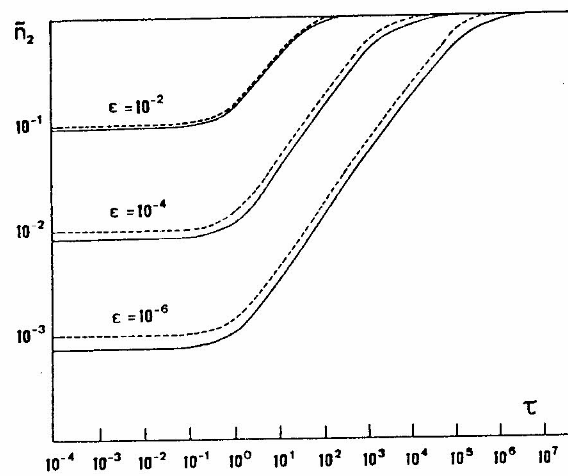

Fig. 3. Reduced density of the excited atoms as the functi[...] optical depth τ for the values of $\epsilon = 10^{-2}, 10^{-4}, 10^{-6}$ a[...] two extreme cases of ζ: $\zeta = 0$ (P.R.) and $\zeta = \infty$ (C.R.).

For the same value of ζ (in figure for $\zeta = 0$) deviations from the case of C.R. are more pronou[...] for smaller values of ϵ. When ϵ is small (ie. devia[...] from LTE are large), the differencies of the intensi[...] the line core and wings are larger and, therefore[...] effects of coherency are more pronounced, leadi[...] smaller amount of the excited atoms and larger de[...]ons of $\widetilde{n}_2(\tau)$ relative to the C.R. case.

More precise about the influence of elastic co[...]ons on $\widetilde{n}_2(\tau)$ is given in Atanacković et al. (1987).

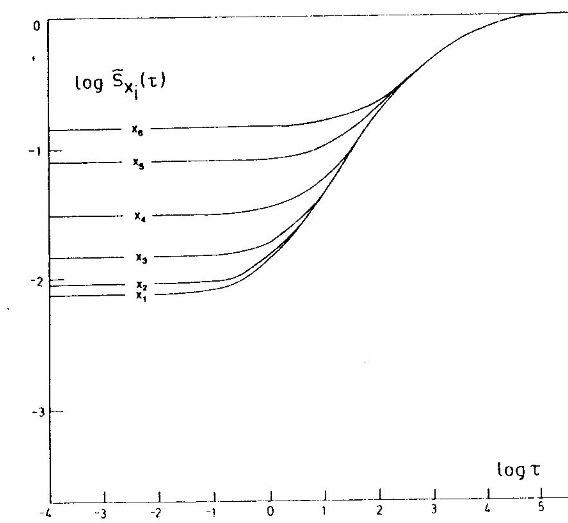

Fig. 4. Frequency dependent source function $\widetilde{S}_{x_i}(\tau)$ [...] 0.314240, x_2 = 0.947788, x_3 = 1.597683, x_4 = 2.279507[...] 3.020637, x_6 = 3.889725 (in Doppler units)) in a layer of[...] optical depth $T = 2 \cdot 10^6$ ($\epsilon = 10^{-4}$, $\eta = 0$, $\zeta = 0$).

As an ilustration of partial redistribution effects, we plotted in Fig. 4, frequency dependent source function $\tilde{S}_{x_i}(\tau)$ at six frequencies in line (0.314240, 0.947788, 1.597683, 2.279507, 3.020637, 3.889725, in Doppler units) for the case when there are no elastic collisions ($\zeta = 0$). In the line core, $\tilde{S}_{x_1} \cong \tilde{S}_{x_2}$, following the behaviour of $\tilde{n}_2(\tau)$. The source function, approaching to the line wings, recovers the Planckian form $(\tilde{S}_{x_i} \to 1)$. Thermalization occurs, for all the frequencies, at $\tau \sim 10^4$.

In order to show the depth dependence of the redistribution processes, we plotted the reduced emission profile coefficient $\tilde{\psi}_x(\tau)$ for different frequencies, over the optical depth τ of the layer without elastic collisions (Fig. 5). The effects of partial coherency are mostly pronounced in the line wings and at the boundary of a layer. However, as the photons from the line wings are created in deeper layers, where $\tilde{\psi}_x = 1$, the effects of partial coherency will not influence significantly the shape of the emerging intensity.

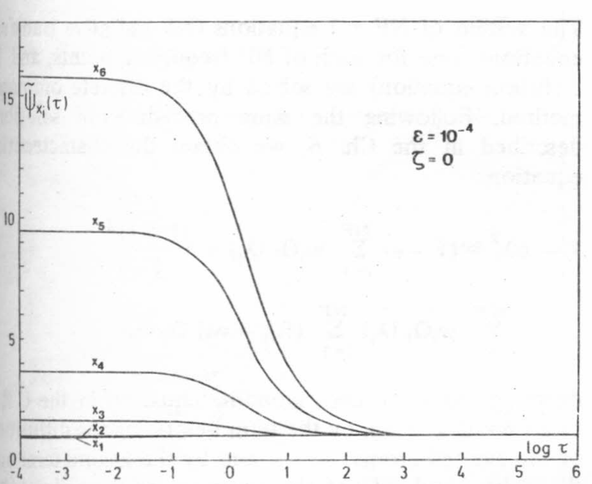

Fig. 5. Reduced emission profile coeficinet $\tilde{\psi}_{x_i}(\tau)$ as the function of optical depth τ of the gas layer where $\epsilon = 10^{-4}$, $\eta = 0$, $\zeta = 0$ for six line frequencies x_i, the same as in Fig. 4.

The smallest value of ζ, for which C.R. becomes a good approximation throughout the layer, can be found from Fig. 6, where we presented $\tilde{\psi}_{x_6}(\tau)$ for several values of parameter ζ. One can take that C.R. approximation is valid over the entire line profile throughout the gas layer for $\zeta > 10$.

7. DIFFUSION OF THE EXCITED ATOMS WITH PARTIAL REDISTRIBUTION

Integrating the kinetic equation (20) over all velocities, we obtain the first moment equation of the form:

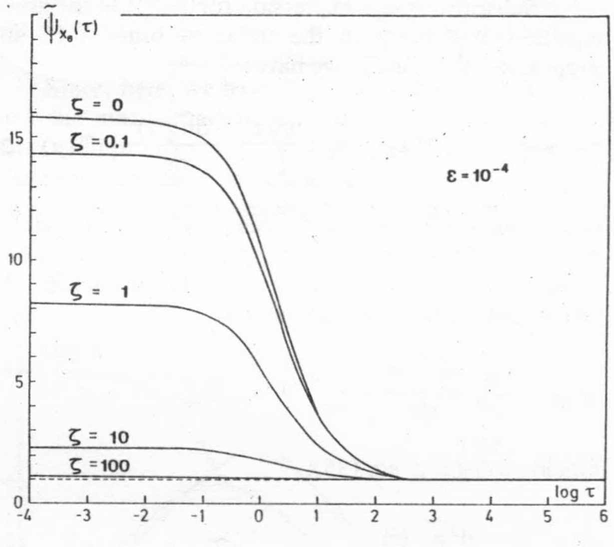

Fig. 6. Reduced emission profile coefficient at frequency x_6, $\tilde{\psi}_{x_6}(\tau)$, in the layer of finite thickness $T = 2 \cdot 10^6$ with $\epsilon = 10^{-4}$, $\eta = 0$ for five values of parameter ζ. Dashed line: $\zeta = \infty$.

$$\eta \frac{d}{d\tau} \Phi_2(\tau) = \tilde{n}_2(\tau) - [\epsilon + (1-\epsilon)\, \tilde{J}_\phi(\tau)]. \tag{35}$$

Compared with the expression (30) for the excited atoms density distribution in the local case, here, an additional term on the left–hand side exists, describing modification of that distribution due to the streaming process. The transport of the excited atoms is described by the flux:

$$\Phi_2(\tau) = \iiint d^3y (y\mu)\, F_2(y,\mu,\tau). \tag{36}$$

In order to determine flux, it is necessary to find the distribution function of the excited atoms $F_2(y, \mu, \tau)$. If we suppose that the elastic collisions are numerous, we can find F_2 in the first, diffusion approximation. Then, since the mean free path of the excited atoms is much smaller than their gradient, kinetic equation can be written in the following way:

$$\eta y \mu \frac{dF_2^{(0)}}{d\tau} = F_2^{(1)} - [\epsilon + (1-\epsilon)\, \tilde{I}_{12}(y,\mu,\tau)]\, f^m(y) + \zeta\, [F_2^{(1)} - \tilde{n}_2 f^m], \tag{37}$$

where $F_2^{(0)}$ is the distribution function in the local ($\eta = 0$) case. From (37), it follows:

$$F_2^{(1)}(y,\mu,\tau) = \frac{1}{1+\zeta}\, [\epsilon + (1-\epsilon)\, \tilde{I}_{12}(y,\mu,\tau)]\, f^m(y) + \frac{\zeta}{1+\zeta}\, \tilde{n}_2\, f^m(y) + \frac{\eta y \mu}{1+\zeta} \frac{d}{d\tau} F_2^{(0)}(y,\mu,\tau) =$$

$$= F_2^{(0)}(y,\mu,\tau) + \frac{\eta y \mu}{1+\zeta} \frac{d}{d\tau} F_2^{(0)}(y,\mu,\tau). \tag{38}$$

Substituting the expression for $F_2^{(o)}$ in the above equation, neglecting all the terms of order $1/\zeta^2$ and supposing $\zeta \gg 1$, finally we have:

$$F_2(y,\mu,\tau) = F_2^{(0)}(y,\mu,\tau) + \frac{\eta y \mu}{\zeta}\left[\frac{d\widetilde{n}_2(\tau)}{d\tau}\right] f^m(y) \quad (39)$$

Comparing with the "local" case, $F_2(y, \mu, \tau)$ includes one term of the order η/ζ and proportional to $d\widetilde{n}_2/d\tau$. Once we have $F_2(y, \mu, \tau)$, according to the eq. (36), the expression for the flux will be:

$$\Phi_2(\tau) = \frac{\eta}{2\zeta}\frac{d\widetilde{n}_2(\tau)}{d\tau}.$$

Finally, using it in eq. (35):

$$\widetilde{n}_2(\tau) - \delta\frac{d^2\widetilde{n}_2(\tau)}{d\tau^2} = \epsilon + (1-\epsilon)\widetilde{J}_\phi(\tau), \quad (40)$$

we obtain the diffusion equation for the excited atoms, where $\delta = \eta^2/2\zeta$ is the diffusion coefficient.

Applying the equation (24), the source function in the diffusion approximation becomes:

$$\widetilde{S}_x(\vec{n}) = \frac{1}{1+\zeta}\left[\epsilon + (1-\epsilon)\frac{1}{\phi_x}\int\oint dx'\,(d\Omega'/4\pi)\right.$$

$$\left. R_I(x',\vec{n}',x,\vec{n})\,\widetilde{I}_{x'}(\vec{n}')\right] + \frac{\zeta}{1+\zeta}\widetilde{n}_2(\tau) + \frac{\eta}{\zeta}\left[\frac{d\widetilde{n}_2(\tau)}{d\tau}\right] x\mu.$$

As we can see, the source function is consisted of one symmetrical part (the first two terms) and the asymmetrical one of the order $1/\zeta$. The intensity, obtained with that source function will also be consisted of these two parts, and since it is included in the expression for the source function thought the redistribution term, which is already of the order $1/\zeta$, the asymmetrical component participates in the problem as the term of order $1/\zeta^2$, negligeable in this approximation.

Retaining only the symmetrical part of intensity, and having in mind discussion from the previous chapter, we can take the following form of the source function into account ($\zeta \gg 1$):

$$\widetilde{S}_x(\vec{n}) = \widetilde{n}_2(\tau) + \frac{(1-\epsilon)}{\zeta}\left[\frac{1}{\phi_x}\int dx'\,R_I(x',x)\,\widetilde{J}_{x'}(\tau) - \widetilde{J}_\phi(\tau)\right].$$

Instead of an algebraic equation for the density of excited atoms (30) in the „local" case, now we have to solve one differential equation of the second order (40). For its solution we need boundary conditions for $\widetilde{n}_2(\tau)$. By analogy with eq. (26), we can define conditions at the surface $\tau = 0$:

$$\widetilde{n}_2^-(\tau=0) = \begin{cases} \widetilde{n}_2^+(\tau=0), & \text{reflection} \\ 0, & \text{destruction,} \end{cases} \quad (41)$$

where we denoted by + and –, the particles moving towards and from the surface, respectively. Finding $n_2^+(\tau)$ from:

$$\widetilde{n}_2^+(\tau) = 2\pi\int y^2\,dy\int F_2(y,\mu,\tau)\,d\mu$$

and substituting (39), for $\tau = 0$ we have:

$$\widetilde{n}_2^+(0) = \frac{1}{2}\widetilde{n}_2(0) + \frac{1}{2\sqrt{\pi}}\frac{\eta}{\zeta}\left[\frac{d\widetilde{n}_2(\tau)}{d\tau}\right]_{\tau=0}.$$

Using (41), finally we have:

$$\left[\frac{d\widetilde{n}_2(\tau)}{d\tau}\right]_{\tau=0} = \begin{cases} \widetilde{n}_2(0)\sqrt{(\pi\zeta/2\delta)}, & \text{destruction} \\ 0, & \text{reflection} \end{cases}$$

The system of NF + 1 equations (NF radiative transfer equations, one for each of NF frequency points, and 1 diffusion equation) are solved by the discrete ordinate method. Following the same procedure of solution described in the Ch. 6, we obtain the characteristic equation:

$$1 - \delta\lambda_l^2 = (1-\epsilon)\sum_{i=1}^{NF} w_i Q_i(\lambda_l) + \frac{(1-\epsilon)^2}{\zeta}\sum_{i=1}^{NF} w_i Q_i(\lambda_l)\sum_{j=1}^{NF}(R_{ij} - w_j)\,Q_j(\lambda_l)$$

differing from the corresponding equation in the C.R. case ($\delta = 0$, $\zeta \to \infty$), by the term describing the diffusion of the excited atoms $-\delta\lambda_\ell^2$ and by the second term on the right–hand side of the equation, of the order $1/\zeta$, representing the effects of partial redistribution.

The system of these nonlinear equations is solved by the Newton–Raphson method. More precise is given in Atanacković et al. (1987). For different values of ϵ, δ and ζ, the effect of the diffusion approximation are shown on the following quantities: $\widetilde{n}_2(\tau)$, $u_2(\tau) = \Phi_2(\tau)/\widetilde{n}_2(\tau)$, $\psi_x(\tau)$ and $\widetilde{S}_x(\tau)$.

The effects of diffusion ($\delta = 0.01, 0.1, 1$) and of partial redistribution ($\zeta = 10$(a) and $\zeta = 100$ (b)) on the excited atoms density distribution $n_2(\tau)$ are shown in Fig. 7, for the both boundary conditions.

In the reflection boundary case, transport of the excited atoms ($\delta \neq 0$) from deeper regions with the elastic reflections tend to increase the concentration of the excited atoms near the boundary thus flattening their gradient in relation to the case without diffusion ($\delta = 0$). The effects of photon redistribution on $\widetilde{n}_2(\tau)$ are negligeable in this reflection boundary case ($\widetilde{n}_2(\tau)$ is for a given value of δ, practically independent on the value of parameter ζ).

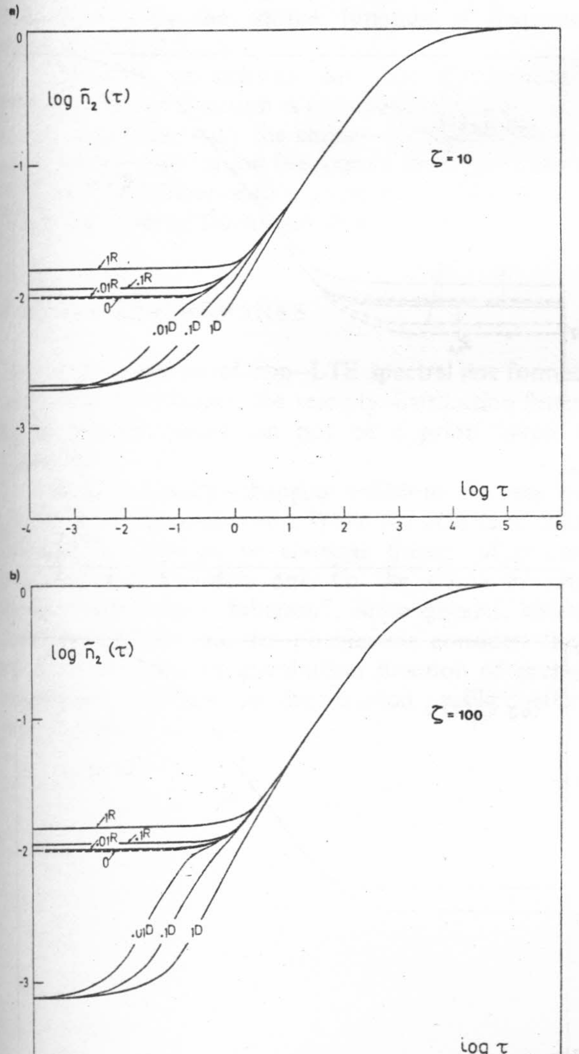

Fig. 7. Excited atoms density distribution $\tilde{n}_2(\tau)$ over the optical depth in a gas layer ($\epsilon = 10^{-4}$) with: a) $\zeta = 10$, b) $\zeta = 100$, for three values of diffusion coefficient δ (0.01, 0.1, 1), for boundary conditions of: destruction (D) and reflection (R). Dashed line: $\delta = 0$.

Owing to disappearance of the excited atoms at the boundary in the destruction boundary case, $\tilde{n}_2(\tau)$ is much smaller for every $\delta \neq 0$ in relation to the case $\delta = 0$. With the increasing number of elastic collisions for the same value of δ, $\tilde{n}_2(\tau)$ decreases at the depths $\tau < L_s \propto \sqrt{\delta}$, where L_s is the characteristic length of streaming (BOS II). The value of $\tilde{n}_2(\tau = 0)$ is practically independent on the diffusion parameter δ. Thermalization ($\tilde{n}_2$ $(\tau \to \infty) \to 1$) is realized at the depth $\tau \sim 10^4$ $(1/\epsilon)$.

Since, here, we have $\Phi_2(\tau) \neq 0$, it is interesting to show the mean (macroscopic) velocity of streaming of the excited atoms $u_2(\tau) = \Phi_2(\tau)/\tilde{n}_2(\tau)$ (Fig. 8.). For the reflection boundary condition, $u_2(\tau)$ is zero at the surface, whereupon increasing to the maximum value ~

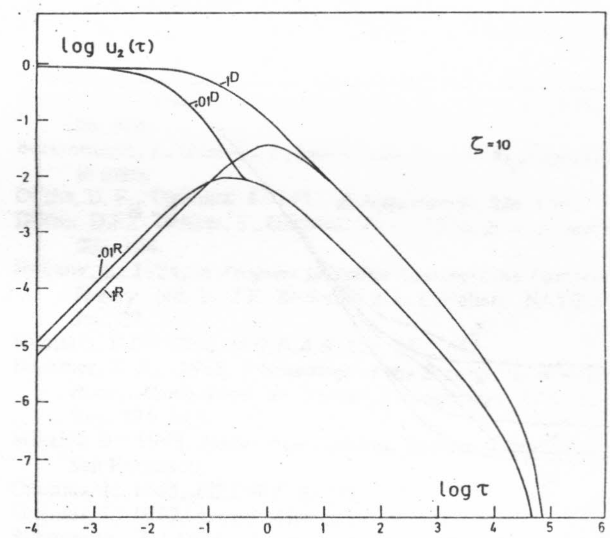

Fig. 8. Mean velocity of the excited atoms $u_2(\tau)$ as the function of optical depth τ. All other quantities are the same as in Fig. 7.

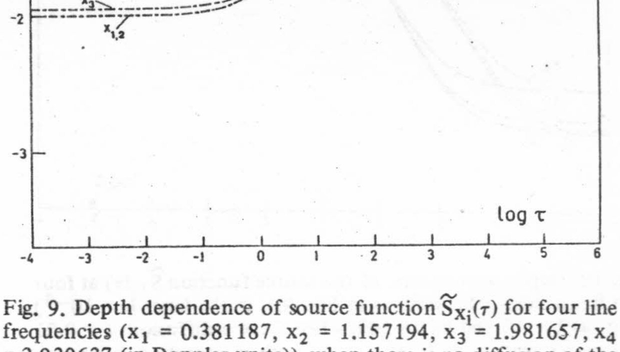

Fig. 9. Depth dependence of source function $\tilde{S}_{x_i}(\tau)$ for four line frequencies ($x_1 = 0.381187$, $x_2 = 1.157194$, $x_3 = 1.981657$, $x_4 = 2.930637$ (in Doppler units)), when there is no diffusion of the excited atoms ($\delta = 0$) in the layer ($\epsilon = 10^{-4}$, $\zeta = 10$).

0.05w for $\delta = 1$ at $\tau \sim 1$, finally decreases with the thermalization depth L_T. When the excited atoms disappear at the surface (destruction), their velocity decreases from the maximum value $\sim$ lw at the boundary, firstly with the streaming length L_s and then with the thermalization length L_T.

The behaviour of the source function in the diffusion approximation is shown in Figs. 9, 10 and 11. In Fig. 9, we plotted the source function $\widetilde{S}_{x_i}(\tau)$ at 4 line frequencies (0.381187, 1.157194, 1.981657, 2.930637, in Doppler units) in case when there is no diffusion (δ= 0). Since we consider the layer with elastic collision parameter $\zeta = 10$, the effects of partial redistribution are less evident.

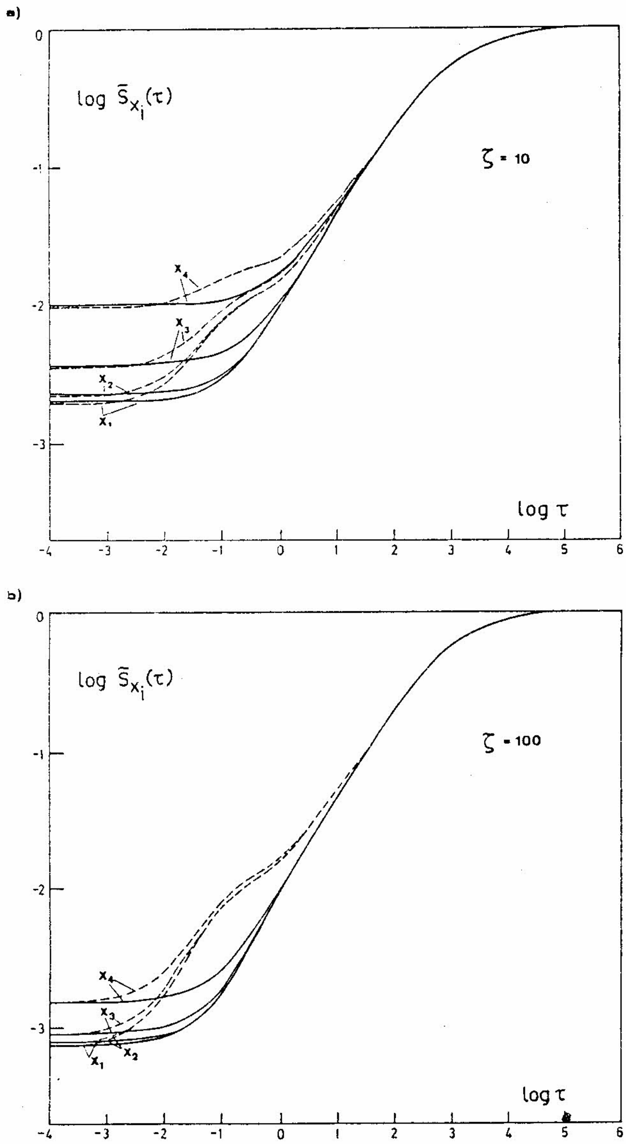

Fig. 10. Depth dependence of the source function $\widetilde{S}_{x_i}(\tau)$ at four line frequencies (the same as in Fig. 9.), in the layer ($\epsilon = 10^{-4}$) with: a) $\zeta = 10$ and b) $\zeta = 100$, when there is diffusion: $\delta = 0.01$ (------) and $\delta = 1$ (———) with destruction boundary condition.

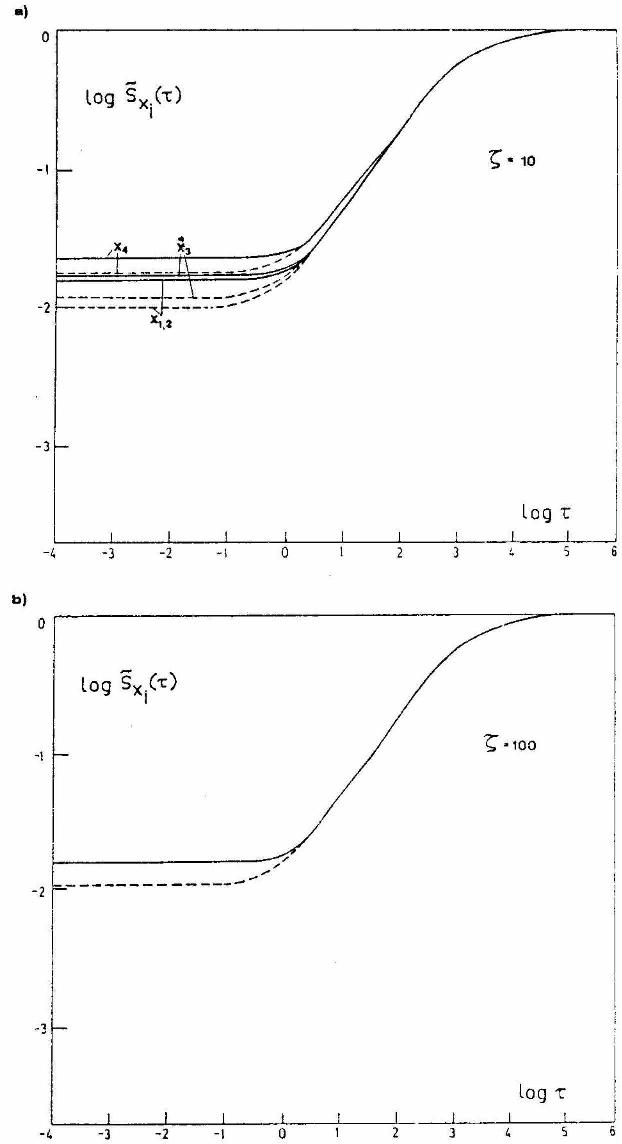

Fig. 11. The same as in Fig. 10, only for reflection boundary condition.

In Figs. 10 and 11. we can see the effects of the diffusion for two boundary conditions: destruction and reflection, respectively. Comparing with the case $\delta = 0$, the source function value obtained with the destruction boundary condition (Fig. 10), is much smaller at all frequencies for the two values of the diffusion parameter

δ (0.01, 1). For the general behaviour of the source function, the same discussion, as for Fig. 7. can be applied. Similarly, for the reflection boundary condition, the growth of the source function in the boundary layer, with the increasing value of δ, is a consequence of the excited atoms density $\tilde{n}_2(\tau)$ increase. In the case when ζ = 100, the source function is frequency independent (C.R.).

It should be pointed out that the frequency dependent source function is obtained, in this diffusion model, coherently with the emission profile coefficient $\tilde{\psi}_x(\vec{n})$ and the distribution function of the excited atoms $F_2(\vec{y}, \tau)$, as a difference to a priori made assumption of C.R. in the paper of Düchs and Oxenius (1977).

8. CONCLUDING REMARKS

In the problem of non–LTE spectral line formation by two–level atoms, the velocity distribution function of excited atoms can not be a priori taken as Maxwellian.

Elastic, velocity–changing collisions are very important in its thermalization. While the effects of these collisions are treated in classical theory of photon frequency redistribution only in the frame of „the atomic redistribution function", more general, kinetic description of the transfer phenomena considers their effect on the velocity distribution function of excited atoms (and, therefore, on the emission profile coefficient), as well.

Kinetic treatment of non–LTE transfer problem also enables taking non–local kinetic aspect of photon frequency redistribution, ie. convective transport of excited atoms, into consideration.

REFERENCES

Atanacković, O., Simonneau, E.: 1985, *Colloquium „Collisions et rayonnement"*, Orleans, P3.

Atanacković, O., Borsenberger, J., Oxenius, J. & Simonneau, E.: 1987, *J.Q.S.R.T.* (submitted).

Avrett, E.H. & Hummer, D.G.: 1965, *M.N.R.A.S.* **130**, 295.

Borsenberger, J., Oxenius, J., Simonneau, E.: 1986a, J.Q.S.R.T. **35**, 303.

Borsenberger, J., Oxenius, J., Simonneau, E.: 1986b, J.Q.S.R.T., in press.

Düchs, D. F., Oxenius, J.: 1977, *Z. Naturforsch.* **32a**, 156.

Düchs, D.F., Rehker, S., Oxenius, J.: 1978, *Z. Naturforsch.* **33a**, 124.

Hubeny, I.: 1984, *in Progress in Stellar Spectral Line Formation Theory*, (ed. by J.E. Beckman & L. Crivellari), NATO ASI Ser., 27.

Hummer, D.G.: 1962, *M.N.R.A.S.* **125**, 21.

Hummer, D.G.: 1965, *Proceedings of the Second Harvard–Smithson. Conference on Stellar Atmospheres*, SAO Spec. Rep. **174** 143.

Mihalas, D.: 1978, *Stellar Atmospheres, 2nd ed.*, W.H. Freeman, San Francisco.

Oxenius, J.: 1965, *J.Q.S.R.T.* **5**, 771.

Oxenius, J.: 1979, *Astron. Astrophys.* **76**, 312.

Simonneau, E.: 1984, *in Progress in Stellar Spectral Line Formation Theory*, (ed. by J.E. Beckman & L. Crivellari), NATO ASI Ser., 73.

ORBITS OF TWO VISUAL DOUBLE STARS (IDS 15428N5059 and IDS 16358S3653)

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(Received: December 4, 1986)

SUMMARY: Presented are preliminary orbital elements, dynamical parallaxes, absolute magnitudes, masses, ephemeris and residuals of two visual double stars.

The orbital elements for visual double stars IDS 15428N5059 and IDS 16358S3653 are deduced by the Thiele–Innes, Van den Bos (1926) method. On the basis of orbital elements dynamical parallaxes, absolutes magnitudes and stellar masses are determinated following Parenago (1954).

The orbital elements of the stars are published in Nos. 99 and 100 of C.I. Comm. des etoiles doubles.

In Tables I and IV are listed the orbital elements, Thiele–Innes constants, dynamical parallaxes, absolute magnitudes and the stelar masses.

In Tables II and V are the ephemeris for 10 years.

Tables III and VI contain data on observations, the observers names abreviations, the references and the residuals.

We are grateful to Charles E. Worley from the U.S. Naval Observatory which supplied us by the measurements, and to Đ. Božičković for the adaptation of computer programmes and for some useful suggestions.

ORBIT OF IDS 15428N5059 = HU 657

App. mag. : 10.1–10.1, Sp.–

Table I

P = 292.4 years		
n = 1°.2314	A = + 0″.2940	$\pi_{dyn.org.}$ = 0″.006
T = 1978.93	B = −0″.2025	M_A = 4.0
e = 0.63	F = −0″.1775	M_B = 4.0
a = 0″.360	G = −0″.1950	$\mathfrak{M}_A$ = 1.24 ☉
i = 135°.8	C = ∓0″.0515	$\mathfrak{M}_B$ = 1.24 ☉
λ = 154°.0	H = ∓0″.2456	a = 60.0 A.U.
ω = 191°.8		
$T_{\Omega,\mho}$ = 1800.63:1977.23		

Table II

t	θ	ρ
1987.0	279°.9	0″.12
1988.0	274.0	0.12
1989.0	268.1	0.12
1990.0	262.4	0.13
1991.0	256.9	0.13
1992.0	251.6	0.13
1993.0	246.6	0.14
1994.0	241.9	0.14
1995.0	237.6	0.14
1996.0	233.4	0.15

Table III

N	t	θ	ρ	Obs.	n	Reference	$(O-C)_\theta$	$(O-C)_\rho$
1	1904.33	122°.7	0″.56	HU	3	Lick Obs.Bul.**2**,180,1904.	+ 0°.8	+ 0″.13
2.	1905.37	310.5	0.57	L	1	Greenwich Observations 1905.	+ 9.2	+ 0.15
3.	1922.824	116.4	0.44	VBS	4	Pub.Yerkes Obs.**5**, Pt.1,1927.	+ 5.6	+ 0.09
4.	1946.55	80.4	0.24	VBS	1	Pub.Yerkes Obs. **8**,159,1954.	− 3.0	+ 0.02
5.	1947.43	81.8	0.20	VBS	1	Pub.Yerkes Obs. **8**, 159, 1954.	0.0	−0.02
6.	1948.64	79.7	0.20	VBS	2	Pub. Yerkes Obs. **8**, 159, 1954.	+ 0.3	−0.01
7.	1949.79	68.3	0.16	VBS	2	Pub. Yerkes Obs. **8**, 159,1954.	− 8.7	−0.04
8.	1952.26	66.4	0.15	VBS	1	Pub.Yerkes Obs. **9** Pt.2, 1960.	− 5.1	−0.04
9.	1957.62	45.6	0.14	VBS	1	Pub.Yerkes Obs. **9**, Pt. 2, 1960.	−11.1	−0.03
10.	1958.52	41.7	0.19	B	3	Pub.Yerkes Obs. **9**, Pt. 1, 1960.	−12.1	+ 0.02
11.	1959.44	39.	0.21	COU	3	J. Obs. **43**, 1, 1960.	−11.7	+ 0.05
12.	1961.44	197.2*	0.18	WOR	3	Astron. J. **67**, 403, 1962.	−26.4	+ 0.02
13.	1963.39	18.4	0.16	B	2	Astron. J. **68**, 582.1963.	−17.8	+0.01
14.	1971.35	347.8	0.15	COU	4	Astron.Astrophys. Suppl. **6**, 185, 1972.	−14.0	+ 0.01
15.	1978.41	328.1	0.13	HEI	3	Astrophys. J.Suppl.**44**,111,1980.	0.0	0.00

*Quadrant changed

ORBIT OF IDS 16358S3653 = R 283

App. mag. : 7.0–7.8; Sp. G5

Table IV

P = 454.95 years		
n = 0°.7913		
T = 1968.21	A = +0".3880	πdyn.orb. = 0".012
e = 0.64	B = −0".4220	M_A = 2.4
a = 1".015	F = −0".4960	M_B = 3.2
i = 121°.8	G = −0".8620	$\mathbf{M_A}$ = 1.67 ☉
Ω = 67°.4	C = ±0".8378	$\mathbf{M_B}$ = 1.43 ☉
ω = 103.7	H = ∓ 0".2042	a = 86.8 A.U.
$T_{\Omega, \mho}$ = 1931.10;1989.24		

Table V

t	θ	ρ
1987.0	250°.3	0.49
1988.0	249.0	0.51
1989.0	247.7	0.52
1990.0	246.5	0.53
1991.0	245.3	0.54
1992.0	244.2	0.55
1993.0	243.1	0.56
1994.0	242.1	0.57
1995.0	241.1	0.58
1996.0	240.1	0.59

Table VI

N.	t	θ	ρ	Obs.	n	Reference	(O–C)θ	(O–C)ρ
1.	1881.63	87°.8	0".42	R	1	Sydney Obs.Results 1871–1881.	− 0°.7	−0".60
2.	1896.6	85.	1.	I	1	M.N.R.Astron. Soc.**57**,533.1897.	+ 1.6	+ 0.04
3.	1896.62	94.4	0.90	SEE	3	Astron. J. **18**, 181,1898.	+ 11.0	−0.06
4.	1897.40	85.7	1.04	SEE	2	Astron. J. **18**,181,1898.	+ 2.6	+ 0.08
5.	1897.52	87.9	1.22	SEE	1	Astron. Nachr. **146**,225, 1898.	+ 4.8	+ 0.03
6.	1897.54	87.0	0.93	COG	1	Astron. J.**18**, 181,1898.	+ 3.9	−0.03
7.	1910.55	75.4	1.21	OL	4	Lick Obs. Bul. **6**,76,1910.	− 2.6	+ 0.32
8.	1911.58	81.7	0.92	I	2	Transvaal Obs. circ.**1**, 111,1912.	+ 4.1	+ 0.04
9.	1919.65	73.2	0.86	DAW	3	Pub. La Plata Obs.**4**, Pt.2, 1922.	− 0.7	+ 0.04
10.	1924.55	73.9	0.93	VOU	4	Ann.BosschaObs.Lembang,**1**,Pt.2,Bl,1926.	+ 2.5	+ 0.16
11.	1930.39	68.9	0.85	WAL	2	Ann.Bosscha Obs. Lembang, **6**, Pt.2,1934.	+ 1.0	+ 0.14
12.	1934.60	64.0	0.61	B	4	Union Obs. Circ. **4**, 362,1937.	− 1.0	−0.06
13.	1935.62	62.8	0.58	FIN	4	Union Obs. Circ. **4**, 263,1936.	− 1.4	−0.07
14.	1937.52	63.7	0.63	SMW	4	Ann. Bosscha Obs. **9**, Pt. 1, 1951.	+ 1.1	0.00
15.	1938.44	62.7	0.63	VOU	3	Ann.Bosscha Obs.lembang, **6**, Pt.4, Dl. 1947.	+ 0.8	+ 0.02
16.	1941.26	56.3	0.48	B	4	Union OBs. Circ. **5**, 312,1949.	− 2.9	−0.09
17.	1942.25	58.2	0.62	VOU	4	J. Obs. **38**, 109,1955.	0.0	+ 0.06
18.	1946.25	48.8	0.85	GTB	1	Mem.Commonw.Obs.M.T.Stromlo,**2**, No 4, 1948.	− 4.6	+ 0.34
19.	1948.30	46.8	0.36	B	3	Union Obs. Circ. **6**, 13,1951.	− 3.6	−0.10
20.	1952.54	37.6	0.30	B	2	Union Obs. Circ. **6**, 266,1956.	− 4.9	−0.08
21.	1955.61	37.4	0.53	HEI	4	M.N.R.Astron. Soc. **116**, 248, 1956.	+ 3.1	+ 0.21
22.	1959.42	18.2	0.23	B	4	Union. Obs. Circ. **6**, 321, 1960.	− 0.8	−0.03
23.	1960.44	12.5	0.19	B	4	Union. Obs. Circ. **6**, 353,1961.	− 1.0	−0.05
24.	1964.61	341.4	0.24	B	4	Republic Obs. Circ. **7**, 70, 1965.	− 1.7	+ 0.04
25.	1965.55	336.9	0.26	KNP	1	Republic Obs. Circ. **7**, 177, 1969.	+ 2.0	+ 0.06
26.	1965.63	332.4	0.19	B	4	Republic Obs.Circ. **7**, 93, 1966.	− 1.8	0.00
27.	1966.44	309.4	0.16	B	1	Republic Obs.Circ. **7**, 157.1968.	−17.8	−0.04
28.	1978.73	280.3	0.32	WRH	1	Astron.Astrophys.Suppl. **39**, 197,1980.	+ 15.3	−0.05
29.	1979.21	283.6	0.31	HEI	3	Astrophys.J.Suppl.**44**, 111,1980.	+ 19.8	−0.07

LITERATURE:

Bos. van den, V.H.: 1926, *Orbital elements of Binary stars,* Union Observatory Circ. N. 68.

Parenago, P.P.: 1954, *Kurs zvezdnoj astronomii,* Moskva.

THE BINARY STAR Σ 2799 = ADS 15007

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SUMMARY: Orbital elements of the visual binray Σ 2799 = ADS 15007 along with other astrophysical constants are presented. Given also are the ephemeris from 1985 to 2011, as well as the list of measurements and corresponding residuals.

The binary system Σ 2799 = ADS 15007 was discovered by W. Struve in 1831. By its brightness ($7^m.0$–$7^m.0$) as well as by its components' distance exceeding 1" the system has been and at present still is attainable to many observers the world over. As a result, a list could be composed of as many as 432 measurements by which the orbital arc around the apoastron is fairly well defined. Although only a 67° arc of the orbit is covered by the observations, a full 1/4 of the total ellipse's area is theraby specified. As the system's orbit has hitherto not been calculated, the one presented here is but preliminary. The correction to the position angle due to precession is ignored. The Thiele–Innes–van den Bos's method was used (Bos, 1926). The constants A, B, F, G are found graphically. Thence the Cambell elements could be derived.

Table 1 gives the identification and the basis data on the system. In Table 2 are the orbital elements, orbital parallax, absolute brightness of the components and their masses. The components' masses have been derived using the Popović–Angelov (1970) mass–luminosity relation for the main HR sequence. The ephemeris are given in Table 3 at two – years intervals from 1985 to 2011. The list of observations, Table 4, contains individual measurements except for the data taken over from ADS or BDS catalogues. By the courtesy of Dr. P. Couteau the list of measurements could be made complete, for which particular thanks are owed to him.

The largest departure of observation from the derived orbit is the one associated with the measurement by Barbier made in 1931. If this measurement is omitted, a very small sum of the (0 – C) quantities is obtained both in the possition angle and the separation, namely : $\Sigma (0 - C)p = + 2^\circ 8$ and $\Sigma (0 - C)_d = +0''.22$.

A third component of the apparent magnitude $9^m 5$ and 137" separation was claimed in 1906 by Guillaume. This additional component failed to attract attention of the observers, since, in all likelihood, it does not belong to the system.

Table 1. The identification and the basic data on the system

Identification	Σ 2799 = ADS 15007 AB = BDS 11001 = IDS 21240N1039
α, δ (2000)	$21^h\ 28.^m9$, + 11°05'
m (ADS)	7.0 – 7.0
m (IDS)	7.5 – 7.5
Sp (A)	F2
dπ (J.–F.)	0."023
dπ(R.–M.)	0."018
p.m. (IDS)	E065N015 sec"/1000Y

Table 2. The elements

P = 618.89 Y	A = – 0."445	M(A) = +3.55
n = 0.°581686	B = + 0.995	M(B) = +3.55
T = 1602.80	F = + 1.318	Mass(A) = 1.41 Sun
e = 0.367	G = + 0.968	Mass(B) = 1.41 Sun
a = 1."66	C = ∓ 1.2530	
i = 129.°1	H = ±0.2994	
ω = 283.°44	t(Ω) = 1669.75	a = 103.8 AU.
Ω = 44.°86	t(Ω) = 2117.26	$\pi_{orb.}$ = 0."016

Table 3. Ephemerides

1985.0	266.°8	1."69	1999.0	262.°2	1."72
1987.0	266.1	1.69	2001.0	261.6	1.72
1989.0	265.4	1.70	2003.0	261.0	1.73
1991.0	264.8	1.70	2005.0	260.3	1.73
1993.0	264.2	1.71	2007.0	259.7	1.73
1995.0	263.5	1.71	2009.0	259.1	1.74
1997.0	262.9	1.71	2011.0	258.4	1.74

Table 4. Observations and residuals

1831.82	332.°9	1.″35	6n	Σ	+ 1.°05	−0.″05
1843.75	329.8	1.48	2	OΣ	+ 4.1	+ 0.08
1853.20	320.8	1.44	2	OΣ	− 0.3	+ 0.04
1863.81	317.4	1.41	7	Δ	+ 1.3	± 0.00
1878.71	312.6	1.30	2	Hl	+ 3.6	− 0.12
1885.71	306.5	1.40	3	Hl	+ 0.7	− 0.04
1889.02	304.5	1.45	13	HΣ	+ 0.2	+ 0.01
1889.94	302.9	1.35	3	Maw	− 1.0	− 0.09
1891.63	302.9	1.37	31	Cel 8, Sp 20, Nis 3	−0.2	− 0.08
1893.80	301.0	1.53	2	Big	−1.2	+ 0.08
1895.71	303.0	1.59	2	Collins	+ 1.7	+ 0.13
1896.51	300.0	1.57	3	Lv	− 0.9	+ 0.11
1897.89	301.2	1.42	3	Hu	+ 0.9	− 0.04
1900.83	298.1	1.56	14	Cel 2, Kgs06, Loh 5, See 1	− 0.9	+ 0.10
1903.0	296.9	1.42	16	GrO	− 1.2	− 0.05
1903.56	297.0	1.37	2	VBs	− 0.8	−0.10
1903.74	297.3	1.47	6	Bowyer	− 0.5	0.00
1904.44	294.6	1.59	4	Wz2, Frm, Th	− 2.8	+ 0.12
1909.14	295.4	1.57	21	Ur07, Dob 3, Lv 2, J3, Has 3, Gui 3	− 2.1	+ 0.09
1912.78	292.9	1.47	39	Gr09, Vou 8, Phl 3, Fox 3, Wz 4, Dob 3, VBs 2, Ol2, R5	− 1.0	− 0.02
1920.46	290.0	1.55	24	Dob 5, Fhl 9, Ber06, Lv 3, Gui 1	− 0.7	− 0.04
1920.721	288.7	1.56	2	GΣ	− 1.8	+ 0.05
1920.738	289.4	1.59	2	Btz	− 1.1	+ 0.08
1921.706	291.0	1.45	2	GΣ	+ 0.9	− 0.06
1922.694	290.4	1.64	4	d	+ 0.7	+ 0.12
1922.791	290.6	1.41	3	G Σ	+ 0.9	− 0.11
1923.845	289.6	1.42	2	G Σ	+ 0.3	− 0.10
1924.75	289.3	1.48	4	B	+ 0.4	− 0.04
1924.786	288.5	1.51	2	G Σ	− 0.4	− 0.01
1925.39	289.2	1.55	67	VBs 4, Gr04, Ber014, Lv 11, Plg 2, Prz 2, Dob 2, Bail 1, Berm 10, Phl 3, R 8, Gau 2, Bz 4	+ 0.6	+ 0.03
1925.631	288.6	1.55	3	G Σ	+ 0.1	+ 0.03
1926.764	287.4	1.56	2	G Σ	− 0.7	+ 0.03
1929.91	284.0	1.46	5	Bz − Igounet	− 2.8	− 0.08
1931.736	293.4	1.69	5	M.D. Barbier	+ 7.3	+ 0.14
1932.670	284.6	1.63	5	G Σ	− 1.1	+ 0.09
1937.79	282.3	1.60	3	P. Muller	− 1.4	+ 0.04
1938.01	282.2	1.60	4	P. Muller	− 1.4	+ 0.04
1938.16	282.6	1.48	3	Bz	− 1.0	− 0.08
1939.588	283.34	1.523	1	H. Jeffers (ph)	+ 0.3	− 0.04
1939.708	282.99	1.512	1	H. Jeffers (ph)	0.0	− 0.05
1940.661	281.3	1.60	4	Sémirot	− 1.3	+ 0.04
1942.576	281.52	1.505	1	H. Jeffers (ph.)	−0.3	− 0.06
1942.639	281.19	1.527	1	H. Jeffers (ph.)	− 0.6	− 0.04
1942.672	281.92	1.566	1	H. Jeffers (ph.)	+ 0.1	0.00
1949.513	279.32	1.600	1	H. Jeffers (ph.)	+ 0.1	+ 0.01
1951.532	278.77	1.560	1	H. Jeffers (ph.)	+ 0.3	− 0.04
1951.72	277.2	1.65	5	P. Muller	− 1.2	+ 0.05
1955.74	274.7	1.69	4	P. Muller	− 2.2	+ 0.08
1957.522	277.6	1.65	2	Bos	+ 1.3	+ 0.04
1957.64	275.7	1.54	3	Sagot R.	− 0.5	− 0.07
1959.90	277.2*	1.65	6	GrO		
1961.550	276.3*	1.56	4	Bos	+ 1.5	− 0.06
1961.79	275.0*	1.66	6	hz	+ 0.2	+ 0.03
1963.666	274.2	1.63	4	Wor	+ 0.1	0.00

Table 4. (continued)

1967.72	272.9	1.68	6	Fossat (ph.)	+ 0.2	+ 0.04
1968.91	272.8*	1.60	3	hz	+ 0.6	– 0.04
1969.568	272.9	1.73	3	R.L. Walker Jr.	+ 0.9	+ 0.08
1969.805	272.8*	1.62	4	A.L. Behall	+ 0.9	– 0.03
1970.710	273.2*	1.59	4	A.L. Behall	+ 1.6	– 0.06
1972.048	272.6*	1.64	4	A.L. Behall	+ 1.4	– 0.01
1973.646	270.8*	1.64	4	Wor	+ 0.2	– 0.02
1973.685	266.7	1.72	1	Ole	– 3.9	+ 0.06
1973.785	272.8*	1.65	4	A.L. Behall	+ 2.2	– 0.01
1976.400	269.3	1.64	3	GP	– 0.4	– 0.02
1976.667	270.9*	1.52	2	F. Holden	+ 1.3	– 0.14
1976.738	273.3	1.82	2	V. Erceg	+ 3.9	+ 0.16
1977.518	269.9	1.71	3	R.L. Walker Jr.	+ 0.6	+ 0.04
1978.708	270.4	1.59	2	GP	+ 1.5	– 0.08
1978.775	270.8	1.64	2	V. Erceg	+ 1.9	– 0.03
1980.91	267.5	1.89	1	Le Beau	– 0.6	+ 0.21
1982.627	266.3	1.74	2	J. Lefevre	– 1.2	+ 0.06
1982.634	266.3	1.56	4	GP	– 1.3	– 0.12
1983.637	267.2	1.69	6	GP	– 2.2	+ 0.01
1985.660	267.4	1.72	4	GP	+ 0.9	+ 0.03
1985.680	268.7	1.56	1	DZ	+ 2.2	– 0.13

* Quadrant reversed.

REFERENCES

Bos, W.H.: 1926, *U.O.C.* **68**, 354.
Popović, G., Angelov, T.: 1970, *Bull. Obs. Astron. Belgrade* **124**, 147.

Bull. Obs. Astron. Belgrade N° 137 (1987) UDC 522.3

VARIATIONS OF COLLIMATION AND FLEXURE OF THE BELGRADE LARGE MERIDIAN CIRCLE UNDER THE DAYTIME CONDITIONS

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ABSTRACT: Results of the laboratory examination of the collimation and flexure constants of the Belgrade Large Meridian Circle (LMC) in the periods 1977–1980 and 1984–1985 are presented. Thereby are established: significant effects of the medium in which the instrument is placed; significant systematic differences in the measurements made at different hours of the day; significant seasonal variations; a difference between the laboratory evaluations of these quantities and their values resulting from the regular star observations; and a difference between the values obtained in the two periods. The measuring accuracy in the second period was twice better than the one in the first period.

INTRODUCTION

The first determination of the collimation (c) and of the horizontal flexure (b) of the Belgrade Large Meridian Circle (LMC) was performed in 1964 in order to ascertain them generally and to carry out, if necessary, an adequate rectification of the instrument, before initiating a regular observation of the latitude stars (Šaletić, 1968). Their later determinations served the needs either of the catalogue elaboration and of a daytime observation of the celestial bodies or of the special investigations under various conditions (Mijatov, 1972/73; Dačić, 1984; Stančić, 1986).

The laboratory evaluation of (c) and (b) via horizontally mounted collimators in the first period 1977–1980 helped, first of all, the values of these quantities and their accuracies to be determined at various times of the day which is of a particular interest for the astronomical daytime observations; and second, by to provide information on their steadiness over longer time intervals. The measurements in the second period 1984–1985 allowed a comparison to be made of the values obtained in two different ambiences – for the open and for the closed pavilion – thus providing information of their eventual diverging effect on the two instrument's parameters. In addition, the daytime and the nighttime values were compared, temeprature effects and the seasonal variations were established and the systematic erros in (b) values,were evaluated which have their origin in the collimator displacement.

The derivation of (c) and (b) from the Kustner series observations was performed only during second period. The Kustner series observed during the first period were analysed during the derivation of the MC system (Dačić 1984), hence they are not used in our corelations.

COLLIMATION EVALUATION

The annual means of the laboratory (c) evaluations in the first period (Table 1) reveal the fact that the collimation is rather steady over longer time intermvals. The mean values at clamps E and W are in a good agreement (the c values at clamp E, by sign changing, reduced to clamp W). This finding is even more true after accounting for the temperature effects from Table 4).

A comparison of the annual values from the first period to those of the second one could not be made because the collimation constant had been corrected on the instrument between 1980 and 1984.

The measuring accouracy ϵ_0, computed according to the formula $\epsilon_0 = \pm\sqrt{\frac{\Sigma \nu_i^2}{n-1}}$, where $\nu_i = c_i - \overline{c}$, is well one the level expected with this kind of meridian instrument in dealing with prolonged laboratory measurings with the equimpent used, with the open pavilion and the daytime conditions, amounting to ± 0.011.

The (c) values for different hours of the day (Table 2) show considerable differences for both clamp E and clamp W. It is worth mentioning that the differences in the measurements carried out immediately before and after the Sun's culmination are considerable at both clamps, amounting to about 0ˢ.03. The largest difference in (c) values for both clamp E and clamp W has been found immediately before, and the lowest one immediately after the Sun's culmination.

The (c) values in the night conditions for the clamp E are notably smaller than they are in the daytime conditions, which is not the case for the clamp W. There is an appreciable difference between the clamps E and W values for the night conditions, the clamp W value,

Table 1. Mean annual collimation (c) and flexure (b) values in the period 1977–1980. t stands for mean temepratues, n for numer of measurements, ϵ_0 for m.r.s. error for **c** and ϵ'_0 for m.r.s. error for **b**

year	c						b					
	KE			KW			KE			KW		
	c	$\bar{t}$	n	c	$\bar{t}$	n	b	$\bar{t}$	n	b	$\bar{t}$	n
1977							$-0''.56$ ± 10	$16^{\circ}.4$	20	$-1''.07$ ± 15	$18^{\circ}.2$	16
1978	$+0^{s}.1118$ ± 21	$21^{\circ}.6$	18	$+0^{s}.1476$ ± 11	$19^{\circ}.2$	47	−0.34 ± 32	22.2	12	−0.99 ± 12	18.7	34
1979				+0.1671 ± 7	15.8	63				−1.01 ± 9	16.1	63
1980	+0.2019 ± 9	16.6	27	+0.1609 ± 10	6.3	25	−0.65 ± 12	17.1	23	−0.81 ± 22	5.4	22
mean value	+0.1568 ± 15	19.1	45	+0.1585 ± 9	13.7	135	−0.55 ± 9	18.0	55	−0.98 ± 7	14.9	135
ϵ_0	±0.0101			±0.0110								
ϵ'_0							±0.47			±0.42		

Table 2. Collimation within a day for the period 1978–1980. Notations as in Table 1.

conditions	hour of the day	KE				KW			
		c	ϵ_0	$\bar{t}$	n	c	ϵ_0	$\bar{t}$	n
d	immediately before the Sun's culmination	$+0^{s}.1818$ ± 21	$\pm 0^{s}.0048$	$24^{\circ}.0$	5	$+0^{s}.1160$ ± 15	$\pm 0^{s}.0051$	$14^{\circ}.5$	12
a	immediately after the Sun's culmination	+0.1541 ± 20	±0.0068	23.5	12	+0.1458 ± 16	±0.0063	18.0	15
y	between $11^h - 13^h$	+0.1523 ± 17	±0.0042	12.4	6	+0.1710 ± 18	±0.0041	8.3	5
	the rest of the day	+0.1935 ± 14	±0.0055	15.2	15	+0.1652 ± 7	±0.0063	14.4	88
night	in the night condition	+0.1270 ± 40	±0.0107	19.9	7	+0.1660 ± 20	±0.0079	18.0	15

Table 3. Flexure within a day for the period 1977–1980. Notations as in Table 1.

Conditions	hour of the day	KE				KW			
		b	ϵ'_0	$\bar{t}$	n	b	ϵ'_0	$\bar{t}$	n
d	immediately before the Sun's culmination	$-0''.64$ ± 24	$\pm 0''.57$	$17^{\circ}.6$	11	$-1''.17$ ± 18	$\pm 0''.38$	$15^{\circ}.9$	19
a	immediately after the Sun's culmination	−0.38 ± 26	±0.43	22.6	14	−0.97 ± 16	±0.39	16.8	23
y	between $11^h - 13^h$	−0.84 ± 13	±0.43	13.0	7	−0.74 ± 37	±0.54	18.4	5
	the rest of the day	−0.52 ± 12	±0.47	17.5	19	−0.96 ± 8	±0.44	14.6	81
night	in the night condition	−0.62 ± 27	±0.36	14.7	4	−0.70 ± 37	±0.24	12.7	7

however, being larger than the one for the clamp E, unlike what one finds for the daytime conditions.

The accounting for the temperature effects from Table 4 does not result in a substantial imroving of the differences stated either at clamp E or clamp W, whereas it does increase their mutual divergence.

The ϵ_0 values for different hours of the day under the daytime conditions and for different clamp positions are in a rather good agreement, being about twice smaller than those relating to the entire period. It is remarkable that the ϵ_0 values are notable larger for the nighttime than for the daytime conditions, this especially being true of the clamp E.

Although the presence of the actual temperature effects only at the clamp E might be talked about, we nevertheless discussed the diverging of the measured values from the computed ones through employing Table 4 parameters in all the cases (clamps, E, W. E+W) in order to derive eventual seasonal variations of these quantities throughout the year (Table 3). Seasonal variations have been disclosed in all the instances. The largest ones take place at the time of the transition from the winter in to the spring, and the lowest at the time of the transition from the summer into the autumn seasons.

As already related, the measurements in the second period were performed with both open and closed pavilion, mostly under the daytime conditions. Table 8 shows that there is a distinct temperature effect for the closed pavilion case in all the instances (E, W, E+W) that effect being considerably stronger than it is in the open pavilion. The accounting for these effects in the Table 7 values does not bring about any substantial diminishing of the differences obtained with either the open or the closed pavilion.

The accuracy ϵ_0 (Table 7) for the open pavilion in the second period is nearly twice better than in the first period, attaining ± 0.0053. On the other hand, no appreciable difference in ϵ_0 is stated between the open and the closed pavilion determinations.

Seasonal variations (Table 9) are present, like ones in the first period, at both open and closed pavilion, the largest appearing at the time of the transition from the winter into the spring season. The seasonal variations in this second period are markedly smaller than in the first period, for the open pavilion are smaller than for the closed one, suggesting different effects of the ambient features.

The quanatities c_0 (Table 10) are the laboratory values employed in the processing of the Kustner series. The divergence Δ_c between the collimation values determined from the star observations and the laboratory measurements are considerable, increasing the difference between the values at the two clamps.

FLEXURE.

The mean annual value (b), (Table 1) in the first period for the clamp E is larger than the one in the clamp W by about $0''.4$. By eliminating the temperature effect from Table 4 from these values the difference between the E and W clamps values gets smaller by about 20%.

Table 4. Linear temperature effect on collimation ($c_i = c_0 + \alpha(t_i - t_0)$) and flexure ($b_i = b_0 + \alpha(t_i - t_0)$) for the period 1977–1980.

	KE	KW	KE + KW		KE	KW	KE + KW
c_0	$+0^{s}.1640$ ± 82	$+0^{s}.1601$ ± 42	$+0^{s}.1610$ ± 38	b_0	$-0''.562$ ± 91	$-0''.974$ ± 64	$-0''.860$ ± 55
α	−0.0023 ± 12	+0.0010 ± 5	+0.0004 ± 5	α	+0.036 ± 15	−0.005 ± 8	+0.006 ± 7
t_0	19.1	13.7	16.0	t_0	18.0	14.9	16.3
n	45	135	180	n	55	135	190

Table 5. Seasonal variation in collimation (c) and flexure (b) in the period 1977–1980.

	c			b		
months	KE	KW	KE + KW	KE	KW	KE + KW
XII–II	$-0^{s}.0117$ (3)	$-0^{s}.0076$ (29)	$-0^{s}.0052$ (32)	$-0''.431$ (2)	$-0''.272$ (29)	$-0''.300$ (31)
III–V	+ 0.0652 (2)	+ 0.0184 (51)	+ 0.0202 (53)	+ 0.256 (1)	+ 0.191 (46)	+ 0.311 (47)
VI–VIII	−0.0055 (28)	−0.0136 (36)	−0.0082 (64)	−0.052 (24)	−0.165 (30)	−0.199 (54)
IX–XI	+ 0.0033 (12)	−0.0110 (19)	−0.0119 (31)	+ 0.066 (28)	+ 0.147 (30)	+ 0.081 (58)

The accuracy ϵ'_o, computed according to the formula $\epsilon'_o = \pm 0.625 \frac{|b_{NS} - b_{SN}|}{n}$ where b_{NS} and b_{SN} are values measured in the course of a set of measurements of (b). After the correction for the difference $\Delta = b_{NS} - b_{SN}$ oppled the accuracies associated with both clamps remained essentially the same, amounting to $\pm$ 0."41. This amount is considerably larger than what one might expected.

Table 3 makes it apparent that there are significant diurnal variations in the (b) values. The largest differences are associatiated with measurements immediately before and after the Sun's clumination. The elimination of the temperature effects taken from Table 4 results in differences in (b) values at the clamp E, as well as those in the mean values at the clamp E and the clamp W, being sensibly diminished. The ϵ'_o values, pertaining to different hours of the day, are somewhat larger for the clamp E than for the clamp W. Unlike collimation, ϵ'_o for the night conditions is here markedly lower than in for the daytime conditions.

Conspicuous seasonal variations (Table 5) are noted in all the instances (E, W, E+W). The largest variations occur at the time of the transition from the winter into the spring seasons, in analogy to what has been stated with the columination.

Substantial systematic errors in the laboratory measurements of (b) are due to the collimators' shifting Δ ($\Delta = b_{NS} - b_{SN}$). The sharpest Δ (Table 6) takes place immediately before the Sun's culmination and in the period 11^h to 13^h, being, surprisingly, essentially negligible immediately after the Sun's culmination, a fact to be particularly pointed out. The displacement Δ is larger at the clamp E than at the clamp W, which may produce a systemeatic difference of about 0."06 in the (b) determinations at the two clamps.

The (b) values in the second period (Table 7) for the same clamps differ among themselves for the open and the closed pavilion. The measuring accuracy ϵ'_o for the open pavilion in the second period is twice higher than in the first period, amounting to $\pm$ 0."22. It transpires also that the ϵ'_o values are disttictly larger for the closed than for the open pavilion.

The annual flexure variation, if both periods are taken into account, is about 0."1, with a tendency towards decreasing in the absolute value.

A celar temperature effect is evident in (b) (Table 8) for the closed pavilion, while it is almost missing in the (b) values for the open pavilion being another confirmation of the earlier findings (Mijatov, 1972/73; Dačić, 1984; Stančić, 1986).

Table 7. Collimation and flexure in the period 1984–1985. Notations as in Table 1. (OP – open vavilion, ZP – closed pavilion).

	KE–OP	KE–ZP	KW–OP	KW–ZP
c	0.ˢ0315 ± 9	−0.ˢ0135 ± 11	+ 0.ˢ0415 ± 9	+ 0.ˢ0285 ± 18
ϵ_o	±0.0050	±0.0061	±0.0056	±0.0052
$\bar{t}$	20.1	13.6	21.8	16.9
n	32	31	39	8
b	−0.36 ± 9	−0.71 ± 9	− 0.51 ± 8	−0.41 ± 29
ϵ'_o	±0.21	±0.30	±0.24	±0.36
$\bar{t}$	20.2	13.8	22.4	17.9
n	32	32	32	9

Table 6. Collimator displacement (Δ) in the period 1977–1980.

conditions	hour of the day	KE	KW	KE + KW
d	immediately before the Sun's culmination	−0."69 (11)	−0."33 (19)	−0."47 (30)
a	immediately after the Sun's culmination	+ 0.14 (14)	−0.04 (23)	+ 0.02 (37)
y	between 11^h – 13^h	−0.25 (7)	−0.60 (5)	−0.39 (12)
	the rest of the day	−0.34 (19)	−0.03 (81)	−0.09 (100)
night	in the night conditions	+ 0.13 (4)	−0.35 (7)	−0.18 (11)
	Σ	−0.24 (55)	−0.11 (135)	−0.15 (190)

Table 8. Linear temperature effect on collimation and flexure in the period 1984–1985.

	KE–OP	KE–ZP	KW–OP	KW–ZP	(KE+KW)–OP	(KE+KW)–ZP
c_0	$+0^{s}.0315$ ±43	$-0^{s}.0135$ ± 43	$+0^{s}.0425$ ± 41	$+0^{s}.0285$ ± 88	$+0^{s}.0375$ ± 40	$-0^{s}.0049$ ± 45
α	+0.0005 ±10	+0.0025 ± 5	+0.0015 ± 7	+0.0050 ± 13	+0.0013 ± 6	+0.0031 ± 5
t_0	20.1	13.6	21.8	16.9	21.0	14.3
n	32	31	39	8	71	39
b_0	$-0''.356$ ±93	$-0''.712$ ± 73	$-0''.508$ ± 77	$-0''.405$ ± 370	$-0''.432$ ± 60	$-0''.645$ ± 93
α	+0.006 ±21	+0.036 ± 9	+0.017 ± 14	+0.048 ± 54	+0.009 ± 12	+0.040 ± 11
t_0	20.2	13.9	22.4	17.9	21.3	14.7
n	32	32	32	9	64	41

Table 9. Seasonal variations in collimation (c) and flexure (b) in the period 1984–1985.

	c		b	
months	(KE+KW)–OP	(KE+KW) – ZP	(KE+KW)–OP	(KE+KW)–ZP
XII–II	–0.0062 (2)	–0.0090 (6)	+ 0.322 (2)	+ 0.085 (6)
III–V	+ 0.0028 (12)	+ 0.0042 (14)	+ 0.002 (12)	–0.163 (14)
VI–VIII	–0.0007 (43)	+ 0.0001 (16)	–0.052 (37)	+ 0.092 (18)
IX–XI	+ 0.0006 (14)	–0.0101 (3)	+ 0.097 (13)	+ 0.038 (3)

Table 10. Kustner series from the period 1984–1985, drawn in; c_0 – laboratory collimation value, Δc – difference of the collimation resulting from the star observation and its laboratory value, a – vertical fluxure, other notations as in Table 1.

clamp	c_0	Δc	$c=c_0+\Delta c$	$\bar{t}$	n	a	b	$\bar{t}$	n
KE	$+0^{s}.039$ ± 2	$+0^{s}.049$ ± 23	$+0^{s}.088$ ± 23	$20^{\circ}.8$	8	$+2''.61$ ± 22	$-1''.59$ ± 8	$21^{\circ}.2$	7
KW	+0.053 ± 2	–0.036 ± 24	+0.017 ± 24	21.3	6	–0.71 ± 23	–2.15 ± 9	15.2	4

As seen from Table 9 in the second period seasonal variations are present, larger at the time of the transition from the winter into the spring season, as it to the case for the first period.

The values of the collimator displacements at clamp E are for the open pavilion $-0''.14$, (32), for the closed pavilion $-0''.10$ (32). No evaluation has been made for the closed pavilion having regard to the measurements for the closed pavilion being few. The Δ values obtained for the clamp E, clamp W AND FOR E + W are: – $0''.12$ (64), $+0''.09$ (41) and $-0''.04$ (105), respectively.

Significant differences are found between the (b) values resulting from the star observation (Table 10) and those appearing in Table 7, about 1.2 at the clamp E and about 1.6 at the clamp W. Clear differences are noticeable also between the amounts of the vertical **a** and the horizontal **b** flexures at both clamp positions (Table 10).

The systematic differences associated with **(b)** obtained from the laboratory examination at the two clamps E and W are notably scaled down by eliminating from them : the temperature effects and the collimator's displacement for the first period, and the collimators' displacement for the second period. It transpires that in the first period beside the effects already referred to, there were at work other factors producing the difference in **(b)** values by about $0''.2$ at both clamp E and clamp W, whereas in the second period the collimator displacement generated the predominant effect.

THE EFFECT OF AMBIENCE ON THE COLLIMATION AND FLEXURE

Our laboratory examination of (c) and (b) enabled comparison to be made of the results obtained: with the open and closed pavilion under the daytime conditions and with the open pavilion under the night conditions.

The open pavilion under the daytime conditions is a dynamical medium throughout which the conditions change continuosly with times, highly intensely, depending on the joint action of the external factors: insolation, air streaming inside pavilion, wind etc. and the internal thermal effects.

The closed pavilion under the daytime conditions is a rather stable medium, with conditions inside it undergoing slower changes, being a consequence above all, of the thermal radiation of the pavilion walls which is the to the insolation and to the temperature changes of the outside air.

The open pavilion under the nighttime conditions to a certain degree is a dynamical medium, subjected to external effects but considerably less than under the daytime conditions, since the principal effect – insolation – is absent.

The temperature effects should be, in principle, larger for a closed pavilion, as it constitutes a comparatively stable medium, its temperature being almost completely transmited to the objects inside it, than for an open pavilion which forms a dynamical medium, the conditions within which undergoing continuos changes. The othered temperature effects found (Table 8) support this statement.

Prominent seasonal variations have been established with the open paviolion at the time of the winter season passing over into spring season in both collimation and flexure, these variations being, however, clearly lesser in the second period than in the first. Nevertheless, no systematic difference of any significance hes been found between the seasonal variations associated with open and the closed pavilion.

Distinct variations in the colimators' displacement Δ in a relatively short interval – comprising the time immediately before and after the Sun's culmination – are explanable by the conditions having considerably been changed after the Sun has crossed the meridian. The value of Δ has been found to decrease immediately after the Sun's culmination, accordingly, the insolation acts contrary to the joint effect of all other factors which generate this displacement. No noteworthy differences in Δ have been found between the open and the closed pavilion.

A comparison of the (c) and (b) daytime determinations in the open pavilion with those made during a night showed that there were no clear-cut differences; however, one should bear in mind that our night determinations were performed early in the evening when this medium had not time enough to stabilize itself sufficiently.

The measuring accuracy in different media does not always comply with what one could have expected on considering general characteristics of the conditions.

As evident, the accuracy in the second period was twice higher, whereas the seasonal variations in (c) and (b) and the collimations' displacement were markedly smaller than in the first period, which testifies to the measuring conditions in the second period having been sensibly more favourable.

CONCLUSION

The laboratory measuring of the collimation and flexure of LMC are perfomable with satisfactory accuracy in the open pavilion under daytime conditions. The accuracy varies with the hours at which the measurements are carried out.

The measures of these parameters may be affected by many systematic effects, the intensity of which is variable depending on the conditions prevailing at the time of measuring. The presence of significant differences is found for different seasons, in particular in the periods of transition from winter into spring. Differences occur also for various hours of the day, in particular immediately before an after the Sun's culmination.

These investigations are suggestive concerusly a need for more intensive regular daytime laboratory determination of the collimation and flexure of LMC for the open pavilion in order to pursue their variations, those seasonal and daily in the first place. Particularly interesting seem the measurements at the time of transition from the winter into the spring season and those immediately before and after the Son's culmination.

Steps should be undertaken to prevent too strong effects of the Sun at its crossing over the meridian since the existing screen proved insufficient to adequately protect against its radiation. This probably could to a certain degree be achieved by covering the existing screen by some reflecting material.

REFERENCES

Dačić, M.: 1984, *Bull. Obs. Astron. Beograd,* **134,** 1.
Mijatov, M.: 1972/73, *Bull. Obs. Astron. Beograd,* **125,** 19.
Stančić, Z.: 1986, *Bull. Obs. Astron. Beograd,* **136,** 120.
Šaletić, D.: 1968, *Publ. Obs. Astron. Beograd,* **14,** 95.

BIBLIOGRAPHY OF PAPERS OF THE BELGRADE ASTRONOMICAL OBSERVATORY RESEARCH ASSOCIATES PUBLISHED IN THE PERIOD 1984–1986

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SUMMARY: Bibliography of papers of the Belgrade astronomical observatory research associates published in the period 1984–1986 is presented and analyzed.

In the three years period 1984–1986 results of the present and retired associates of the Belgrade Astronomical Observatory were published under 211 titles (articles, notes, abstracts, observations data) in a number of domestic and foreign periodicals and editions. The following tabulation gives the relevant information.

Year	Number of titles appearing in the editions of			
	Belgrade Astron. Observatory	other establishments in Yugoslavia	establishments abroad	Total
1984	11	5	21	37
1985	24	27	43	94
1986	21	11	48	80
Total	56	43	112	211

As evident, most of the papers, 53.1%, were published abroad and no more than 26.5% in the Observatory's own editions.

We continue the paper numeration which was introduced in the previous bibliography published in the Bull.Obs. Astron. Belgrade, No. 135, 1985, pp. 64–70.

1984.

– In the Bull.Obs. Astron. Belgrade, **134**, 1984 :

206. M.Dačić, Instrument system of the Belgrade Meridian Circle, 1–8.
207. M.Mijatov, V.Trajkovska, Analysis of some characteristics of the Vertical Circle, 9–15.
208. Đ.Bozhichkovich, M.Mijatov, Investigation of the divided circle of the Belgrade Large Vertical Circle, 16–25.
209. R.Grujić, G.Teleki, Investigation of wind effects on the Belgrade latitude observations, 26–31.
210. A.Kubičela, I.Vince, Effects of extrafocal observation with the Solar Spectrograph of the Belgrade Astronomical Observatory. II. Cases of various wavelength and space–resolutions, 37–38.
211. G.Teleki, Progress report on the astronomical refraction, 39–47.
212. V.Erceg, Les orbites de quatre étoiles doubles visuelles (ADS 2111=BU 83, ADS 2609 AB = BU 787 AB, ADS 3058 = HU 302, GLE 1), 54–57.
213. D.Zulević, Orbits of two visual binaries, 58–59.
214. G.M.Popović, Micrometer measures of double stars (Series 37), 60–68.
215. D.Zulević, Micrometer measures of double stars (Series 38), 69–77.

– In Proc. XII SPIG, Šibenik, Yugoslavia, 1984 :

216. M.S.Dimitrijević, Energy distribution in the near–threshold positron ionization of atoms, 109–111.
217. M.S.Dimitrijević, P.Grujić, An old two–electron–system revised, 112–115.
218. A.A.Mihajlov, M.S.Dimitrijević, Determination for the cross section for elastic scatering of the electrons on cut off Coulomb potential in quasi classical method, 416–419.
219. A.A.Mihajlov, M.S.Dimitrijević, M.M.Popović, Determination of electrical conductivity of plasma by the use of classical transport cross sections calculated on the basis of the cut off coulomb potential model, 420–423.
220. M.S.Dimitrijević, The trajectory effect and broadening of neutral atom lines, 465–468.
221. M.S.Dimitrijević, The trajectory effect in calculations of the phase shift for binary collisions and broadening of neutral atom lines, J.Phys. B., **17**, 1984, L 283 – L 287.

222. M.S.Dimitrijević, N.Konjević, On the dependence of Stark widths and shift on the ionization potential, Z.Naturforsch., **39a**, 1984, 553–555.
223. M.S.Dimitrijević, P.V.Grujić, Langmuir's helium model revisited, Z.Naturforsch., **39a**, 1984, 930–938.
224. M.S.Dimitrijević, S.Sahal–Bréchot, Stark broadening of neutral helium lines, J.Quant. Spectrosc. Radiant Transfer, **31**, 1984, 301–313.
225. M.S.Dimitrijević, Electron impact line widths of the resonance lines Be–like ions, Astron. Astrophys., **131**, 1984, 327–328.
226. M.S.Dimitrijević, S.Sahal–Bréchot, Stark broadening of neutral helium lines of astrophysical interest. Regularities within spectral series, Astron. Astrophys., **136**, 1984, 289–298.
227. I.Vince, M.S.Dimitrijević, V.Kršljanin, Collision broadening and Solar limb effect: NaI $3p^2Po$–ns^2S lines, VIII Int. Conf. Spectr.Line Shapes, Aussois 1984, F4.
228. M.S.Dimitrijević, N.Konjević, Elektronnoe ushirenye spektral'–nyh linij ionizirovannyh atomov, Proc. Fotoprocesi, vozbuzhdeniya i jonizacii, Leningrad, 1984, 41.
229. M.S.Dimitrijević, N.Konjević, O Shtarkovskom ushirenii linij nejtral'nyh atomov rubidiya, kadmiya i cinka, Proc. Fotoprocesi vozbuzhdeniya i jonizacii, Leningrad, 1984, 47.
230. N.Konjević, M.S.Dimitrijević, W.L.Wiese, Experimental Stark widths and shifts for non–hydrogenic spectral lines of ionized atoms (a critical review and tabulation of selected data), J.Phys. Chem. Ref. Data, **13**, 1984, 649–686.
231. N.Konjević, M.S.Dimitrijević, W.L.Wiese, Experimental Stark widths and shifts for non–hydrogenic spectral lines of neutral atoms (a critical review and tabulation of selected data), J.Phys. Chem. Ref. Data **13**, 1984, 619–647.
232. V.Protić–Benišek, Merkurovi prolazi i paralaksa Sunca (Transits of Mercury and Solar parallax), Publ. Obs. Astron. Belgrade, **32**, 1984, 1–159.
233. V.Zappala, M.D. i Martino, Z.Knežević, G.Đurašević, New evidence for phase effect on asteroid lightcurve shape: 21 Lutetia, Astron. Astrophys., **130**, 1984, 208–210.
234. V.Zappala, P.Farinella, Z.Knežević, P.Paolicchi, Collisional origin of the asteroid families: mass and velocity distributions, Icarus, **59**, 1984, 261–285.
235. V.Zappala, Z.Knežević, Rotation axes of asteroids: results for 14 objects, Icarus, **59**, 1984, 436–455.
236. S.Ninković, Opredelemye mass sharovyh skloplenij po sopstvennym dvizheniyam, Astrofizika, Erevan, USSR, **20**, 1984, 283–288.
237. D.Zulević, Orbite nouvelle ADS 2446, Circ. Inf. 93, IAU Comm. 26, 1984.
238. V.Erceg, Orbite nouvelle ADS 5707, Circ. Inf. 93, IAU Comm. 26, 1984.
239. V.Erceg, D.Olević, Orbite nouvelle ADS 8718 = Hu 641, Circ. Inf. 94, IAU Comm. 26, 1984.
240. (R.Grujić), (M.Đokić), (N.Đokić), (S.Šegan), (R.Krga), Daily values of latitudes, VZD–Belgrade, Monthly Not. of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1984.
241. (M.Jovanović), (B.Jovanović), (L.Đurović), Daily values of UTO–UTC. Transit intrument – Belgrade, Monthly Not. of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1984.
242. M.Jovanović, B.Jovanović, L.Đurović, Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzhba vremeni BL (Belgrad), Vsemirnoe vremya, Byulleten' E37–E40, Moskva, 1984.

1985.

– In the Bull. Obs. Astron. Belgrade, **135**, 1985:

243. A.Yu.Yatsenko, G.Teleki, Harzer's work on astronomical refraction viewed from today's standpoint, 1–15.
244. A.Kubičela, I.Vince, Z.Ivanović, Effects of extrafocal observation with the solar spectorgraph of the Belgrade Astronomical Observatory. III. Integration of the limb effect, 21–24.
245. S.Jankov, Instrumental profile of the Belgrade solar spectrograph, 25–31.
246. G.Đurašević, J.Arsenijević, Z.Knežević, Short–term variations of o And? , 32–39.
247. G.Teleki, Growth of the knowledge of stallar positions, 40–44.
248. V.Erceg, Orbites de trois étoiles doubles visuelles (ADS 3686, IDS 05312S5108, ADS 5707AB), 45–46.
249. S.Sadžakov, M.Dačić, Observations of the Sun and planets with the Belgrade Large Meridian Circle, 47–53.
250. M.Protitch–Benishek, Comet astrographic positions obtained at Belgrade Astronomical Observatory during 1977–1982, 54–55.
251. H.Debehogne, V.Protitch–Benishek, 135 precise astrometric positions of minor planets obtained at the GPO telescope of ESO, La Silla, 56–63.
252. G.Teleki, Bibliography of papers of the Belgrade Astronomical Observatory research associates published in the period 1980–1983, 64–70.

– In the Proc. of the VII National Conf. of Yugoslav Astronomers, Publ. Astron. Society „Rudjer Bošković", Belgrade, 4, 1985:

253. M.S.Dimitrijević, A.Tomić, Radovan Danić – a popularizer of astronomy: (I) Printed papers, 41–45.

254. A.Tomić, M.S.Dimitrijević, Radovan Danić – a popularizer of astronomy: Lectures and courses, 47–49.
255. G.M.Popović, A contribution to the knowledge of astronomical terminology by the end of the XVIII century in slavenoserbian language, 111–113.
256. V.Trajkovska, A note on Copernicus from 1837, 127–128.
257. G.Teleki, O.Atanacković, Growth of knowledge of astronomical refraction, 151–155.
258. V.Kršljanin, Microturbulence and stellar spectral lines, 177–179.
259. S.Sadžakov, M.Dačić, Position determination of stars in the neighbourhood of radio–sources (abstract), 181.

– In the Proc. of the VI National conf. of Yugoslav Astronomers, Publ. Obs. Astron. Belgrade, **33**, 1985:

260. M.S.Dimitrijević, Astrophysical significance of spectral line shapes investigation, 11–14.
261. I.Vince, M.S.Dimitrijević, Influence of different line broadening mechanism on the limb–effect within NaI ($4s^2S$–np^2P^o) series, 15–18.
262. Z.Ivanović, I.Vince, Correction to the solar line–of–sight velocities for topocentric motion of the observer, 19–22.
263. A.Kubičela, M.Rakić, Photodiode PS–100–30 as a position sensor in astronomy, 23–27.
264. S.Ninković, A contribution to the study of the structure and dynamics of the galactic halo (abstract), 31.
265. S.Ninković, Results of the galactocentric orbit calculation for a globular cluster NGC 5466, 32–35.
266. J.Arsenijević, Seasonal variation of the Hvar extinction coefficients, 36–40.
267. R.Grujić, R.Krga, Z.Stančić, „Night error" in the Belgrade latitude observations made in the period 1960–1980, 62–65.
268. G.Teleki, R.Grujić, Effects of the level bubble length variation on the latitude values, 66–69.
269. M.Đokić, Correction to the angular value of the screw revolution of the Belgrade Zenith–telescope micrometer derived from latitude observations, 70–74.
270, O.Atanacković, Preliminary investigation of the image motion at the Belgrade Observatory, 83–87.
271. G.M.Popović, The IDS triple systems, 88–91.
272. V.Kršljanin, Contemporary cosmology and philosophy, 107–110.
273. S.Ninković, Teaching astronomy in the secondary schools, 116–117.

– In the Proc. Coll. „Collisions et rayonnement", Orleans, France, 1985 :

274. O.Atanacković, E.Simonneau, Effects of elastic collisions on the local frequency redistribution in the transfer of resonant line photons, 1985, P3.
275. M.S.Dimitrijević, N.Konjević, A simple formula for estimating Stark broadening parameters of neutral atom lines, P21.
276, M.S.Dimitrijević, S.Sahal–Bréchot, L.elargissement Stark des raies du potassium neutre, P22.
277. M.S.Dimitrijević, Truong–Bach, Sur l'inegalité des largeur Stark a l'interieur d'un multiplet ou supermultiplet de l'argon, P23.

– In the Proc. XVII ICPIG, Budapest, Hungary, 1985:

278. A.A.Mihajlov, M.S.Dimitrijević, M.M.Popović, Determination of electrical conductivity of plasma on the basis of the cut–off Coulomb potential model, 357.
279. M.S.Dimitrijević, V.Kršljanin, Semiempirical Stark shifts of ion lines, 975.
280. M.S.Dimitrijević, S.Sahal–Bréchot, Stark broadening of NaI lines: regularities within a spectral series, 978.
281. M.S.Dimitrijević, Dependence of Stark width and shifts on the ionization potential: np^{k-1} $(n+1)s$–np^k resonance transitions, Astron. Astroph., **145**, 439–442.
282. M.S.Dimitrijević, S.Sahal–Bréchot, Stark, broadening of HeI lines of astrophysical interest: regularities within spectral series and influence of Debye shielding, Spectral Line Shapes III, W. de Gruyter, Berlin, New York, 1985, 53–54.
283. I.Vince, M.S.Dimitrijević, V.Kršljanin, Collision broadening and solar limb effect: Na I $3p^2P^o$–ns^2S, Spectral Line Shapes III, W. de Gruyter, Berlin, New York, 1985, 649–650.
284. I.Vince, M.S.Dimitrijević, V.Kršljanin, Pressure broadening and solar limb effect. Progress in Stellar Spectral Line Formation Theory, D.Reidel Publ. Comp., Dordrecht, Boston, Lancaster, 1985, 373–380.
285. M.S.Dimitrijević, S.Sahal–Bréchot, Comparison of measured and calculated Stark Broadening parameters for neutral–helium lines, Phys. Rev.A., **31**, 1985, 316–320.
286. M.S.Dimitrijević, S.Sahal–Bréchot, Stark broadening of neutral sodium lines, J.Quant. Spectrosc. Radiant Transfer, **34**, 1985, 149–161.
287. M.S.Dimitrijević, P.Grujić, Classical spectrum of an oscillatory helium model, Fizika, Zagreb, **17**, 1–6.
288. M.S.Dimitrijević, Milutin Milanković i pokušaj objašnjenja Majkelson–Morlijevog ogleda, Matematičko fizički list, Zagreb, 1/ 140, 1984/ 1985, 5–9.
289. A.Mihajlov, M.Dimitrijević, D.Đorđević, Kvaziklasično i klasično određivanje čestica na odsečnom kulonovom potencijalu, IV Jugosl. sastanak o fizici atomskih sudara, Plitvice, 1985, C2.

290. S.Ninković, On tidal radius determination for a globular cluster. Astron. Nachr., **306**, 1985, 237–239.
291. G.Teleki, Atmosfernye vliyaniya i vybor mest dlya astronomicheskih stancij, Kinematika i fizika nebesnyh tel, Kiev, **1**, 2, 85–91.
292. P.Savić, G.Teleki, Origin and dynamics of Earth's core, Acta Geodaet., Geophys. et Monatinst, Hung., Budapest, **20**, 1985, 13–27.
293. O.Atanacković, Le troisième volume d'Epitome fundamentorum astronomiae, Bull. Inf. CDS, Strasbourg, **28**, 1985, 15–16.
294. J.Arsenijević, A possible eruptive event on M–supergiant Mi Cephei, Astron. Astrophys., **145**, 1985, 430–432.
295. Z.Knežević, P.Farinella, Recent work on asteroid families, XIX IAU Gen. Assembly, Commission 15, New Delhi, 1985.
296. S.Ninković, On the structure and mass of the galactic halo, Astrophysics and Spece Science, **110**, 1985, 379–391.
297. S.Ninković, P.Brosche, M.Geffert, A.R.Klemola, One more space motion of a globular cluster: NGC 4147, Astronomical Journal, **90**, 1985, 2033–2038.
298. S.Ninković, Orbital excentricity study for the spherical component of our Galaxy, XIX Gen. Assembly, Commission 33, New Delhi, 1985.
299. I.Pakvor, Progress report on the Belgrade catalog of absolute R.A.s of bright polar stars, XIX Gen. Assembly, Comm. 8, New Delhi, 1985.
300. V.Protich–Benishek, Observations of comets Panther and Chyrimov–Gerasimenko from Belgrade Astronomical Observatory, Minor Planet Circular Nos. 9437, 9514, 1985.
301. V.Protitch–Benishek, Precise astrographic positions of Comet P/Halley from Belgrade Observatory, Minor Planet Circular, Nos. 10209, 10210, 10211, 1985.
302. V.Protitch–Benishek, Precise astrographic positions of comet Giacobini–Zinner observed at Belgrad Astronomical Observatory, Minor Planet Circular, Nos. 9981, 9988, 9989, 1985.
303. S.Sadžakov, M.Dačić, Predvarytel'nye rezultaty nablyudenij programmy dvojnyh i opornyh zvezd v okrestnosti radioistochnikov, XXIII Astrometricheskaya Konf., Leningrad, 1985.
304. S.Sadžakov, M.Dačić, Position Determination of stars in the neighbourhood of radio–sources, Bull. appl. math., Budapest, 296/85 (XXXVII), 1985.
305. S.Sadžakov, M.Dačić, Preliminary results of observations of double stars and the stars near radio–sources with the Belgrade Meridian Circle, XIX IAU Gen. Assembly, Comm. 8, New Delhi, 1985.
306. S.Sadžakov, M.Dačić, Nablyiudeniya bol'shih planet na meridiannom kruge v Belgrade, XXIII Astrometricheskaya Konf., Leningrad, 1985.
307. S.Sadžakov, Analysis of systematic $\Delta\,\delta_\alpha$ deviations of GCLS and AGK3 catalogues from 20 catalogues obtained from latitude observations, XIX IAU Gen. Assembly, Commission 8, New Delhi, 1985.
308. G.Teleki, Astrometric site selection, XIX IAU Gen. Assembly, Commission 50, New Delhi, 1985.
309. G.Teleki, Recent investigations of astronomical refraction, XIX IAU Gen. Assembly, Commission 8, New Delhi, 1985.
310. G.Teleki, On the Belgrade catalogue of declinations of 308 polar stars, XIX IAU Gen.Assembly, Commission 8, New Delhi, 1985.
311. S.Ninković, M.Geffert, S.Wagner, Photographic observations of minor planets, Acta Astronomica, **35**, 1985, 181–182.
312. V.Tajkovska, First results of major planets observations with the Belgrade Vertical Circle, XIX IAU Gen. Assembly, Commission 8, New Delhi 1985.
313. D.Olević, V.Erceg, Orbites nouvelles, ADS 8926, Circ. Inf. 95, Comm. 26, UAI, 1985.
314. V.Erceg, D.Olević, Orbites nouvelles SLR 19, Circ. Inf. 96, UAI Comm. 26, 1985.
315. G.M.Popović, D.Zulević, Etoiles doubles nouvelles, Circ. Inf. 96, UAI Comm. 26, 1985.

– In Proc. VIII Gen. Assembly, Union of Societes of Mathematicians, Physicists and Astronomers of Yugoslavia (VIII Kongres matematičara, fizičara i astronoma Jugoslavije – Saopštenja), Priština, 1985.

316. V.Trajkovska, Analiza rezultata posmatranja planeta na VVK u Beogradu, 335.
317. S.Ninković, G.Popović, Tamni pratioci zvezda, 339.
318. A.Kubičela, Dva prodora u dinamici Sunčeve fotosfere, 339.
319. A.Kubičela, M.Karabin, Z.Ivanović, Merenje radijalnih brzina tačaka na Sunčevom disku, 340.
320. V.Kršljanin, Zastupljenost natrijuma u Sunčevoj fotosferi, 340.
321. I.Vince, Uticaj sudarnih procesa na limb–efekt u pegama.Linija $3p\,^2P^o - 6s\,^2S$, 341.
322. J.Arsenijević, S.Jankov, G.Đurašević, I.Vince, Promene optičke polarizacije nekih Be zvezda, 341.
323. M.Vukičević–Karabin, J.Arsenijević, Aktivni fenomeni na Suncu i zvezdama, 342.
324. S.Sadžakov, M.Držić Sistematske greške sopstveih kretanja u katalozima GC, IKŠZ i AGK3, 344.
325. A.A.Mihajlov, M.S.Dimitrijević, Uticaj jon–atomskih sudara na apsorpciju zračenja u atmosferama zvezda A tipa, 344.
326. S.Sadžakov, M.Dačić, Z.Stančić, Ocena tačnosti položaja zvezda u katalogu dobijenom pomoću automatskog meridijanskog kruga u Brorfeldu, 345.
327. R.Grujić, Đ.Teleki, O katalogu deklinacija Beogradskih zenitskih zvezda, 345.

328. Đ.Teleki, Sadašnje mogućnosti u određivanju refrakcijskih uticaja, 350.
329. M.Jovanović, B.Jovanović, Služba vremena Astronomske opservatorije u Beogradu – polje rada, problemi, perspektive, 351.
330. M.Đokić, Određivanje konstante aberacije iz širinskih posmatranja na zenit–teleskopu u Beogradu, 351.
331. Z.Stančić, M.Mijatov, Nova određivanja kolimacije i savijanja na VMK AO u Beogradu, 352.
332. Đ.Božičković, Ispitivanje libela beogradskog Vertikalnog kruga, 353.
333. Đ.Božičković, An efficient method of determining and removing the inclination of the microscope–micrometers (in Russin), Astron. Cirkul'ar, Moscow, **1395**, 1985, 4–5.
334. M.Jovanović, B.Jovanović, L.Đurović, Svodka astronomicheskih nablyudenij sluzhb vremeni, Sluzhba vremeni BL (Belgrad), Vsemirnoe vremya, Bulleten' E41–E44, 1985.
335. (M.Jovanović), (B.Jovanović), (L.Đurović), Daily values of UTO–UTC, Transit instrument – Belgrade, Monthly Not. of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1985.
336. (R.Grujić), (M.Đokić), (N.Đokić), (S.Šegan), (R.Krga), Daily values of latitudes. VZT–Belgrade, Monthly Not. of Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1985.

1986

– In the Bull. Obs. Astron. Belgrade, **136**, 1986 :

337. A. Kubičela, M. Karabin, I. Vince, Z. Ivanović, Further Belgrade results of the large–scale photospheric velocity research, 1–5.
338. J. Arsenijević, S. Jankov, G. Đurašević, I. Vince, Variations of the linear optical polarization of kapa Draconis, 6–11.
339. V. Kršljanin, I. Vince, Collision broadening and microturbulence sensitivity of some Na I non–resonant lines, 12–19.
340. M. Đokić, Constant of aberration from the latitude observations with the Belgrade Zenith–Telescope, 29–30.
341. D. Olević, S. Šegan, R. Pavlović, Accuracy of the astrographic positions obtained with the Belgrade short–focus astrograph, 36–39.
342. Đ. Božičković, Investigation of levels of the Belgrade Vertical Circle, 40–48.
343. G.M. Popović, New double stars discovered at Belgrade Observatory with the Zeiss refractor 65/1055 cm. Supplement VII, 49–52.
344. M. Vukičević–Karabin, J. Arsenijević, Solar and stellar activity phenomena, 53–60.
345. G. Teleki, Present–day potentialities of refraction influences determination and perspective developments, 61–72.
346. I. Pakvor, The stability analysis of the vacuum meridian marks of the Large Transit Instrument at Belgrade Observatory, 75–77.
347. V. Erceg, D. Olević, Orbits of four visual double stars (ADS 8718, ADS 8926, IDS 14012S4924, IDS 14571S4012), 78–81.
348. V.Protiž–Benišek, H.Božić, Occultation of Sigma Sagittarii by Venus on 17 November 1981 observed from Hvar Observatory (Yugoslavia), 82–83.
349. G.M. Popović, Micrometer measures of double stars (Series 39), 84–93.
350. D.J. Zulević, Micrometer measures of double stars (Series 40), 94–99.
351. V. Trajkovska, Preliminary results of planet observations with the Belgrade Vertical Circle, 100–103.
352. D. Olević, S. Šegan, R. Pavlović, Fundamental asteroid positions obtained with the Belgrade Zeiss astrograph, 104–118.
353. Z. Stančić, Instrumental systems of the Belgrade Large Meridian Circle in the period 1981–1984, 119–125.
354. V. Trajkovska, Investigation of the graduation errors of the Belgrade meridian circle, 126–129.
355. M. Jovanović, L. Đurović, A survey of meridian observations carried out with the transit instrument of the Belgrade Observatory in the period 1952 to 1983, 130–132.

– In the Publ. Obs. Astron. Belgrade, **35**, 1986 :

356. G. Teleki, C. Sugawa, On the nature of astronomical refraction,
357. G. Teleki, Optical refraction: terminology and standards,
358. O. Atanacković, E. Simonneau, Effects of elastic collisions on the local frequency redistribution in the transfer of resonant line photons, Annales de physique Suppl. au No. 3, **11**, 1986, 137–138.
359. M.S. Dimitrijević, N. Konjević, Simple formulae for estimating Stark broadening parameters of neutral atom lines, Annales de physique, Suppl. au No. 3, **11**, 1986, 179–180.
360. M.S. Dimitrijević, S. Sahal–Bréchot, L'elargissement Stark des raies du potassium neutre, Annales de physique, Suppl. au No. 3, **11**, 1986, 181–182.
361. M.S. Dimitrijević, Truong–Bach, Sur l'inegalité des largeurs Stark à l'interieur d'un multiplet ou supermultiplet de l'argon II, Annales de Physique, Suppl. au No. 3, **11**, 1986, 183–184.
362. A.A. Mihajlov, M.S. Dimitrijević, Influence of ion–atom collisions on the apsorption of

radiation, Astron. Astrophys., **155**, 1986, 319–322.

363. M.S. Dimitrijević, On the Stark broadening within a F I transition array, Astron. Astrophys., Suppl. Series, **64**, 1986, 591–594.
364. M.S. Dimitrijević, N. Konjević, Simple formulae for estimating Stark widths and shifts of neutral atom lines, Astron. Astrophys., **163**, 1986, 297–300.
365. M.S. Dimitrijević, Truong–Bach, On the Stark broadening of singly ionized argon lines, Z. Naturforschung, **41a**, 1986, 772–776.
366. V. Krašljanin, M.S. Dimitrijević, Electron–imapct shifts of ion lines: modified semiempirical approach, Astron. Astrophys., **165**, 1986, 269–274.
367. G. Đurašević, Critical equipotential surfaces in close binary system, Astrophys. and Space Sc., **124**, 1986, 5–25.
368. Z. Knežević, Comparison of the asteriod proper elements obtained from various theories, Asteroids, Comets, Meteors II (C.I. Lagerkvist, B.A. Lindblad, H. Lundstedt, H. Rickman, Eds.), 1986, 129–134.
369. Z. Knežević, Secular variations of major planets' orbital elements, Celestial Mechanics, **38**, 1986, 123–138.
370. A. Kubičela, Relation between solar sidereal and synodic rotation axes, Solar Physics, **106**, 1986, 403–410.

– In the Proc. IAU Symp. 109, „Astrometric Techniques", Gainesville, Florida, D. Reidel Publ. Comp., 1986:

371. L. Mitić, I. Pakvor, Vacuum meridan marks of Belgrade Observatory, 525–527.
372. S. Sadžakov, M. Dačić, Comparison of Tokyo PZT catalogues with AGK3 and with three other independent catalogues, 571–580.
373. G.Teleki, The need for better co–operation and intercomparison in fundamental astrometry, 749–755.
374. S. Ninković, K ocenke orbital'nego ekscentrisiteta, Astrofizika (USSR), **24**, 1986, 411–416.
375. S. Sadžakov, M. Dačić, V. Fomin, Comparison of the Potsdam PZT catalogue with four NPZT catalouges, Astron. Astrophys., Suppl. Series, **65**, 1986, 379–381.
376. P. Savić, G. Teleki, Commets on the origin of the Earth–Moon system, Earth, Moon and Planets, **36**, 1986, 139–143.
377. V. Zappala, Z. Knežević, Pole coordinates of the asteroid 511 Davida via amplitude–magnitude method, Icarus, **65**, 1986, 122–128.
378. G. Teleki, A kozmikus csillagászat fejlódése (The development of space astronomy), Fizikai Szemle, Budapest, 4/86, 1986, 129–137.
379. V. Erceg, D. Olević, Orbite nouvelle de I 1262, Circ. Inf. 98, UAI Comm. 26, 1986.
380. D. Olević, V. Erceg, Orbite nouvelle de R 283, I, II, Circ. Inf. 99, UAI Comm. 26, 1986.
381. V. Erceg, D. Olević, Orbite nouvelle de ADS 9781–657, Circ. Inf. 100, UAI Comm. 26, 1986.
382. I. Pakvor, Progress report on vacuum meridian marks, Mitt. Lohrmann–Obs., Dresden, **51**, 1986, 127–130.
383. G.M. Popović, Orbite nouvelle de ADS 1507 = Σ 2799, Circ. Inf. 98, UAI Comm. 26, 1986.
384. G.M. Popović, Orbite nouvelle de ADS 9595 = HU 1160, Circ. Inf. 100, UAI Comm. 26, 1986.
385. D. Zulević, Orbite nouvelle de ADS 10459 = β 628, Circ. Inf. 98, UAI Comm. 26, 1986.
386. D. Zulević, Orbite nouvelle de ADS 8242 Ku 39, Circ. Inf. 98, UAI, Comm. 26, 1986.
387. D. Zulević, Orbite nouvelle de ADS 10385 = Hu 169, Circ. Inf. 99, UAI Comm. 26, 1986.
388. J. Arsenijević, S. Jankov, G. Đurašević, Long–term polarization changes of 88 Her, IAU Coll. 98 „De Stars", Boulder, 1986.
389. M.S. Dimitrijević, Stark broadening of spectral lines in the spectrum of Am 15 Vulpeculae, IAU Coll. 94 „Physics of the Formation of Fe II lines Outside LTE", Capri, 1986, 47.
390. M.S. Dimitrijević, S. Sahal–Bréchot, Stark broadening of K I: regularities within spectral series, 8. Int. Conf. on Spectral Line Shapes, Williamsburg, A10, 1986, 1–2.
391. M.S. Dimitrijević, A.A. Mihajlov, M. Popović, On the electron impact broadening for the resonance lines of the alkalis, VIII European Sectional Conf. on Atomic and Molecular Physics of Ionized Gases, 1986, 89–90.
392. M.S. Dimitrijević, N. Konjević, Ion line Stark broadening in stellar plasmas, The Physics of Ionized Gases, Contr. papers of SPIG, Šibenik (Yugoslavia) 1986, 313–316.
393. M.S. Dimitrijević, M.–C. Artru, Stark broadening of Ga II and Ga III stellar lines, The Physics of Ionized Gases, Contr. papers of SPIG, Šibenik (Yugoslavia), 1986, 317–320.
394. M.S. Dimitrijević, N. Feautrier, S. Sahal–Bréchot, Resonance structures in electron scattering cross sections and Stark broadening, The Physics of Ionized Gases, Contr. papers of SPIG, Šibenik (Yugoslavia), 1986, 303–305.
395. M.S. Dimitrijević, N. Konjević, V. Kršljanin, Modified semiempirical estimates of ion lines Stark broadening I, Theory, 8. Int. Conf. on Spectral Line Shapes, Williamsburg, 1986, A11, 1–2.
396. M.S. Dimitrijević, N. Konjević, V. Kršljanin, Modified semiempirical estimates of ion lines Stark broadening II. Application, 8. Int. Conf. on Spectral Line Shapes, Williamsburg, 1986, A12, 1–2.

397. M.S. Dimitrijević, V. Kršljanin, Modified semiempirical estimates of ion lines Stark shifts: spectra of hot DA white dwarfs, 13. Int. Symp. on Physics of Ionized Gases, Šibenik (Yugoslavia), 1986, 321–324.

398. B. Grabowski, M.S. Dimitrijević, Trajectory effects on the phase shift in the impact approximation, The Physics of Ionized Gases, Contr. paper of SPIG, Šibenik (Yugoslavia), 1986, 299–302.

399. P. Farinella, P. Paolicchi, Ch. Froeschle, Cl. Froeschle, R. Gonzi, M. Carpino, V. Zappala, Z. Knežević, Numerical experiments on the orbital evolution of family asteroids, 18. Annual Meeting of the Division for Planetary Sc. of the American Astron. Soc., Paris, 1986.

400. A. Kubičela, I. Vince, M.S. Dimitrijević, R. Dümmler, Differential Fe I limb effect around λ = 630.2 nm, 8. Int. Conf. on Spectral Line Shapes, Williamsburg, 1986, DA1, 1–2.

401. V. Protić–Benišek, Results of comet Halley investigations at the Belgrade Astronomical Observatory, 20. ESLAB Symp. „Exploration of Halley's Comet", Heidelberg, 1986, 436.

402. V. Protić–Benišek, Results of comet Halley investigations at the Belgrade Astronomical Observatory, Proc. 20. ESLAB Symp. „Exploration of Halley's Comet", ESA Spec. Publ. 250, Paris, 1986, 265–266.

403. S. Sadžakov, Investigation of the systematic errors of the Belgrade General Catalogue of Latitude Stars (IKŠZ), Int. Symp. „Figure and Dynamics of the Earth, Moon, and Planets", Prague, 1986.

404. N.S. Simonović, P. Grujić, M.S. Dimitrijević, Triatom fragmentation near the breaking threshold, Conf. „Collision Dynamics of Clusters and Long Lived States", Bled (Yugoslavia), 1986.

405. I. Vince, M.S. Dimitrijević, Solar spectral line asymmetries and pressure broadening, 8. Int. Conf. on Spectral Line Shapes, Williamsburg, 1986, DA2, 1–2.

406. I. Vince, M.S. Dimitrijević, Influence of spectral lines pressure shift on the convective layer diagnostic, 13. Int. Symp. on Physics of Ionized Gases, Šibenik (Yugoslavia), 1986, 325–327.

407. I. Vince, A részecskeütközesek hatása a nap– és csillagkonvekció diagnosztikájára, Int. Conf. „Magyarok Szerepe a Világ Termeszéttudományos és Müszaki Haladásában", Budapest, 1986, 897–902.

408. I. Vince, Uticaj sudarnih procesa na limb–efekt (Influences of collisional process on the limb effect), Doctoral Thesis, Belgrade, 1986.

409. O. Atanacković, Analiza nelokalnih efekata u ne–LTR prenosu zračenja u rezonantnim linijama zvezdanih atmosfera (Analysis of non–local effects in non–LTE line transfer in stellar atmospheres), Master of Scinece Thesis, Belgrade, 1986.

410. V. Kršljanin, Štarkov pomak jonskih linija kod toplih zvezda (Stark shifts of ion lines at hot stars), Master of Science Thesis, Belgrade, 1986.

411. S. Jankov, Restauracija astronomskih spektrograma korišćenjem Vinerove filtracione funkcije u uslovima nedostatka „a priori" informacije o objektu istraživanja (Restauration of astronomical spectrograms using Wiener's filtering function in the absence of „a priori" informations on the object being investigated), Master of Science Thesis, Belgrade, 1986.

412. M. Jovanović, B. Jovanović, L. Đurović, Svodka astronomicheskih nablyudenij sluzhb vremeni. Sluzhba vremeni BL (Belgrade). Vsemirnoe vremya, Bululleten' E45–E48, 1986.

413. (M. Jovanović), (B. Jovanović), (L. Đurović), Daily values of UTO–UTC, Transit instrument – Belgrade, Monthly Not. of the Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1986.

414. (R. Grujić), (M. Đokić), (N. Đokić), Daily values of latitudes, VZT–Belgrade, Monthly Not. of Int. Polar Motion Service, Mizusawa, Nos. 1–12, 1986.

415. H. Debehogne, V. Protitch–Benishek, D. Olević, 275 precise astrometric positions of minor planets obtained at the GPO Telescope of ESO, La Silla, Acta Astronomica, Warshaw, **36**, 1985, 457–472.

416. V. Protitch–Benishek, Observations of Comet Halley, Minor Planet Circular, 10331.

Index according to the authors

Bulletin de l'Observatoire astronomique de Belgrade No 137, 1987.

CONTENTS