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HARZER'S WORKS ON ASTRONOMICAL REFRACTION VIEWED FROM TODAY'S STANDPOINT

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SUMMARY. A detailed survey and a critical analysis of P. Harzer's ideas and methods of computation of astronomical refraction in a three–dimensional medium is presented. On stating that Harzer's conceptions were of interest, ways of their possible application in the current astronomical practice are indicated.

1. INTRODUCTION

The view has repeatedly been expressed that Harzer's works on astronomical refraction – in particular his studies bearing upon tables of refraction (1922–1924; 1924) – were of fundamental importance, represented a turning point in the study of this phenomenon and were preserving their interest even today. Harzer's basic ideas are laid down in these works: proceeding from the physical laws and a real (global) model of the atmosphere based on meteorologic measurements to determine refractional influences for particular place and time – clearly in a three–dimensional space. Such conceptions are in force, unaltered, to our days.

That Harzer failed to fully put his ideas into effect is not his fault: the reasons are to be sought in the rather limited knowledge available in the second decade of the 20th century coupled with difficulties in executing cumbersome computations with modest computing facilities of that time.

Harzer's work are of interest also from the aspect of producing up–to–date tables (algorithm) of refraction. The fact is, namely, that in the current practice one needs, in addition to the modern computing technique, the corresponding tables of refraction for reckoning these influences. This interest derives from his works accomplishing a useful compromise of two counterposed requirements:

– utmost rigour in taking into account the physical state of the atmosphere, and
– utmost simplicity of computing the refractional influences.

Concerning the second demand due regard must be paid to Harzer's theory furnishing three–dimensional refraction components. Thus, his tables (or algorithm) cannot be as simple as for instance the popular Pulkovo Tables.

It is not our objective to simply reproduce Harzer's studies but to reconsider in a thorough way – as much as possible – the train of those details which elude immediate noticing in the original text – all this from the standpoint of the present–day knowledge. This necessity stems from the fact that Harzer's works are difficult of making a straight–forward use of. First, because many of his formulae and premises are advanced without being evolved or explained (for instance, not a single figure is attached) – only broad outlines are indicated. Second, because Harzer's presentations in general are heavy–laden and complicated, burdened with details which currently appear irrelevant.

It is our desire, therefore, to revive Harzer's ideas and to facilitate their application in present–day researches and practice.

In this analysis of ours we intend to make use also of Harzer's unpublished manuscripts, safeguarded in the Kiel University Library. A part of these was kindly sent to us by Dr. Reichel, Director, to whom our sincere thanks are due. However, the manuscripts proved of no great use – of which we were forewarned by Dr. Reichel – due, on one hand, to the fact that only a part of Harzer's works is covered by them and, more important, they were in a poor condition. Consequently, all that we were left with was to provide interpretations of Harzer's deduction of formulae, methods and intentions on the basis merely of his published papers. One may safely assume that our interpretations not always coincide with Harzer's reflections but it is hoped the divergencies are not substantial. It should be remarked that Harzer's notations have here and there been changed – for two reasons: for better clarity (avoiding the same notations of different data) and for simpler the printing (gothic lettering changed for latin).

2. LIGHT–RAY PROPAGATION IN A THREE–DIMENSIONAL MEDIUM

In deriving the equation of the light ray propagation through an, generally, inhomogenous optical medium in a three–dimensional space, Harzer proceeded from the known integral of the optical path

$$I = \int n \, ds \tag{1}$$

and, looking for its minimum, derived the following equations

$$\left.\begin{aligned} \frac{d\alpha}{ds} &= \frac{\partial \ln n}{\partial x} - \alpha \frac{d \ln n}{ds} \\ \frac{d\beta}{ds} &= \frac{\partial \ln n}{\partial y} - \beta \frac{d \ln n}{ds} \\ \frac{d\gamma}{ds} &= \frac{\partial \ln n}{\partial z} - \gamma \frac{d \ln n}{ds} \end{aligned}\right\} \tag{2}$$

where

x, y, z – coordinates in an arbitrary, fixed, rectangular reference system,

$\alpha = \frac{dx}{ds}$ – direction cosine,

$\beta = \frac{dy}{ds}$ – direction cosine,

$\gamma = \frac{dz}{ds}$ – direction cosine,

$ds = \sqrt{dx^2 + dy^2 + dz^2}$

n – refractive index, possesing features of the function n(x, y, z).

In his presentation Harzer fails to relate the minimum of (1) to the known Fermat–principle and the equation (2) to the known Euler's equations. We will show here how one can arrive at the formulae (2) using, unlike Harzer, the apparatus of the variation calculus (Born, Wolf, 1964a).

The formula (1) can be written in the form

$$I = \int n \, ds = \int n(x, y, z) \sqrt{x'^2 + y'^2 + 1} \, dz \tag{3}$$

where $x' = dx/dz$ and $y' = dy/dz$. The formula (1) thus transformed has a general form

$$I = \int_{z_1}^{z_2} \phi(x', y', x, y, z) \, dz \tag{4}$$

whose first variations with respect to x and y furnish the following second order differential equations

$$\left.\begin{aligned} \phi_x - \frac{d}{dz} \phi_{x'} &= 0 \\ \phi_y - \frac{d}{dz} \phi_{y'} &= 0 \end{aligned}\right\} \tag{5}$$

where ϕ_x, ϕ_y, $\phi_{x'}$ and $\phi_{y'}$ denote the partial differentials of the function ϕ. Knowing (5), there follows from (3)

$$\frac{\partial n}{\partial x}\sqrt{x'^2+y'^2+1} \quad -\frac{d}{dz}\,\frac{nx'}{\sqrt{x'^2+y'^2+1}}=0$$

$$\frac{\partial n}{\partial y}\sqrt{x'^2+y'^2+1} \quad -\frac{d}{dz}\,\frac{ny'}{\sqrt{x'^2+y'^2+1}}=0$$

Taking into account that

$$ds=\sqrt{x'^2+y'^2+1}\,dz$$

we arrive at

$$\frac{d(n\,\alpha)}{ds}=\frac{\partial n}{\partial x} \quad \text{and} \quad \frac{d(n\,\beta)}{ds}=\frac{\partial n}{\partial y} \tag{6}$$

The third Euler's equation

$$\frac{d(n\,\gamma)}{ds}=\frac{\partial n}{\partial z} \tag{7}$$

can be obtained using the relation

$$\alpha^2+\beta^2+\gamma^2=1 \tag{8}$$

Thus, from (6) and (7) there directly follow Euler's equations (2). They specify the necessary conditions for the minimum of the integral (1). It can, moreover, be shown (Born, Wolf, 1964b) that they specify also the sufficient conditions for the minimum, that minimum being a strong one – although it is a relative minimum (it is namely impossible to state what minimum is an absolute one).

Let us revert to the basic equations (2). For them to be solved it is necessary that their right–hand sides are known. Harzer solved the problem in the following manner.

By an optical surface Harzer understood the surface of the air layer over which the refractive index is constant. Denote the surface of equal refractive index by SERI. A SERI will, in general, be given by

$$f(x,y,z,A)=0 \tag{9}$$

where A is a parameter, constant for a given SERI, but variable from one surface to another. Let the point P of the light ray be on a SERI. Let us proceed from the point P, along the trajectory of the light ray in the contrary direction to its propagation, by an amount ds. The quantity A will thereby change by dA, deducible from the total differential (9):

$$\frac{\partial f}{\partial x}dx+\frac{\partial f}{\partial y}dy+\frac{\partial f}{\partial z}dz+\frac{\partial f}{\partial A}dA=0 \tag{10}$$

From the known formulae of direction λ, μ and ν of the normal on the given surface at the point P (i.e. the normal on the tangent plane), the following expressions are obtained

$$\left.\begin{aligned} &\frac{\partial f}{\partial x}=\lambda F \qquad \frac{\partial f}{\partial y}=\mu F \qquad \frac{\partial f}{\partial z}=\nu F \\ &F^2=\left(\frac{\partial f}{\partial x}\right)^2+\left(\frac{\partial f}{\partial y}\right)^2+\left(\frac{\partial f}{\partial z}\right)^2 \end{aligned}\right\} \tag{11}$$

where F is a positive quantity. This normal specifies the position of the (optical) zenith of the optical surface for the point P.

From (10) and (11) one finds dA

$$dA=-\frac{F}{\frac{\partial f}{\partial A}}\,(\lambda dx+\mu dy+\nu dz) \tag{12}$$

Harzer introduces two new quantities ϵ and ρ, whose meaning will be understood later on:

$$\epsilon=\alpha\lambda+\beta\mu+\gamma\nu \tag{13}$$

$$\rho=\frac{\frac{\partial f}{\partial A}}{F\frac{d\ln n}{dA}\sqrt{1-\epsilon^2}} \tag{14}$$

From the last three expressions it is possible to derive, with regard to the values α, β and γ, the following total differential of n with respect to x, y and z:

$$d\ln n=\frac{d\ln n}{dA}\,dA=-\frac{1}{\rho\sqrt{1-\epsilon^2}}\,(\lambda dx+\mu dy+\nu dz)$$

$$=\frac{-\epsilon}{\rho\sqrt{1-\epsilon^2}}\,ds \tag{15}$$

The partial differential with respect to x is

$$\frac{\partial \ln n}{\partial x}=-\frac{\lambda}{\rho\sqrt{1-\epsilon^2}} \tag{16}$$

and those with respect to y and z are analogous.

From (15) one obtains $\frac{d\ln n}{ds}$. Then, in regard to (16) there follow from (2) the new equations of propagation

$$\left.\begin{aligned}\frac{d\alpha}{ds} &= \frac{\epsilon\alpha-\lambda}{\rho\sqrt{1-\epsilon^2}}\\ \frac{d\beta}{ds} &= \frac{\epsilon\beta-\mu}{\rho\sqrt{1-\epsilon^2}}\\ \frac{d\gamma}{ds} &= \frac{\epsilon\gamma-\nu}{\rho\sqrt{1-\epsilon^2}}\end{aligned}\right\} \quad (17)$$

The sum of squares in (17) furnishes

$$\left(\frac{d\alpha}{ds}\right)^2 + \left(\frac{d\beta}{ds}\right)^2 + \left(\frac{d\gamma}{ds}\right)^2 = \frac{1}{\rho^2} \quad (18)$$

meaning that – in consideration of the well known mathematical rules (one is referred to the textbooks on differential calculus and vector analysis) – ρ is in fact the radius of curvature of the ray trajectory at the point P.

Once we know what the quantities α, β and γ, i.e. λ, μ and ν are equal to, it is readily concluded that the quantity ϵ from (13) is in fact cosine of the angle between the normal on the given surface and the ray – that is, the cosine of the incidence angle. From (14) one can ascertain that the radius of curvature ρ for different rays at the point P is inversely proportional to the sine of the incidence angle.

In continuation, Harzer derives the so called sine law which reads

$$n\sqrt{1-\epsilon^2} = \text{const.} \quad (19)$$

This he proves in the following fashion. With regard to (15) and (17) one derives

$$\frac{d(n\sqrt{1-\epsilon^2})}{ds} = \sqrt{1-\epsilon^2}\,\frac{dn}{ds} - \frac{n\epsilon}{\sqrt{1-\epsilon^2}}\left(\lambda\frac{d\alpha}{ds} + \right.$$

$$\left. + \mu\frac{d\beta}{ds} + \nu\frac{d\gamma}{ds}\right) = -\frac{n\epsilon}{\rho} - \frac{n\epsilon}{\sqrt{1-\epsilon^2}}$$

$$\left(\frac{\epsilon\alpha\lambda-\lambda^2+\epsilon\beta\mu-\mu^2+\epsilon\gamma\nu-\nu^2}{\rho\sqrt{1-\epsilon^2}}\right) = -\frac{n\epsilon}{\rho} -$$

$$-\frac{n\epsilon}{\sqrt{1-\epsilon^2}}\left(\frac{\epsilon^2-1}{\rho\sqrt{1-\epsilon^2}}\right) = -\frac{n\epsilon}{\rho} + \frac{n\epsilon}{\rho} = 0$$

It can also be proved that the normal on the optical surface and the light ray are in the same plane. Harzer arrives at this by way of the bi–normal on the osculating plane of the light ray curve at the point P. The direction consines of the bi–normal are

$$\beta\frac{d\gamma}{ds} - \gamma\frac{d\beta}{ds}, \quad \gamma\frac{d\alpha}{ds} - \alpha\frac{d\gamma}{ds}, \quad \alpha\frac{d\beta}{ds} - \beta\frac{d\alpha}{ds}$$

They can, by means of (17), be transformed into following expressions

$$\frac{\mu\gamma-\beta\nu}{\rho\sqrt{1-\epsilon^2}} \qquad \frac{\alpha\nu-\gamma\lambda}{\rho\sqrt{1-\epsilon^2}} \qquad \frac{\beta\lambda-\alpha\mu}{\rho\sqrt{1-\epsilon^2}}$$

If the bi–normal happens to be perpendicular to the normal on the optical surface, then the condition should be satisfied

$$\left(\frac{\mu\gamma-\beta\nu}{\rho\sqrt{1-\epsilon^2}}\right)\lambda + \left(\frac{\alpha\nu-\gamma\lambda}{\rho\sqrt{1-\epsilon^2}}\right)\mu + \left(\frac{\beta\lambda-\alpha\mu}{\rho\sqrt{1-\epsilon^2}}\right)\nu = 0$$

which is just being the case. Accordingly, the normal on the surface is the so called principal normal, lying in the osculating plane.

3. REFRACTION OF THE RAYS AND ITS EFFECTS ON THE APPARENT POSITIONS OF THE CELESTIAL BODIES

The expressions (17) are in fact equations of the ray propagation in an arbitrary coordinate system. One is, of course, bound to pass over to a system actually used in astronomy. Harzer proceed in the following way.

He put the coordinate origin in the Earth's centre. The x–axis is in the meridian plane of the observing point P_0, directed toward south, y–axis is perpendicular to the meridian plane, directed toward west, and z–axis is parallel with the optical zenith direction for the point P_0. Polar coordinates can also be applied. The following ones are used:

r – radius vector with respect to the Earth's centre,
ψ – geocentric latitude, and
ω – geocentric longitude (reckoned westward from the meridian of the point P_0).

These values for the certain ray points are marked with the indices.

The rectangular and polar coordinates are connected as follows:

$$\left.\begin{aligned} x &= r(-\cos\chi_0\sin\psi + \sin\chi_0\cos\psi\cos\omega)\\ y &= r\cos\psi\sin\omega\\ z &= r(\sin\chi_0\sin\psi + \cos\chi_0\cos\psi\cos\omega)\end{aligned}\right\} \quad (20)$$

or else

$$\left.\begin{aligned} r\cos\psi\cos\omega &= x\sin\chi_0 + z\cos\chi_0 \\ r\cos\psi\sin\omega &= y \\ r\sin\psi &= -x\cos\chi_0 + z\sin\chi_0 \end{aligned}\right\} \quad (21)$$

where χ_0 is the angle between the direction towards the optical zenith of the point P_0 and the equator plane.

Geometrical counterpart of the relations (20) and (21) is illustrated in Fig. 1.

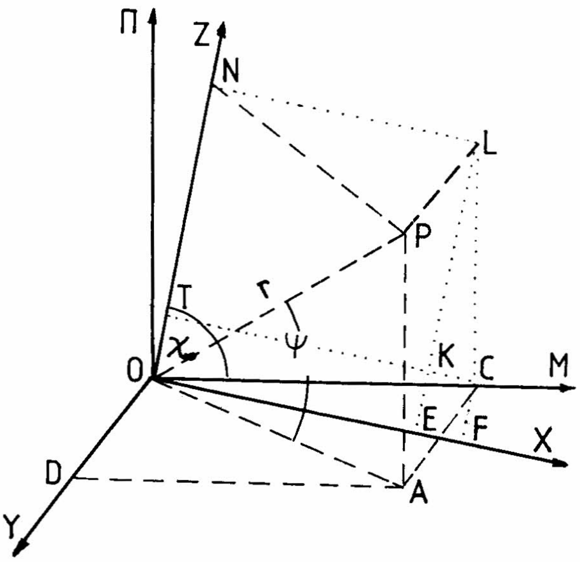

Fig. 1. Interconnection of the rectangular and polar coordinates

In Fig. 1. is indicated another rectangular coordinate system (Π, M, y), in addition to the x, y, z system, associated with the Earth's rotation axis. The zOx and ΠOM planes of the two systems coincide with the meridian plane of P_0.

Using the notations in Fig. 1, one derives:

$x = OE = OF - EF = OF - KC = r\sin\chi_0\cos\psi\cos\omega -$
$- r\cos\chi_0\sin\psi$
$y = OD = r\cos\psi\cos(90^o - \omega) = r\cos\psi\sin\omega$
$z = ON = OT + TN = r\cos\chi_0\cos\psi\cos\omega +$
$+ r\sin\chi_0\sin\psi.$

The value of F from (11), expressed in polar coordinates, assumes the following form

$$F^2 = \left(\frac{\partial f}{\partial r}\right)^2 + \left(\frac{1}{r}\frac{\partial f}{\partial\psi}\right)^2 + \left(\frac{1}{r\cos\psi}\frac{\partial f}{\partial\omega}\right)^2 \quad (22)$$

The cosines of angles λ, μ and ν relative to SERI can be derived in analogous way as in (20). If the normal on SERI at P is, imaginary, transferred into the coordinate origin 0, the angle formed with the equator plane YOM is equal to χ (see Fig. 5). Assuming the point P to be the tip of the unit vector OP, we obtain, in analogy to (20):

$$x_P = -|\vec{OP}|\cos\chi_0\sin\chi + |\vec{OP}|\sin\chi_0\cos\chi\cos\omega$$

$$y_P = |\vec{OP}|\cos\chi\sin\omega$$

$$z_P = |\vec{OP}|\cos\chi_0\cos\chi\cos\omega + |\vec{OP}|\sin\chi_0\sin\chi$$

and thence, knowing that

$$\frac{x_P}{|\vec{OP}|} = \lambda \qquad \frac{y_P}{|\vec{OP}|} = \mu \qquad \frac{z_P}{|\vec{OP}|} = \nu$$

we obtain

$$\left.\begin{aligned} \lambda &= -\cos\chi_0\sin\chi + \sin\chi_0\cos\chi\cos\omega \\ \mu &= \cos\chi\sin\omega \\ \nu &= \sin\chi_0\sin\chi + \cos\chi_0\cos\chi\cos\omega \end{aligned}\right\} \quad (23)$$

On denoting with η and ζ respectively the azimuth and the zenith distance relative to the optical zenith of the point P_0, the direction cosines of the ray at the point P are

$$\left.\begin{aligned} \alpha &= \sin\zeta\cos\eta \\ \beta &= \sin\zeta\sin\eta \\ \gamma &= \cos\zeta \end{aligned}\right\} \quad (24)$$

and at the point P_0 of this same ray

$$\left.\begin{aligned} \alpha_0 &= \sin\zeta_0\cos\eta_0 \\ \beta_0 &= \sin\zeta_0\sin\eta_0 \\ \gamma_0 &= \cos\zeta_0 \end{aligned}\right\} \quad (25)$$

Consider now how the direction cosines of the light ray vary from the celestial body P_* onward to the observing point P_0. The light ray impinges on the boundary point P_a of the atmosphere – according to Harzer – in a straight line, undergoing thereafter bending until it reaches the point P_0. The direction cosines from P_a to P_0 are, generally, subject to continuous variation. Denoting the direction cosines from P_a to P_* by α_*, β_* and γ_*, the distance of the points P_0 and P_a by d_{0a} and by z_a, y_a, z_a and x_0, y_0, z_0 the coordinates of the points P_a and P_0, we may accept – if the effects of aberration are disregarded – the direction cosines from P_0 to P_* to be proportional to

$$\alpha_* + \frac{x_a - x_o}{d_{oa}} \qquad \beta_* + \frac{y_a - y_o}{d_{oa}} \qquad \gamma_* + \frac{z_a - z_o}{d_{oa}}$$

Harzer puts forward – failing to produce evidence – that the second terms in these expressions are telling only at observing the objects in the Earth's neighbourhood (e.g. the Moon) and then only at larger zenith distances. In order to substantiate this statement of Harzer's about the parallactic effect, let's inspect Fig. 2 with the notations ζ_0 – apparent zenith distance of the celestial object P_*, ζ' – true zenith distance of P_* (i.e. atmospheric effects assumed nil), ζ_* – position angle of P_* at P_a relative to the optical zenith, and i – true zenith distance of P_a (i.e. atmospheric effects assumed nil). The effect of refraction is equal to $(\zeta' - \zeta_0)$. From Fig. 2 the following relations

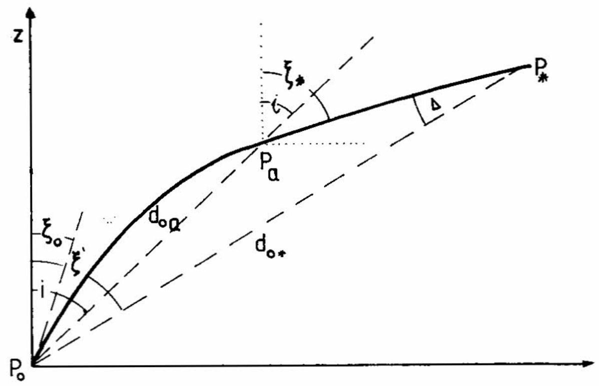

Fig. 2. Projection of the light ray trajectory on the surface passing through the z–axis and the tangent of the ray at the point P_0

may be derived

$$\zeta' = \zeta_* - \Delta$$

$$\frac{\sin \Delta}{d_{oa}} = \frac{\sin(180^\circ - \zeta_* + i)}{d_{o*}}$$

Inserting in the cos ζ' of the former relation the sin Δ from the latter we have

$$\cos \zeta' = [\cos \Delta - \frac{d_{oa}}{d_{o*}} \cos(\zeta_* - i)] \cos \zeta_* + \frac{d_{oa}}{d_{o*}} \cos i$$

In the case of P_* being at large distance, Δ and d_{oa}/d_{o*} tend to zero, therefore $\cos \zeta' \approx \cos \zeta_*$. Were we to look for the projection on the coordinate planes XYZ, a similar result would follow – the effects in the ZX and ZY planes might even be weaker, and that in XY plane negligible (for the real trajectory of the ray is practically in the vertical plane, implying the changes in azimuth to be small). Thus, if stars are observed, one may assume the direction to the star, observed from the point P_o (if the Earth were without the atmosphere) to be specified by the direction cosines α_*, β_* and γ_*. Therefore, the differences between the apparent – at the point P_o – and the true direction cosines are given by

$$\delta\alpha = \alpha_0 - \alpha_* \quad \delta\beta = \beta_0 - \beta_* \quad \delta\gamma = \gamma_0 - \gamma_*$$

whence the corresponding variations in azimuth and zenith distance are

$$\delta\eta = \eta_0 - \eta_* \; \delta\zeta = \zeta_0 - \zeta_* \tag{26}$$

the corresponding quantities being given by (24) and (25).

It should at once be observed that relations (26) would hold for the astrometric observations related to the optical zenith. This, however, is not the case in practice, the measurements being related to the astronomic zenith – specified by the normal on the level surface for the point P_o (this normal is in fact the plumb line). Harzer neglects the difference between the astronomic and geodetic zeniths (the latter is specified by the normal on the Earth's ellipsoid) dealing only with the geodetic zenith. Here we shall present Harzer's interpretation.

On denoting the angular distance between the optical and the geodetic zeniths by $\mathcal{H}_0 = \chi_0 - \varphi$ (where φ – latitude) we derive the following relation between the azimuth (η) and the zenith distance (ζ), referred to the optical zenith, and the azimuth and the zenith distance η_G, ζ_G referred to the geodetic zenith (see Fig. 3):

$$\left.\begin{aligned} &\sin\zeta \cos\eta = \cos\mathcal{H}_0 \sin\eta_G \cos\zeta_G + \sin\mathcal{H}_0 \cos\zeta \\ &\sin\zeta \sin\eta = \sin\zeta_G \sin\eta_G \\ &\cos\zeta = \cos\mathcal{H}_0 \cos\zeta_G - \sin\mathcal{H}_0 \sin\zeta_G \cos\eta_G \end{aligned}\right\} \tag{27}$$

that is

$$\left.\begin{aligned} &\sin\zeta_G \cos\eta_G = \cos\mathcal{H}_0 \sin\zeta \cos\eta - \sin\mathcal{H}_0 \cos\zeta \\ &\sin\zeta_G \sin\eta_G = \sin\zeta \sin\eta \\ &\cos\zeta_G = \cos\mathcal{H}_0 \cos\zeta + \sin\mathcal{H}_0 \sin\zeta \cos\eta \end{aligned}\right\} \tag{28}$$

Thus we derived the formulae (24)–(28) furnishing the variations in the coordinates – in reference to the geodetic zenith – brought about by the atmospheric refraction.

It is worthwhile mentioning that Harzer in his work gave also the formulae for approximate computations of all these quantities, which otherwise are stringently determined by (24) through (28). We abstain from reproducing here these approximate formulae.

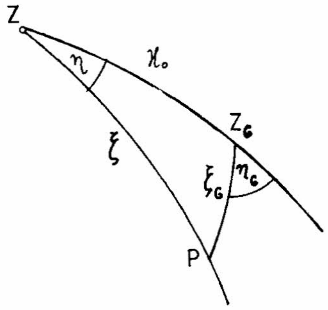

Fig. 3. Spherical triangle specified by the optical zenith (Z), geodetic zenith (Z_G) and the point P

4. ANALYTICAL APPROXIMATION OF TRUE OPTICAL SURFACES

The atmospheric model – in reference to which the refraction effects are reckoned – constitutes the stumbling block in all the refractional theories. Harzer resolved on elaborating, on the basis of meteorological measurements, such a model which involved a family of SERIs defined by the general expression (9). His considerations resulted in the following formula

$$f = r - A \sum_m [R_m \cos 2m\,\psi + S_m \sin (2m+1)\,\psi] = 0 \tag{29}$$

whose derivation we give in the ensuing text.

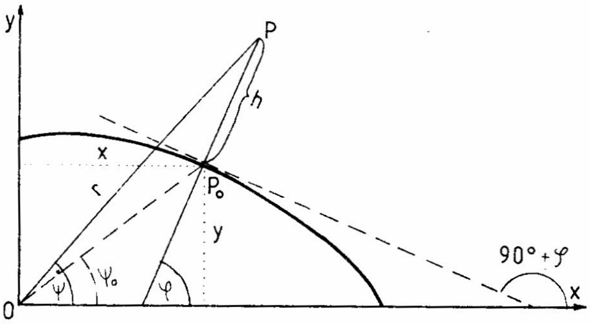

Fig. 4. Position of the point P above the ellipse representing the cross–section of the Earth's geoid approximated by an ellipsoid of rotation

Harzer represented the Earth's geoid as an ellipsoid of rotation, with semi–axes a and $a\sqrt{1-e}$, wherein, instead of the square of eccentricity, he simply put e.

For any point on the ellipse, the point P_0 inclusive (see Fig. 4), the equation holds

$$\frac{x^2}{a^2} + \frac{y^2}{a^2(1-e)} = 1 \tag{30}$$

Express now x and y in terms of latitude φ. By differentiating the equation of ellipse we get

$$\frac{x}{a^2}\,dx + \frac{y}{a^2(1-e)}\,dy = 0$$

On putting in this equation the value of the slope of the tangent line on the ellipse at the point P_0

$$\frac{dy}{dx} = \mathrm{tg}\,(90^\circ + \varphi) = -\,\mathrm{ctg}\,\varphi$$

we obtain

$$\frac{x}{a^2} - \frac{y\,\mathrm{ctg}\,\varphi}{a^2(1-e)} = 0$$

yielding

$$y = x(1 - e)\,\mathrm{tg}\,\varphi.$$

By inserting this in (30) one has

$$x = \frac{a\cos\varphi}{\sqrt{1 - e\sin^2\varphi}}$$

then

$$y = \frac{a(1-e)\sin\varphi}{\sqrt{1 - e\sin^2\varphi}}$$

From Fig. 4 we arrive at the following relations

$$r\cos\psi = r_0\cos\psi_0 + h\cos\varphi$$

$$= \frac{a\cos\varphi}{\sqrt{1 - e\sin^2\varphi}} + h\cos\varphi$$

$$r\sin\psi = r_0\sin\psi_0 + h\sin\varphi$$

$$= \frac{a(1-e)\sin\varphi}{\sqrt{1 - e\sin^2\varphi}} + h\sin\varphi$$

Multiply the former equation by $\cos\varphi$ and the latter by $\sin\varphi$, and sum them up, thereupon multiply the former by $\sin\varphi$ and the latter by $\cos\varphi$, and sum them up likewise. The Harzer's basic formulae follow

$$\left.\begin{aligned} r\cos(\varphi-\psi) &= a\sqrt{1-e\sin^2\varphi}+h \\ r\sin(\varphi-\psi) &= \frac{a\,e\sin\varphi\cos\varphi}{\sqrt{1-e\sin^2\varphi}} \end{aligned}\right\} \quad (31)$$

The height h was represented by Harzer by a Fourier series of the form

$$h = a\sum_m \left[H_m\cos 2m\varphi + T_m\sin(2m+1)\varphi\right] \quad (32)$$

which he could do. Namely, any continuous function in the interval from $-\pi$ to $+\pi$ can be expanded into Fourier series, convergent throughout the interval (except, evidently, in $-\pi$ and $+\pi$). The quantities e, H_m ($m \geqslant 1$) and T_m ($m \geqslant 0$) in (32) are small – this can be demonstrated on examples – therefore we will restrain to the squares e^2, eH_1 and H_1^2, neglecting the higher powers.

By squaring and summing up (31) we get

$$r = \left[\left(a\sqrt{1-e\sin^2\varphi}+h\right)^2 + \left(\frac{a\,e\sin\varphi\cos\varphi}{\sqrt{1-e\sin^2\varphi}}\right)^2\right]^{1/2}$$

which, using the relation (32) and the notations

$$\begin{aligned} k &= 1 + H_o = 1 + \frac{h}{a} \\ c_1 &= \frac{e}{4k} \\ c_2 &= e\frac{H_1}{4k^2} = c_1\frac{H_1}{k} \end{aligned} \quad (33)$$

can be expanded as follows

$$r = \left[a(1-e\sin^2\varphi)^{0.5}+h\right](1+\theta)^{0.5} =$$

$$= \left[a(1-e\sin^2\varphi)^{0.5}+h\right]\left(1+\frac{1}{2}\theta-\frac{1}{8}\theta^2+\ldots\right)$$

$$\approx a(1-e\sin^2\varphi)^{0.5}+h+\frac{1}{2}\left[a(1-e\sin^2\varphi)^{0.5}+\right.$$

$$\left.+h\right]\theta = a\left[1-\frac{e}{2}\sin^2\varphi-\frac{e^2}{8}\sin^4\varphi-\ldots\right]+a\sum_{m=o}$$

$$\left[H_m\cos 2m\varphi+T_m\sin(2m+1)\varphi\right] + \frac{1}{2}\,\frac{a^2e^2}{4}$$

$$\sin^2 2\varphi\,\frac{a(1-e\sin^2\varphi)^{0.5}+h}{(1-e\sin^2\varphi)\left[a(1-e\sin^2\varphi)^{0.5}+h\right]^2} =$$

$$= a\left[1-\frac{e}{4}+\frac{e}{4}\cos 2\varphi - \frac{3e^2}{64}+\frac{e^2}{16}\cos 2\varphi -\right.$$

$$-\frac{e^2}{64}\cos 4\varphi + H_o + H_1\cos 2\varphi + H_2\cos 4\varphi$$

$$+\sum_{m=3} H_m\cos 2m\varphi + \sum_{m=o} T_m\sin(2m+1)\varphi +$$

$$+\frac{a^2e^2}{16}\,\frac{1-\cos 4\varphi}{a\left[(1-e\sin^2\varphi)^{1.5}+\frac{h}{a}(1-e\sin^2\varphi)\right]}$$

$$= a\left(1-\frac{e}{4}+\frac{e}{4}\cos 2\varphi-\ldots\right) +$$

$$+\frac{a^2e^2}{16}\,\frac{1-\cos 4\varphi}{1+H_o-\left(\frac{3}{2}-\frac{3}{2}e\sin^2\varphi+\frac{h}{a}\right)e\sin^2\varphi} =$$

$$= a\left[k-\frac{e}{4}-\frac{3ke^2}{64k}+\frac{e^2}{16k}+\left(H_1+\frac{e}{4}+\frac{e^2}{16}\,\frac{k^2}{k^2}\right)\right.$$

$$\cos 2\varphi + \left(H_2 - \frac{e^2}{16}\,\frac{k^2}{4k^2}-\frac{e^2}{16k}\right)\cos 4\varphi +$$

$$+\sum_{m=3} H_m\cos 2m\varphi + \sum_{m=o} T_m\sin(2m+1)\varphi =$$

$$= ak\left[1-c_1-\frac{3k-4}{4}c_1^2+\left(\frac{H_1^2}{k}+c_1+\right.\right.$$

$$\left.+kc_1^2\right)\cos 2\varphi + \left(\frac{H_2}{k}-\frac{k+4}{4}c_1^2\right)\cos 4\varphi +$$

$$+\sum_{m=3} H_m\cos 2m\varphi + \sum_{m=o} T_m\sin(2m+1)\varphi \quad (34)$$

The value of φ can be derived from the second equation in (31), making use of (34):

$$\psi-\varphi = -\arcsin\left(\frac{a}{r}\,\frac{e\sin\varphi\cos\varphi}{\sqrt{1-e\sin^2\varphi}}\right)$$

$$\approx \frac{-ae\sin\varphi\cos\varphi}{r(1-e\sin^2\varphi)^{0,5}} = -\frac{e}{2k}$$

$$\frac{\sin 2\varphi}{\left[1-c_1-\frac{3k-4}{4}c_1^2+\left(\frac{H_1}{k}+c_1+kc_1^2\right)\cos\varphi\right.}$$

$$\frac{}{\left.-\frac{k+4}{4}c_1^2\cos 4\varphi\right]\left(1-\frac{e}{2}\sin^2\varphi\right)} = \ldots\ldots =$$

$$= -\frac{2c_1\sin 2\varphi}{1-\left[c_1+kc_1-\left(\frac{H_1}{k}+c_1+kc_1\right)\cos 2\varphi\right]} =$$

$$= -2c_1\left[\sin 2\varphi+(k+1)c_1\sin 2\varphi -\right.$$

$$\left.-\frac{1}{2}\left(\frac{1}{k}H_1+c_1+kc_1\right)\sin 4\varphi\right.$$

which results in

$$\psi = \varphi - [2c_1 + 2(k+1)\,c_1^{\,2}]\sin 2\varphi - [c_2 + (k+1)\,c_1^{\,2}] \sin 4\varphi \qquad (35)$$

In order to eliminate from (34) the angle φ, by replacing it by ψ, one should proceed from (35) and look for the values $\cos 2\varphi$ and $\cos 4\varphi$:

$$\cos 2\varphi = \cos[\,2\psi + 2\,\{[\,2c_1 + 2(k+1)\,c_1^{\,2}]\sin 2\psi + [c_2 + (k+1)\,c_1^{\,2}]\sin 4\psi\,\}]$$

$$\cos 4\varphi = \cos[\,4\psi + 4\,\{[2c_1 + 2(k+1)\,c_1^{\,2}]\sin 2\psi + [c_2 + (k+1)\,c_1^{\,2}]\sin 4\psi\,\}]$$

By expanding these expressions and by substituting in (34), we obtain the equation of the optical surface (29) in another form

$$r = A \sum_m [R_m \cos 2m\,\psi + S_m \sin(2m+1)\,\psi] \qquad (29)$$

where the following abbreviations are introduced:

$$\left.\begin{aligned} A &= ak\left(1 - c_1 - 2c_2 - \frac{3k+4}{4}\,c_1^2\right)\\ R_0 &= 1\\ R_1 &= \frac{H_1}{k} + c_1 + c_2 + (k+1)\,c_1^2\\ R_2 &= \frac{H_2}{k} + 2c_2 - \frac{k-4}{4}\,c_1^2\\ R_m &= \frac{H_m}{k} \qquad (m \geqslant 3)\\ S_m &= \frac{T_m}{k} \qquad (m \geqslant 0) \end{aligned}\right\} \qquad (36)$$

The quantity A, representing the mean value of r for the meridian of the optical surface, is taken as a parameter (this has been related to in connection with the equation (9)). The quantities R_m and S_m are supposed known functions of this parameter.

Yet another parameter, denoted (see Fig. 5) τ

$$\chi = \psi + \tau \qquad (37)$$

where χ and ψ are given earlier, was introduced by Harzer. From Fig. 5, in regard to PK = dr and PK' = –dr, there follows

$$KF = (r + dr)(-d\psi) = -r d\psi - dr\, d\psi \approx -r d\psi$$

$$K'F' = (r - dr)(d\psi) = r d\psi - dr\, d\psi \approx r d\psi$$

Thereupon

$$\mathrm{tg}\, P\hat{F}K = \mathrm{tg}\, P\hat{F}'K = \mathrm{tg}\,\tau = -\frac{1}{r}\frac{dr}{d\psi}$$

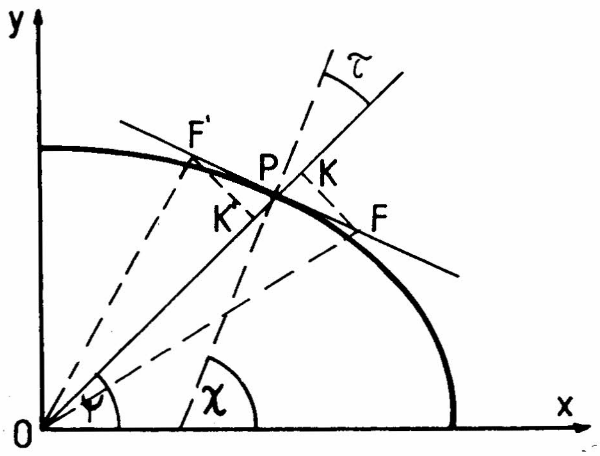

Fig. 5. Illustrating the angle τ

If it is born in mind that this relation pertains to the intersection of the surface defined by the equation (29), we can write (as Harzer did)

$$\mathrm{tg}\,\tau = -\frac{1}{r}\frac{\partial r}{\partial \psi} \qquad (38)$$

This small angle τ can also be expressed by a series of the from

$$\tau = 2R_1 \sin 2\psi + (4R_2 - R_1^{\,2})\sin 4\psi + \sum_{m=3} 2mR_m \sin 2m\psi - \sum_{m=0} (2m+1)\,S_m \cos(2m+1)\,\psi \qquad (39)$$

obtained by taking the derivative of (34) with respect to ψ and making the corresponding division.

Besided these realtively minor approximations and neglectings in deriving the above equations, Harzer procured at actual applications other simplifications as well.

He first simplified even more the relations (32) and (29) by retaining only the first five terms with cosines, i.e. all the terms with sines have been omitted – having thereby assumed the distribution of the air layers over the north and the south hemisphere to be symmetrical, entailing the mutual cancelation of these terms. As a result he obtained the following simplified formulae

$$h = a \sum_{m=o}^{4} H_m \cos 2m\varphi \qquad (40)$$

$$r = A \sum_{m=o}^{4} R_m \cos 2m\psi \qquad (41)$$

Another simplification followed from his having assumed the SERIs to be surfaces of rotation, wherewith (22) is converted into

$$F^2 = \left(\frac{\partial f}{\partial r}\right)^2 + \left(\frac{1}{r}\frac{\partial f}{\partial \psi}\right)^2 \qquad (42)$$

sinc $\frac{\partial f}{\partial \omega} = 0$. From (38) we obtain

$$\mathrm{tg}\,\tau = -\frac{1}{r}\frac{\partial r}{\partial \psi} = +\frac{1}{r}\frac{\frac{\partial f}{\partial \psi}}{\frac{\partial f}{\partial r}}$$

and (42) is transformed into

$$F^2 = \frac{\partial f}{\partial r}(1 + \mathrm{tg}^2\,\tau) = \frac{1}{\cos^2\tau}\left(\frac{\partial f}{\partial r}\right)^2 \qquad (43)$$

The family of the SERIs meridian curves being given by (29) and $R_o = 1$ (see (36)) we have

$$\left.\begin{aligned} &\frac{\partial f}{\partial r} = 1 \\ &\frac{\partial f}{\partial A} = -\frac{\partial r}{\partial A} = -\sum_{m=o}\left[\frac{d(AR_m)}{dA}\cos 2m\psi\right. \\ &\left.+\frac{d(AS_m)}{dA}\sin(2m+1)\psi\right] \\ &F^2 = \sec^2\tau \end{aligned}\right\} \qquad (44)$$

wherewith (14) becomes

$$\rho\sqrt{1-\epsilon^2} = \frac{\frac{\partial f}{\partial A}}{F\frac{d\ln n}{dA}} = -\cos\tau\,\frac{\frac{\partial r}{\partial A}}{\frac{d\ln n}{dA}} \qquad (45)$$

Note, finally, that on reducing f to the simple form

$$f = r - A = 0$$

one in fact arrives at the case of the spheric–symmetrical SERIs model, in common use in the calculus of the refractional influences. In Harzer's works one finds also the expressions corresponding to this case.

5. PHYSICAL, GEODETIC (GEOPHYSIC) AND METEOROLOGICAL FACTORS

The application of the above formulae nacessitates the knowledge of an array of physical, geodetic (geophysic) and meteorological data. Harzer made use of such data as were available in the second decade of the 20th century. Our present–day knowledge, clearly, is a good deal more plentiful. We are, consequently, able to implement Harzer's ideas more fully than he himself could in his time. It is our wish to carry out, in another paper, a complete comparison of data used by Harzer and those currently available, as well as to bring out their bearing upon the final values of refraction. On the present occasion we shall dwell on some remarks only, essential in evaluating Harzer's work.

5.1. Refractive index

At computing the refractive index n Harzer used two formulae: the one applied to the troposphere and the other to the stratosphere. In both cases he deduced the refractive index corresponding to the air at a given point on the basis of refractive indices of separate air contituents – for normal conditions and for the wave length 574 nm. The expressions derived were referred to the ether. The chromatic effect was also computed.

I should be indicated that currently rather dependable formulae are available – accurate up to 0.5 10^{-8} – for computation of the refractive index for given meteorological conditions and different wave lengths. This accuracy is quite satisfactory in so far as the refraction as such is concerned. The problems is not in the formules but in their application (Teleki, 1974a).

5.2. Geodetic (geophysic) and physico–chemical data

The geodetic (geophysic) data Harzer borrowed from Helmert (the book from 1884) and the physico–chemical data from Landolt's and Börnstein's tables from 1912.

It goes without saying that currently we are in possession of considerably better values for the purpose.

5.3. Meteorological data

Harzer, quite understandably, did not possess sufficiently accurate meteorological information on the surface layer, the less so on the state of the atmosphere at greater altitudes. Wherever possible, he used the measured values but, failing these – this was the case in particular with the variation of meteorological elements with altitude – he resorted to some interpolated, more or less correct, data or assumptions. Measured data on the hight–altitude layers of the atmosphere – up to 20 km above the ground at the most – were available for only 6 localities on the Earth's surface: Batavia (latitude -6^o), Atlantic Ocean ($+30^o$), North America ($+42^o$), England ($+51^o$), Middle Europe ($+52^o\!.5$) and Pavlovsk ($+59^o\!.75$). However, he made use of only 5 localities, omitting England on account of her vicinity to the Middle Europe. For the heights 20 km through 72 km Harzer was compelled to rely on mere hypotheses. Nevertheless he performed computations, using both measured and hypothetical data, of the SERIs (refer to 5.6.) whose trustworthiness may, evidently, be questioned.

Currently, there is a great number of meteorological stations for the investigation of the surface layer, aerological measurements are carried out at about 600 stations, artificial satellites and other facilities are in use. As a result we now possess a qualitatively and quantitatively superior knowledge of our atmosphere than it could have been possible in Harzer's time.

Proceeding from what Harzer had achieved and taking into consideration our present–day possibilities, the following more significant comments could be made:

5.4.1. Within the modern dynamical meteorology a branch has taken shape, termed „objective weather analysis", designed to describe the field of meteorological elements by polynomials (Radinović, 1968). Accordingly, it is concerned with the problems Harzer had to tackle when dealing with the SERIs. This branch of meteorology is also concerned with the rationalization of the network of meteorological stations. It could be established that real interpolation of data on elements in the free atmosphere surrounding the stations was feasible provided the stations, collecting the data, were not mutually farther than 700 km nor too close to each other. All this has to be recalled because of the fact that Harzer was able to use data acquired at only few stations mutually separated by distances of up to several thousands kilometers. Thus, his description of SERIs could not have been very reliable. Today, we enjoy a far better situation, being able to derive SERIs closer to reality. Yet there is more to that. In his computations Harzer used Lagrange's interpolation formulae. It should in this connection be observed that parabolic interpolations (whereto belongs the Langrangean one) are good for analytical functions only, and then only provided the data used are free from accidental errors. If the data entered contained errors, the results get considerably spoiled. This is why the suitability of these interpolation formulae or those serving for numerical intergration ought first to be tested on actual examples.

5.4.2. There is no possibility of interpolating meteorological data on the planetary boundary layer, least of all for those on the surface layer (Teleki, 1974b). The computations like those Harzer performed – aimed at providing interpolated data on the surface layer in Kiel – unfortunately lack reality.

5.4.3. According to Harzer, the atmosphere starts influencing the light ray at about 85 km height. He calculated the refractive index up to 72 km height. This conforms with the present–day conceptions according to which the „refraction boundary" is in fact below 100 km height. The value $(n-1)$ at 70 km height is less than $1\ 10^{-7}$, yielding at 80^o zenith distance a refraction effect of $\pm\ 0.''01$. This amount in fact lies inside the range of errors typical of astrometrical observations (Teleki, 1968).

5.4.4. It seems that Harzer way of approaching the question of effects produced by the diurnal and annual variations in the meteorological elements, wind included, is to be revised (Harzer's method of computing the wind velocity effects on the air pressure and on the air density is inadequate).

5.5. The mode of interpolation

Harzer computed, for all five mentioned stations, the air pressure for each 1 km layer up to 11 km height, and then for each 4 km layer up to 72 km height. The computations have been performed using numerical interpolation according to formulae he himself developed. He used data on temperature and humidity according to heights, thus arriving at values of $(n-1)$. Thence he determined individual SERIs (designating them by the serieal number δ from 0 to 29). Thereby, as the argument of interpolation he used not h, but $\sqrt{s} = \sqrt{\frac{h}{R}}$, R denoting the radius vector of the point P_o at the latitude φ, computed by the formula

$$R = a\,[\,1 - (\frac{5}{2}\,c - b)\sin^2\varphi]$$

Here: a – major semi–axis of the Earth's ellipsoid of rotation (= 63773971 dm), b and c are constants associated with the Earth's principal moment of inertia.

In that he intoruced $\sqrt{s}$ as the argument of interpolation Harzer underlined the objective need of setting more SERIs at lower heights, where the density is higher, than at greater heights (currently, the selection of the „step" of interpolation can be had programmewise on the computers). Harzer adopted as the step the quantity $\Delta\sqrt{s} = 0.003\ 779\ 530$, meaning that he had the SERIs computed for the heights

$$h_i = [\,\sqrt{\frac{h_i - 1}{R}} + \Delta\sqrt{s}]^2\,R$$

Thus he obtained 3 SERIs (h = 91 m, 364 m and 818 m) within the first km layer while the last SERI (at 71 273 m) is 5000 m distanc from its precedent.

Harzer adopted the + 52°5 latitude as the reference latitude. He computed the heights of SERIs in dm corresponding to this point according to the number to the steps $\Delta\sqrt{s}$. There were altogether 28 steps. Thereupon he found by integrating the (n–1) values corresponding to those heights. As a result he produced a table, appearing in his paper from 1922–24, which we, in view of its importance, reproduce as Table I.

particularly so concerning the lateral components. None the less the remark is to be passed that the meridian cross–sections of the SERIs obtained after Harzer represent relatively real layers – the limiting factors being those stated earlier. It is to be emphasized that Herzer succeded in getting an analytical approximation of, let call them, real SERIs (meridian profiles) with an accuracy – according to our calculations – of up to ± 1 dm.

The basic question in connection with the SERIs reads: can one talk about the layers of equal density on

Table I. Heights (in dm) for individual stations (at different latitudes φ) at which the (n–1) values are equal (reproduced from Harzer, 1922–24, p.18). δ is the serial number of the SERIs.

δ	$10^7 \cdot (n-1)$	$\varphi = -6°$	$\varphi = +30°$	$\varphi = +42°$	$\varphi = +52°5$	$\varphi = +59°75$
0	2825.5955				0	2271
1	2799.2391				909	3108
2	2721.1971			1498	3636	5635
3	2594.6572	2453	4837	6487	8182	9919
4	2424.9344	9733	11909	13292	14545	16063
5	2220.3937	18949	19956	21771	22727	24137
6	1995.4920	29699	30477	31951	32727	33953
7	1757.4784	42117	42765	43906	44545	45536
8	1517.1551	56198	56863	57823	58181	58618
9	1279.5875	71971	72971	73742	73636	73298
10	1044.5999	91314	91638	91648	90909	89431
11	808.3324	115010	114375	111515	110000	107270
12	588.9385	141670	137650	133169	130909	127901
13	412.6387	164151	159982	156146	153636	151156
14	281.7798	186650	183527	180669	178182	176151
15	187.4088	209830	208760	206965	204545	202926
16	121.3221	234405	235732	235079	232727	231549
17	76.4592	260607	264441	265004	262727	262016
18	46.9169	288397	294888	296741	294545	294326
19	28.0349	317775	327076	330291	328182	328477
20	16.3166	348739	360997	365654	363636	364477
21	9.2512	381285	396665	402829	400909	402320
22	5.1108	415418	434058	441823	440000	442016
23	2.7519	451129	473191	482627	480909	483570
24	1.4449	488415	514070	525245	523636	526990
25	0.7402	527256	556690	569681	568182	572308
26	0.3705	567630	601060	615946	614545	619582
27	0.1817	609477	647191	664027	662727	668933
28	0.0877	652684	695121	713925	712727	720619

5.6. Optical surfaces

Making use of data in Table I we plotted in Fig. 6. the distribution of SERIs ($\delta \geqslant 3$) as found by Harzer. It is seen that the curves concerned are not arcs of a circle, accordingly, SERIs are not circular spheres. But what matters is: the meridian profiles of the SERIs over the whole of the Earth's globe are the same. This is a serious limitation of Harzer's theory which assuredly leaves its mark on the ultimate accuracy of refraction tables,

a global scale – and if, what is their shape? Meteorological explorations disclose (Glagolov, 1970; Teleki, 1974c) that the Earth's atmosphere can on the average be represented by concentric layers of equal density, whose boundaries are fuzzy. The altitudes of boundaries of some layers cannot quite exactly be determined not only on account of fuzziness of these boundaries but also because of insufficiency of our knowledge of some phenomena in them. It follows that Harzer in principle was right in forming the SERIs. He deduced two kinds

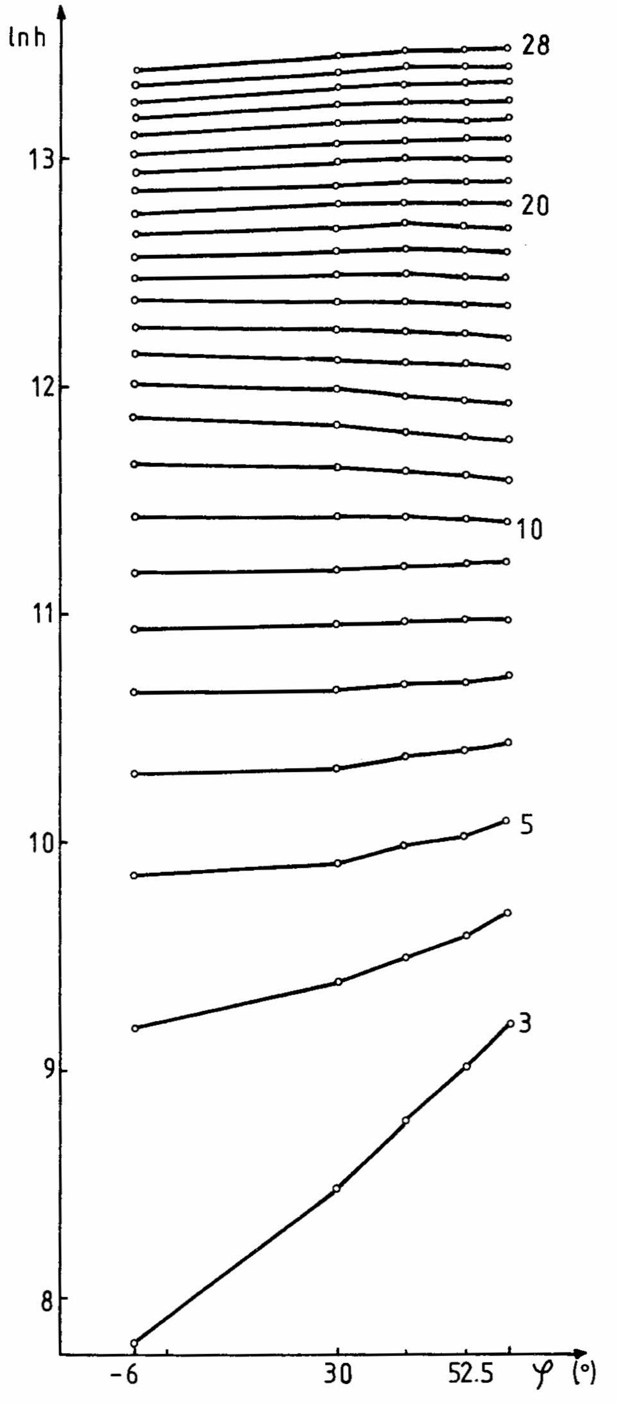

Fig. 6. Natural logarithms of heights (ln h) of the surfaces of equal density ($\delta \geqslant 3$) above some points on the Earth's surface – according to data in Table I.

of stratification: the real one – based on the measured and some hypothetical data – and the concentric – spherical one, corresponding to some averaged state of the atmosphere.

In his derivation of refractional influences for Kiel basic computations were related to the real SERIs and the rest to the spherical – concentric atmospheric layers. What were the reasons for Harzer having proceeded in this way? First of all, for practical reasons, to shorten the computations (it took him 6.5 years to elaborate his tables!). Out of 478 rays whose deflection he computed for the observing site at Kiel, the first 20 rays (for the zenith distance 90° and azimuths 0°, 45°, 90°, 135° and 180°; for the zenith distances 0°, 30°, 50°, 60°, 70°, 80°, 85° and 88° for the azimuths 0° and 180°) were treated in reference to the real SERIs. He realized that there was but a minor difference between the data provided through the real and those resulting from the spherical–concentric model. He therefore decided to compute the corresponding values for the remaining 458 rays using the spherical–concentric layers. Maybe, it is, not even to mention that at present, where computers are available, such simplifications are a matter of irrelevance.

6. APPLICATION

Let us assume that the necessary meteorological, geodetic (geophysic) and physical data are available, that the atmosphere is in a normal state and that the SERIs are surfaces of rotation – just like how Harzer proceeded. The formulae set forth in Sections 2, 3 and 4 are made use of in conformity with the following algorithm:

6.1. Determination of data for the point P_0:

- Determination of h from Table I for the given optical surface,
- From Table II one obtains the values H_1, H_2, H_3 and H_4; as one realizes from Table I these data are determined for SERIs using $\delta \geqslant 3$; for the first three surfaces Harzer used the emphirical formula

$$\ln \ln (n-1)^{-1} = q_0 + q_1 b + q_2 b^2$$

$$b = 100\left(\frac{A}{D_0} - 1\right)$$

where D_0 – an arbitrary value, while q_1, q_2 and q_3 are determined by combining the pairs a and A for the surfaces from $\delta = 3$ through $\delta = 13$, using the method of least squares, having regard to the weights;

Table. II. Values $k = 1 + H_0$, H_1, H_2, H_3 and H_4. The original data, given in logarithmic form, are borrowed from Harzer (1922–24), p.20.

δ	$k = 1 + H_0$	$H_1 \cdot 10^7$	$H_2 \cdot 10^7$	$H_3 \cdot 10^7$	$H_4 \cdot 10^7$
3	1.00013137	– 1101.995	266.127	– 146.939	36.582
4	1.00023777	– 1937.074	302.162	– 187.538	57.154
5	1.00038057	– 1222.221	516.416	– 277.434	169.691
6	1.00053602	– 1046.863	460.988	– 245.742	146.672
7	1.00071617	– 823.701	359.021	– 190.405	110.687
8	1.00091811	– 500.253	171.842	– 110.563	78.699
9	1.00114577	– 128.218	– 60.714	– 33.775	53.391
10	1.00139472	687.685	– 448.094	165.443	– 38.950
11	1.00166341	2251.749	–1123.388	557.134	– 339.617
12	1.00201464	2761.658	– 972.881	604.171	–348.826
13	1.00240337	2074.770	– 517.368	336.565	–184.556
14	1.00280412	1416.706	– 240.973	123.873	– 62.737
15	1.00322602	756.850	– 58.832	– 82.807	33.210
16	1.00367609	44.328	122.149	– 307.086	131.416
17	1.00415156	– 643.294	268.478	– 518.704	226.845
18	1.00466330	– 1509.106	519.720	– 794.419	347.496
19	1.00520011	– 2347.685	731.324	–1056.866	463.799
20	1.00576616	– 3236.905	957.921	–1335.365	587.800
21	1.00636015	– 4151.547	1181.517	–1620.540	714.101
22	1.00698528	– 5152.879	1445.306	–1935.485	854.751
23	1.00763893	– 6191.701	1714.273	–2261.413	999.769
24	1.00832227	– 7288.195	2002.257	–2606.513	1151.993
25	1.00903648	– 8467.788	2325.358	–2980.368	1315.527
26	1.00978408	– 9777.549	2715.001	–3402.593	1497.476
27	1.01056844	–11284.439	3213.142	–3897.355	1702.511
28	1.01139825	–13153.459	3926.539	–4528.767	1947.915

– Determination of the values k, c_1 and c_2 according to (33); the value $a = 6377391$ dm and $\log e = 7.82441$;
– Computation of r_0, ψ_0 and A according to (34), (35) and (36);
– The quantities AR_m, $\frac{d(AR_m)}{dA}$ and $\frac{d \ln n}{dA}$ can be had from tables in Harzer (1922–24), p. 22–24;
– $(\frac{\partial r}{\partial A})_0$ computed according to (44);
– Determination of σ_0 according to (39), than $\chi_0 = \psi_0 + \sigma_0$ and $\mathcal{H}_0 = \chi_0 - \varphi$;
– Taking into account that $\omega_0 = 0$ one obtains from (20) x_0, y_0 and z_0;
– The values η_0 and ζ_0 follow from (27) where η_{Go} and ζ_{Go} are geodetic zenith distances and azimuths, respectively;
– Knowing ζ_0 and η_0, from (25) are deduced α_0, β_0 and γ_0.

6.2. Determination of the corresponding values for the point P_1:

– Having obtained for the point P_0 the values x_0, y_0, z_0 and α_0, β_0 and γ_0 we compute, in continuation, using the step $\Delta\sqrt{s}$, according to (17) by mechanical equaring α_1, β_1 and γ_1 for the neighboruing point P_1; account should be taken of at the point P_0 $\lambda = \mu = 0$ and $\nu = 1$, since the normal on the point P_0 coincides with the z–axis, thereafter

$$\epsilon = \gamma = \cos \xi_0$$

$$\rho = -\cos \sigma_0 \frac{(\frac{\partial r}{\partial A})_0}{(\frac{d \ln n}{dA})_0 \sin \xi_0}$$

– Mechanical integration of the equations

$$\frac{dx}{ds} = \alpha \qquad \frac{dy}{ds} = \beta \qquad \frac{dz}{ds} = \gamma$$

furnishes x, y and z for the point P_1;

– From (21) are derived r_1, ψ_1 and ω_1;
– Knowing r_1 and ψ_1 we obtain from tables in the same way as we did for the point P_0 the corresponding values A, AR_m, $\frac{d \ln n}{dA}$, $\frac{\partial r}{\partial A}$, χ and σ;
– λ, μ and ν are obtained from (23), ϵ from (13) and $\rho\sqrt{1-\epsilon^2}$ from (45);

– Now we are able to proceed to the solution of the equations (17) for the point P_1.

6.3. Determination of the corresponding values for the point P_i ($i > 1$):

– The computations are performed in the same manner as they were for the point P_1.

6.4. Closing computations:

– From (24) are derived the values ζ and η;
– Formulae (28) furnish ζ_G and η_G;
– The influences of refraction is obtained from (26).

Inasmuch as a stricter implementation of Harzer's ideas is desired, the simplifications effected in (40) through (45) are not to be used and most of allowences in the formulae (1) through (39) should be cancelled. Full justness of the Fermant's principle – lying at the core of all Harzer's computations – in its application to the real atmosphere is further to be doubted (Teleki, 1974d), but there is for the time being neither better nor more rigorous solution.

7. CONCLUSION

It may be stated that Harzer correctly recast his basic ideas into mathematical formulae, being thereby compelled – for a number of reasons – to help himself with some simplifications and allowances. As it is unquestionable that Harzer's ideas keep being of interest even today, we deem it opportune to go about their implementation – as necessary conditions do exist – clearly, with more consistency than it was possible in his time.

For smaller zenith distances – even up to 45° – the three – dimensional model of atmosphere yields practi cally the same results as the spheric–symmetric model. This, of course, is true on the condition that the effects of the perturbed ground layers are ignored (Teleki, Saastamoinen, 1982). From this statement it follows that three–dimensional refraction effects should be inquired into for two basic reasons: first, because the observations are also performed at larger zeinth–distance and, second, because of the probably very strong influence of the surface layers. It is precisely due the these perturbed surface layers that the compensation of the refraction anomalies, owing to the different tilts of the lower and higher atmospheric layers of equal densities (Wünschmann, 1931; Teleki, Saastomoinen, 1982) is overturned, requiring special analysis.

In these indispensable studies of refraction Harzer's works – particularly if brought up–to–date as proceeded in the present paper – may prove highly rewarding.

The present analysis was carried out while one of the authors (A. Yu. Yatsenko) was a guest at the Belgrade Astronomical Observatory in 1984.

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ON THE ROOM REFRACTION

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SUMMARY. Description is presented of the method of determination of the room refraction in the pavilion of the meridian circle of the Engelhardt Observatory, Kazan, USSR, from temperature observations. Given are also temperature differences, as furnished by this method, for the average summer and winter nights throughout the pavilion meridian, along with the tilts of surfaces of equal refractive indices and the magnitudes of the room refraction at 0^{o} through ± 90^{o} zenith distances.

1. INTRODUCTION

The term "room refraction" shall be understood as meaning the extra bending of the light ray in the meridian plane, taking place at its passing through the observing room, in excess of the bending implied by the theory underlying the standard refraction tables.

2. PAVILION

The pavilion of the meridian circle (MC) of the Engelhardt Observatory at Kazan, USSR, is a twin metallic parallelopiped, made of corrugated iron, with the east–west length of 10 m, north–south of 7 m and the height from the floor to the uppermost point in the roof of 6 m. A natural ventilation is provided: it takes place through the openings, distributed all over the pavilion's perimeter in the lower part of its walls, and the exhaust–pipes in its roof. By sliding back the two shutters in the roof an apperture 1.2 m wide is created.

3. METHOD OF INVESTIGATION

At our studying the room refraction inside the pavilion of MC, Engelhardt Observatory, we took the usual course of measuring the temperature at different points in the observing room. However, out of purely practical considerations, the question was approached from a different direction than has hitherto been practised by the researchers. The basic idea of our method is the following. The atmosphere inside the pavilion and at some distance from it is conditionally divided into horizontal air layers 2 m thick. Next, we compute, for particular time moments and zenith distances, the bending of the light ray employing thereby the temperature measurings made at given points in the observing room and outside it for each layer separately. The computations are performed using the common differential equation of refraction.Yet, instead of the zenith distance z the incidence angle θ of the light ray on the given layer is introduced. This angle is, in its turn, computed from the temperature observations at the points concerned. The refraction values thus obtained for all the layers are summarized and the results compared with the tabular refraction values. The distribution of points at which the temperature was measured is illustrated in Figures 2 and 3.

4. THE PROBLEM OF TEMPERATURE MEASUREMENTS

In order to check the method in practice we employed, in the first approximation, the very simplest outfit – the mercury thermometer (one division = 0$.^{\circ}$2 C, therefore the reading accuracy = ± 0$.^{\circ}$02 C). It should forthwith be stressed that the notions "the accuracy of temperature measurements under conditions of actual observations" and "the outfit accuracy" of a thermometer do not coincide.

4.1. Outfit accuracy

The experts in thermometry maintain (Popov, 1954) that: "... all the errors distorting the thermometer indication can rigorously be taken into account and be expressed, with sufficient accuracy, by adequate corrections ...". As there is some vagueness about this question in astrometry we shall dwell upon it more closely. Let us enumerate the origins, vitiating the thermometer indication (Popov, 1954):

1. External pressure. The deviation of the external pressure from 101325 Pa gives rise to a minor

deformation in the mercury socket, consequently the thermometer indication is modified.

2. Internal pressure. It is composed of: a) mercury meniscus pressure (due to the capillary forces), b) pressure of the mercury or gas vapours in the thermometer and c) hydrostatic pressure, dependent on the temperature and position of the thermometer relative to the plumb line.
3. Division value. The division value, generally speaking, is different in different parts of the thermometer scale.
4. Zero point lowering. This is a consequence of the glass ageing which leads to a slow depression of the zero point in the course of many years.
5. Column forward bending. It arises from an incomplete loading of the thermometer in a medium whose temperature is measured.
6. Thermic inertia. In the thermometry this error is, by convenience, referred to as "rate of cooling (warming) constant" τ, which is dependent on individual properties of the thermometer (the thickness and the shape of the mercury socket and of its walls, the shape of the ampulla, the sort of glass and the composition of the protective tube in general and the like), on the medium properties (thermal capacity, rate of the temperature variation).
7. Dead motion. The motion of the mercury within the narrow capillary proceeds unevenly, by jumps.

The factors 1, 2a, and 7 are apparent in extremely precise thermometers only, as for instance in calorimetric thermometers, in which the capillary diameters attain hundredths of a milimeter and the measuring accuracy is as high as ± 0°001 C or even higher. As for the meteorological thermometers we have been using, all these effects play an insignificant role. The factor 5 is completely absent in our case. The factors 2b, 2c, 3, 4 and also the constant part of 6 failed to affect our results by virtue of the differential character of our temperature measurements and due to the corresponding corrections having been applied. The latter have been determined by repeated comparison with one of them, *conditionally selected reference thermometer*. From what has been said it follows that the outfit accuracy of the thermometer (relative one) equals in our case the reading accuracy of its indication, i.e. ± 0°02 C.

4.2. The accuracy of temperature measurings in actual observations.

This accuracy is dependent on the variable part of the factor 6, i.e. on the thermic inertia of the thermometer and the medium properties. According to investigations (Volchkov and Ponomarev, 1966) the temperature at a given point in the observing room is continually fluctuating around some mean value, which in its turn undergoes even variation as days are progressing, in conformity with the temperature variation outside the observing room. These fluctuations vitiate in a random way the thermometer indications which results in the accuracy of the unit reading of the mean temperature (Fig. 1) being curtailed.

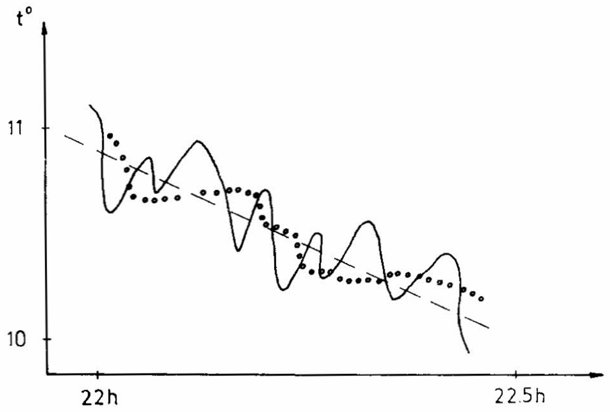

Fig. 1. Variation in time of the possible instantaneous temperature (solid line) at an arbitrary point inside the observing room, variation of the mean temperature (dashed line), and thermometer indication (dotted line).

Note that efficient measures have been taken concerning the thermometer protection against the direct infrared radiation. The meteorological thermometer is, generally ill–suited for measuring the instantaneous temperature. This is why we set ourselves, from the very beginning, the task of determining but the *systematic part* of the room refraction, obtenable from the mean temperature field established after many nights work.

5. RESULTS OF THE TEMPERATURE MEASUREMENTS

In Fig. 2 by I–I and II–II are marked the masts, erected outside the pavilion at 1.3 m distance from its walls. AA, BB, CC and DD are elastic wires stretched between the masts. By these wires the pavilion's interior is, conditionally, divided into three layers: BAAB, CBBC, and DCCD. The thermometers were suspended on these wires and could easily be displaced along them. For reading the thermometers we climbed the ladder. The temperature was measured with 7 thermometers at 21 points, distributed as shown in Figs. 2 and 3. Each one of the thermometers served for temperature determination at three neighbouring points. At each of these points the thermometers were kept not less than 10 minutes to allow them absorbing the correct temperature. The measuring cycle at all 21 points took a little above 20 minutes. The reduction of the temperature values to one moment furnished the temperature meridian cross–section of MC pavilion for that moment. In 30 nights we obtained 132 temperature cross–sections and in 8 days 30 day–time cross–sections. The measurements were carried out from 9 September 1978 to 30 June 1979 by clear windless weather in summer and winter alike, embracing a temperature range from $-25^{\circ}C$ to $+23^{\circ}C$.

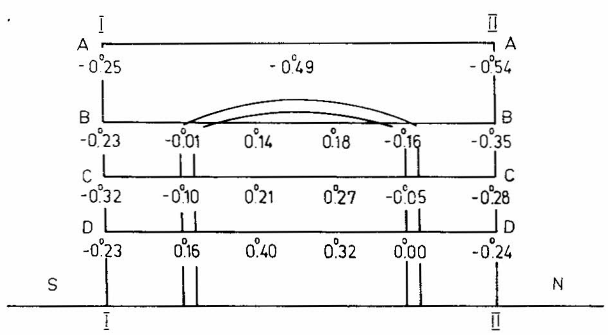

Fig. 2. Temperature differences in the MC pavilion and its vicinity from many measurements on summer nights. AA, BB, CC and DD are elastic wires stretched between the masts I–I and II–II. The double line marks the cross–section of the pavilion in N–S direction.

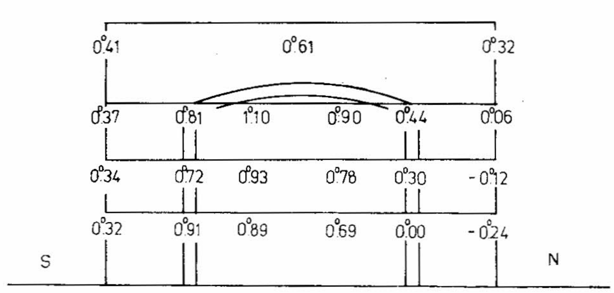

Fig. 3. Temperature differences in MC pavilion and its vicinity, meaned from many measurements on winter nights.

As a result of the processing of measurements we succeded to bring out the peculiarities of the temperature distribution in the observing room of our MC. We note first that the temperature distribution in the observing room is variable with the seasons and the day time. A continuous irregular variation of the temperature distribution is perceived, but the overall lawfulness is preserved. In Figs. 2 and 3 are shown the temperature differences between 20 points inside the observing room and a conditionally selected point (marked by 0°.00) computed as means from many respective measurements on summer ($t^{o} > -5^{o}C$) and winter ($t^{o} < -5^{o}C$) nights.

The accuracy $\Delta a_{\bar{t}}$ of the temperature values $\bar{t}$ at the j–th (j = 1, 2, ..., 21) point is given by

$$\Delta a_t = \sqrt{(\Delta a)^2 + (\Delta a')^2} = \pm 0^{\circ}.04 \qquad (1)$$

where Δa – reading error at the j–th point before its reduction to the system of the conditionally selected reference thermometer, $\Delta a'$ – the error in the correction to the reduction of $\bar{t}_j$ into the reference thermometer system. Since Δa and $\Delta a'$ have a common origin, they can be computed by the same formula, known from the probability theory

$$\Delta a = \Delta a' = \sqrt{t_{\alpha}^2(n)\, \Delta S^2 + (k_{\alpha}/3)^2 \delta^2} = \pm 0^{\circ}.02 \quad (2)$$

where δ – the outfit error, equalling $\pm 0^{\circ}.02$ C, $\Delta S = \sqrt{\Sigma(t-\bar{t})^2/n(n-1)}$ – mean error of the mean value $\bar{t}'$ or of the correction to $\bar{t}'$. $t_{\alpha}(n)$ – the value in the Student's statistics at $\alpha = 0.90$ and n – the number of temperature cross–sections (n = 62 for the summer nights and n = 73 for the winter nights), $k_{\alpha} = t_{\alpha}(\infty)$.

6. COMPUTATION OF TILTS OF THE SURFACES OF EQUAL REFRACTIVE INDICES

The results illustrated in Figs. 2 and 3 made it possible to deduce, upon computing the pressure at these points according to the barometric formula, the air density at these same points for the mean summer and winter nights, respectively. It turned out that the air pressure during night inside the pavilion was always lower than outside it.

During the summer nights an assymetry takes place only in the shutter of the pavilion in N–S direction, while no assymetry exists in the interior or the exterior of it. Inside the observing room the air density increases with height. This is a highly interesting result.

On winter nights the air density both inside and outside the observing room sharply decreases with the height. A density assymetry sets in. The air to the north is denser both inside the observing room and outside it.

From the density values ρ we obtained the magnitudes of the tilts i of the equal refractive index surfaces (ERIS) at all the points investigated according to the method proposed in (Zverev, 1946). From Fig. 4 one can easily derive the formula giving the ERIS tilt **i**:

$$i = \operatorname{arc\,tg} \frac{\partial \rho / \partial d}{\partial \rho / \partial h} \qquad (3)$$

signifying the dependence of **i** on the horizontal $(\partial\rho/\partial d)$ to vertical $(\partial\rho/\partial h)$ density gradients ratio.

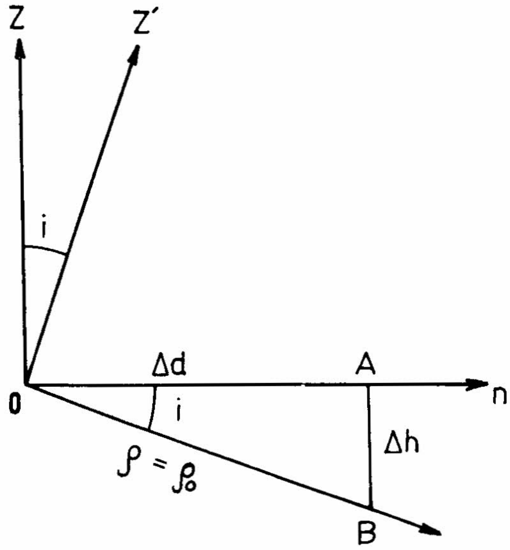

Fig. 4. Towards deduction of the tilt i of the equal refractive index surfaces (ERIS).

The Figs. 5 and 6 illustrate the mean distributions of the ERIS tilts for the summer and winter nights, respectively. It is seen that these tilts assume the pavilion shape irrespective of the season. In other words, the classical theory of the room refraction (Bakhuyzen, 1868) appears on the whole true. This conclusion does not contradict the dependence of the temperature distribution on seasons, since the ERIS tilts are a function of the horizontal to vertical density gradients ratio which is a quantity of quite a different nature than the temperature. The ERIS tilts are illustrated in Figs. 5 and 6 for sake of clarity only. In fact, we have been dealing with the analytical expressions of the ERIS tilts.

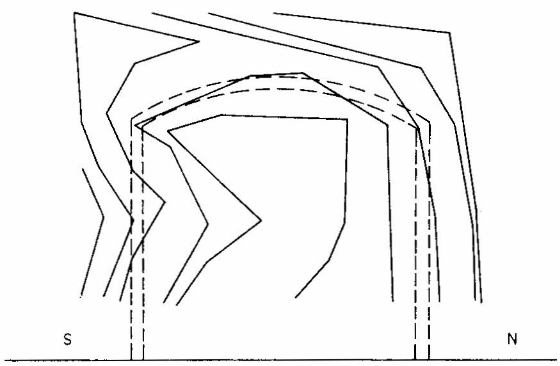

Fig. 5. The distributions of the ERIS tilts for the summer night in N–S direction.

In Fig. 7 is shown a part of the conditional layer (Fig. 2) CBBC for $19^{h}.5$ mean local time on 22 February 1979. Each point of investigation can be taken as an origin of the rectangular coordinate system. Thereupon, making use of the air density values at 4 neighbouring points, the ones to the north, south, above and below, the ERIS tilts were obtained by the formula (3) within the corresponding quadrant of coordinate system whose origin is the given point. Such a point in Fig. 7 is marked by an asterisk. It now becomes easy to compute the ERIS tilts, proceeding from geometrical considerations, for any zenith distance **z** at points of intersection of the light ray with the straight lines AA, BB, CC and DD. The calculus is separately performed for below each of these lines as for above them. For the light ray in Fig. 7 the ERIS tilt of the upper boundary of the layer CBBC is +86° and that of the lower boundary it amounts to −80°.

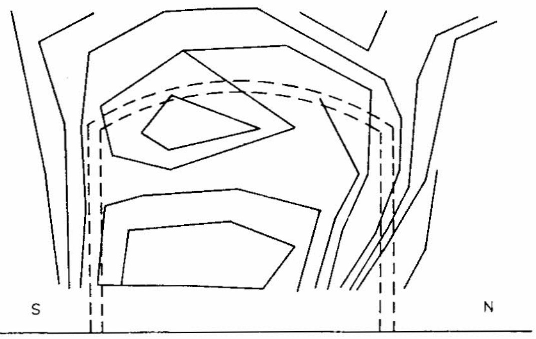

Fig. 6. The distributions of the ERIS tilts for the winter night in N–S direction.

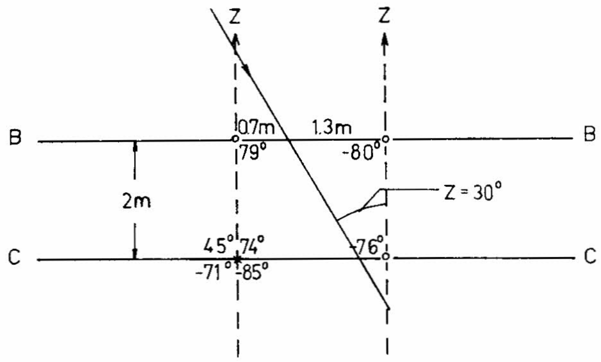

Fig. 7. An example of the analytical derivation of the ERIS tilts at particular points on the light ray trajectory at the zenith distance 30° at $19^{h}.5$ on 22 February 1979.

7. ROOM REFRACTION CALCULUS

Once the ERIS tilts along the light ray path across the observing room determined, we computed the refraction value for the zenith distances 10°, 20°, ..., 80°, ..., 89° at determinate time moments separately for each conditional layer. Thereby the light ray incidence angle on the ERIS θ at the given **z** has been used instead of the zenith distance. The incidence angle was computed by the formula θ = z–i, where i – the ERIS tilt. First it was **i** of the upper boundary of the conditional layer for a given z, then **i** of the lower boundary. The usual differential equation of refraction

$$r = \int_{1}^{n_0} \frac{a\, n_0 \sin\theta}{\sqrt{r^2 n^2 - a^2 n_0^2 \sin^2\theta}} \frac{dn}{n} \qquad (4)$$

was used. The refraction values obtained with $i^{k,z}_{upper}$ and $i^{k,z}_{lower}$ k = 1, 2, 3, were meaned and the mean refraction values deduced for the given layer **k** at the given zenith distance z. At calculating θ as well as at interpolating **i** account is taken of the sign of i, securing that the angle θ has always been less than 90°, but having always either positive or negative sign. The sign of the refraction changed correspodingly, being moreover dependent on the ratio of the air density above the conditional layer to the one below it. The refraction values for each zenith distance were summarized according to the layers and are presented in Table I.

Table I: Mean room refraction. The accuracy of the tabulated values = ± 0.″02.

	Summer night		Winter night	
z	South	North	South	North
10°	+0.″02	–0.″01	+0.″06	–0.″08
20	+0.02	0.00	+0.10	–0.06
30	+0.04	+0.05	+0.06	–0.02
40	–0.02	+0.01	+0.02	+0.01
50	+0.01	–0.04	–0.06	–0.12
60	–0.02	+0.09	–0.08	–0.18
70	+0.06	–0.09	–0.02	–0.14
80	+0.08	0.00	+0.06	–0.13
82	+0.09	+0.01	+0.08	–0.09
86	+0.06	+0.04	+0.09	–0.07
89	+0.05	+0.06	+0.07	–0.09

What is the reason of the refraction being that small? This is due to two causes. First, the refraction values for different layers have opposite signs, i.e. they cancel each other. Second, the light ray incidence angle θ on the ERIS is less than 30° at almost all the zenith distances.

The smallnes of the incidence angle θ on the ERIS suggested an important conclusion: at computing the common tabular refraction one should not employ the temperature at the occular, as has always been done at the Engelhardt Observatory, but rather the one at the light ray entrance into the pavilion's "operative zone". The corresponding corrections for the transition $t^o_{oc} - t^o_{o.z.}$ are easily obtainable from the data in Figs. 2 and 3 for any zenith distance. The corrections, obtained in the way indicated, to the refraction Δr as a sum with the mean refraction furnished the Table II.

Table II: The sum $\Delta r = f(t^o_{oc} - t^o_{o.z.})$ and the mean room refraction.

	Summer night		Winter night	
z	South	North	South	North
10°	0.″00	+0.″03	–0.″07	+0.″07
20	+0.03	+0.05	–0.10	+0.07
30	+0.02	+0.03	–0.04	+0.05
40	+0.10	+0.12	+0.02	+0.05
50	+0.08	+0.18	+0.16	+0.25
60	+0.14	+0.06	+0.12	+0.38
70	+0.16	+0.31	+0.16	+0.59
80	+0.39	+0.43	+0.16	+1.09
83	+0.52	+0.54	+0.20	+1.46
89	+2.52	+2.46	+1.27	+6.76

The application of the data in Table II both to the observed catalogue of 203 stars (Yatsenko, 1980) and to the major planets observations at Engelhardt Observatory resulted in most cases in a diminishion of the 0–C differences. By this, the veracity of the results and conclusions advanced was confirmed.

8. CONCLUSIONS

The correctness is confirmed of the theoretical foundations of our method, as well as its efficiency. It is manifested by the acquision of a large body of information at little expenditure of time and means.

The room refraction in the Engelhardt Observatory MC pavilion in most cases (89%) is below 0.″15.

At computing the refraction one should use the air temperature at the light ray entrance into the "operative zone" of the pavilion.

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EFFECTS OF EXTRAFOCAL OBSERVATION WITH THE SOLAR SPECTROGRAPH OF THE BELGRADE ASTRONOMICAL OBSERVATORY. III. INTEGRATION OF THE LIMB EFFECT

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SUMMARY. Besides six already known limb effect functions, another one (the Belgrade–Oxford function) has been evaluated. Simulating numerically extrafocal observations of the solar disk, a set of corrections for space–integration of solar radiation within the squares of 3'.8, 2'.0 and 1'.0 sides has been calculated for all the limb effect functions. The corrections amount up to 11 ms^{-1} (or up to 4 ms^{-1} – in the case of Belgrade observations).

1. INTRODUCTION

Corrections to the observed solar rotation line–of–sight velocities due to averaging of the radiation within certain parts of an extrafocal solar image have been found earlier (Kubičela and Vince, 1983, and 1984). Similarly, the integration of radiation in square regions of 3'.8 x 3'.8 in the extrafocal solar image usually applied in the Belgrade observational program – of similar other observations – may introduce false values in the limb effect observations.

A set of corresponding limb effect corrections is being evaluated numerically in this paper.

2. THE LIMB EFFECT

In spite of a long history of the limb effect problem, its nature is not yet clear. The dependence of the centre–to–limb line shifts on the heliocentric angle is known for almost 80 years (Halm, 1907). Some other characteristics of the limb effect, e.g. its spectral line dependence, became evident much later.

In order to study consequences of the integration of radiation within some given areas of the solar disk, one needs a quantitative knowledge of the limb effect. To evaluate the corresponding corrections, we used the following alternative functions describing dependence of the limb effect L_G (G being a current index of the functions, G = 1, 2, . . .7) on the heliocentric angle θ, valid only for certain Fraunhofer lines (in ms^{-1}):

From Howard and Harvey (1970), for FeI 525.0 nm

$$L_1 = 339\,(1 - \cos\theta)^2, \tag{1}$$

from Plaskett (1973), for $\lambda \approx 630$ nm

$$L_2 = -\,1360\,(\cos\theta - 1) + 735\,(\cos^2\theta - 1), \tag{2}$$

from Howard et al. (1980), for FeI 525.0 nm

$$L_3 = 740\,(1 - \cos\theta)^3, \tag{3}$$

from Bruning (1981), for FeI 525.0 nm

$$L_4 = 510 - 590\cos\theta - 1130\cos^2\theta + 1680\cos^3\theta - 470\cos^4\theta, \tag{4}$$

again from Bruning (1981), for FeI 557.6 nm

$$L_5 = 220 - 730\cos^2\theta + 510\cos^4\theta, \tag{5}$$

and from La Bonte and Howard (1982), for FeI 525.0 nm

$$L_6 = -\,155\,(1 - \cos\theta) + 727\,(1 - \cos\theta)^3. \tag{6}$$

So far, observations at Belgrade were carried out in the line FeI 630.25 nm and the limb effect results were published on two occasions (Kubičela and Karabin, 1977, and 1979). The interval of heliocentric angle covered in those observatons was from 0° to 52°. In order to interpolate the Belgrade measurements of the limb effect along the central meridian we combined them with the preliminary Oxford data for the same wavelength and for predominantly high heliocentric latitudes published by Adam et al. (1976). As a first approximation, a 4-th power polynomial in cos θ has been interpolated through both sets of data. The corrections found according to the procedure described in Chapter 3, were applied to the Belgrade limb effect measurements and, combining them again with the Oxford data, a second approximation of the Belgrade–Oxford function L_7 (θ), in ms^{-1}, for FeI 630.25 nm, has been obtained:

$$L_7 = 548 - 2050\cos\theta + 4142\cos^2\theta - 4683\cos^3\theta + 2042\cos^4\theta. \tag{7}$$

The two approximations of this function differ by only 10 ms^{-1} at the limb and by 0.5 ms^{-1} at the centre of the solar disk. The second approximation itself for $\theta = 0^{o}$ yields $L_7 = -0.7$ ms^{-1}, having a tangent not strictly horizontal. Some systematic discrepancies may arise between Belgrade and Oxford data because of different parts of the spectral line profile used in measurements for both sets of data: line shifts are measured in the wings at Belgrade and in the line's core at Oxford. Hence Belgrade data define mainly the central portion of the limb effect curve and the Oxford ones modify its peripheral part. We consider these inadequacies to be acceptable for the purpose.

All seven limb effect curves, L_1 to L_7, are shown in Figure 1 as functions of $\sin\theta$, the relative distance from the centre of the solar disk.

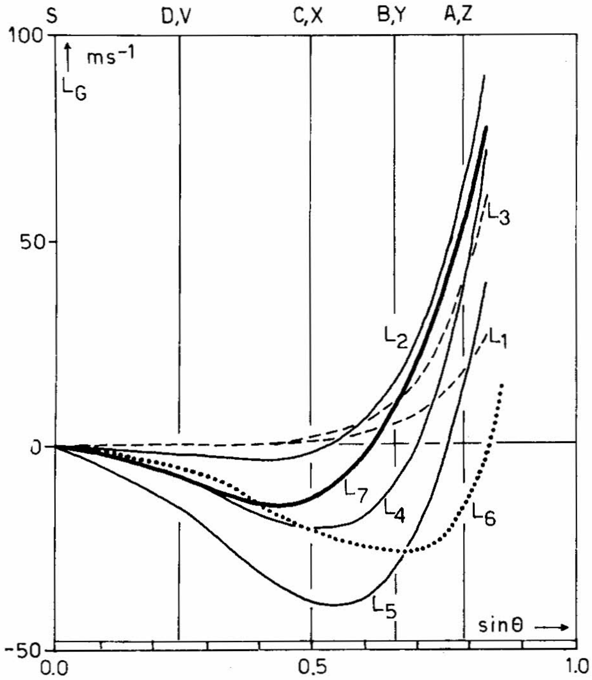

Fig. 1. Seven limb effect curves L_G versus $\sin\theta$ (θ = heliocentric angle) bringing into prominence their shape at the central part of the solar disk. The positive sense of the ordinate corresponds to a red shift.

3. THE NUMERICAL PROCEDURE

Following, in general, the concept of dividing the observed 3.8 x 3.8 square region of the solar disk into 25 small equal squares (Kubičela and Vince 1983), a limb effect value has been calculated for each one of them and for each of the limb effect functions (1) through (7).

The limb effect field within the solar disk is characterized by a central symmetry. The limb effect value in a spectral line and at a given point of the solar disk (small square) should depend only on θ but, as the orientation of the 3'8 x 3'8 square regions changes with P (position angle of the solar rotation axis) the corresponding angle θ will also depend on P. Hence, the rectangular coordinates of the centres of 25 small squares specified by indices i (i = 1, 2 ,. . . 5) and k (k = 1, 2,. . 5) are found from

$$x_{i,k} = X + d(i-3)\cos P + d(k-3)\sin P \qquad (8)$$
$$y_{i,k} = Y - d(i-3)\sin P + d(k-3)\cos P$$

where X and Y are the coordinates of the central point (i = 3, k = 3) of the observed square region and d is the length of the side of a small square (being for our case of integration of radiation within 3'8 x 3'8 equal to 1 mm or 0.0476 of the radius of the solar image). The relations (8) obviously describe the rotation of the square regions by the angle P around their central points. Then, in consideration of the geocentric central projection of the solar globe into the solar disk, the heliocentric angles of the centres of each small square are calculated as

$$\theta_{i,k} = \arc\sin\left(R_o^{-1}\sqrt{x_{i,k}^2 + y_{i,k}^2}\right) - R_o^{-1}\,S\sqrt{x_{i,k}^2 + y_{i,k}^2} \qquad (9)$$

where S is the angular radius of the solar disk and R_0 the radius of the solar image (in the same units as $x_{i,k}$ and $y_{i,k}$). Heliocentric angles (9) have been used in calculating the limb effect values $L_{G,i,k}$.

The integration of radiation within the observed square region has been numerically simulated by the weighted mean

$$\bar{L}_G = \left[\sum_{i=1}^{5}\sum_{k=1}^{5} I(\lambda)_{i,k}\right]^{-1}\sum_{i=1}^{5}\sum_{k=1}^{5} I(\lambda)_{i,k}\,L_{G,i,k} \qquad (10)$$

where $I(\lambda)_{i,k}$ is the photospheric continuum intensity. It depends on $\theta_{i,k}$ and the wavelength, λ, according to the relation

$$I(\lambda)_{i,k} = 1 - u_1 + u_1\cos\theta_{i,k}$$

where $u_1 = 0.625$ for $\lambda = 525$ nm, $u_1 = 0.590$ for $\lambda = 557$ nm and $u_1 = 0.525$ for $\lambda = 630$ nm (Allen, 1977).

Instead of the calculated limb effect (10) – that can be taken as being equivalent to the observed one over the whole square region – one would expect to get the limb effect value $L_{G3,3}$ corresponding to the central point of the square region (i = 3, k = 3).

The limb effect correction for the limited space resolution (3'8 x 3'8 in our case or 2' x 2' and 1' x 1' in some other ones) is then

$$C_G = L_{G,3,3} - \overline{L}_G \cdot \qquad (11)$$

Corrections (11) are given in Table I where the first and second columns contain the points of the solar disk regularly observed at Belgrade and their heliocentric angles θ. As the quantities C_G depend on the applied space resolution (d in (8)) they have been, besides the Belgrade resolution 3.8 x 3.8 calculated also for the squares 2' x 2' and 1' x 1'. These resolutions are indicated in the third column. In the remaining seven columns the limb effect corrections, evaluated according to various limb effect functions, L_1 to L_7, and for the three cases of integration areas, are given. The corrections have to be applied to the observed line shifts taking the redward sense as the positive one.

Some dependence of C_G on the position angle of the solar rotation axis P, has been expected. However, it turned out that this influence, for the considered conditions 0.1 ms^{-1} at most, was practically negligible and therefore not shown in Table I.

6. CONCLUSION

A sample of limb effect curves, Figure 1, some of them monotonous (mainly the old ones) and some with a minimum at $0.45 < \sin\theta < 0.70$ (the more recent ones) have been taken into consideration. The averaged limb effect values – like the solar roation – differ from the non–averaged ones by an amount of up to about 10

Table I: Limb Effect Corrections, C_G (in ms^{-1})

Points	θ (°)	Resolution (')	L_1	L_2	L_3	L_4	L_5	L_6	L_7
A, Z, R_W, R_E	51.9	3.8	−4.6	−9.9	−9.5	−10.7	−6.3	−8.5	−4.4
		2.0	−1.2	−2.6	−2.5	−2.9	−1.8	−2.2	−1.2
		1.0	−0.3	−0.7	−0.6	−0.7	−0.5	−0.5	−0.3
E_1, H_1 O_1 R_1	44.8	3.8	−2.8	−5.6	−4.3	−6.7	−5.5	−3.5	−3.7
		2.0	−0.8	−1.5	−1.1	−1.8	−1.5	−0.9	−1.0
		1.0	−0.2	−0.4	−0.3	−0.5	−0.4	−0.2	−0.3
F_2, G_2, P_2, Q_2	44.5	3.8	−2.7	−5.5	−4.1	−6.6	−5.4	−3.4	−3.7
		2.0	−0.7	−1.5	−1.1	−1.8	−1.5	−0.9	−1.0
		1.0	−0.2	−0.4	−0.3	−0.5	−0.4	−0.2	−0.3
B, Y, T, U	40.9	3.8	−2.1	−4.1	−2.7	−5.0	−4.7	−2.1	−3.5
		2.0	−0.6	−1.1	−0.7	−1.4	−1.3	−0.5	−1.0
		1.0	−0.2	−0.3	−0.2	−0.4	−0.3	−0.1	−0.2
F_1, G_1, E, H, O, R, P_1, Q_1	33.8	3.8	−1.3	−2.3	−1.1	−2.6	−3.0	−0.5	−2.8
		2.0	−0.4	−0.6	−0.3	−0.7	−0.8	−0.1	−0.8
		1.0	−0.1	−0.2	−0.1	−0.2	−0.2	0.0	−0.2
C, X, K, N	29.8	3.8	−0.9	−1.5	−0.6	−1.6	−2.0	−0.1	−2.2
		2.0	−0.3	−0.4	−0.2	−0.5	−0.6	0.0	−0.6
		1.0	−0.1	−0.1	0.0	−0.1	−0.1	0.0	−0.2
F, G, P, Q	20.6	3.8	−0.4	−0.4	−0.1	0.0	+0.1	+0.4	−0.6
		2.0	−0.1	−0.1	0.0	0.0	+0.1	+0.1	−0.2
		1.0	0.0	0.0	0.0	0.0	0.0	0.0	−0.1
D, V, L, M	14,4	3.8	−0.2	0.0	0.0	+0.7	+1.3	+0.5	+0.3
		2.0	0.0	0.0	0.0	+0.2	+0.4	+0.1	+0.1
		1.0	0.0	0.0	0.0	+0.1	+0.1	0.0	0.0
S	0.0	3.8	0.0	+0.4	0.0	+1.3	+2.5	+0.5	+1.5
		2.0	0.0	+0.1	0.0	+0.4	+0.7	+0.1	+0.4
		1.0	0.0	0.0	0.0	+0.1	+0.2	0.0	+0.1

ms^{-1}. Such a quantity may not be taken as negligible in contemporary photospheric velocity research.

The corrections calculated on the basis of L_7 will be applied in the reductions of Belgrade observations of photospheric large–scale velocities in the line FeI 630.25 nm. Further improvements of L_7 are, however, possible as well as a change of the wavelength (spectral line) used at the observations. In that case, some other L_G function may be used or a new limb effect curve can be found in a way as proceeded at deriving the relation (7).

APPENDIX

A Comment on Previous Results

Due to an unnoticed programming error, some numerical results in the first paper of the current series (Kubičela and Vince, 1983) are inaccurate. In general, the found corrections have to be smaller and their dependence on P and B_0 less conspicious. The published conclusion does not change. The columns in Table IV has to be corrected and read:

CM		0	0	0	0	0	0	0	0	0
RE,	RW	8	8	8	8	8	8	8	8	8
T,	U	5	5	5	5	5	5	5	5	5
N,	K	3	3	3	3	3	3	3	3	3
M,	I	1	1	1	1	1	1	1	1	1
G2,	F2	3	3	3	2	2	2	2	2	2
G1,	F1	2	2	2	2	2	2	2	2	2
G,	F	2	2	2	2	2	2	2	2	2
Q,	P	2	2	2	2	2	2	2	2	2
Q1,	P1	2	2	2	2	2	2	2	2	2
Q2,	P2	2	2	2	2	3	3	3	3	3
H1,	E1	5	5	5	5	5	4	4	4	5
H,	E	4	4	4	4	4	4	4	4	4
R,	O	4	4	4	4	4	4	4	4	4
R1,	O1	5	4	4	5	5	5	5	5	5

Similarly, in Table I of the second paper of the same series (Kubičela and Vince, 1984) the columns for a = 3'8, 2'0 and 1'0 (the ones for a = 0'5 being zero) should read:

CM		0	0	0	0	0	0	0	0	0
RE,	RW	8	2	1	11	3	1	15	4	1
T,	U	5	1	0	7	2	0	9	2	1
N,	K	3	1	0	4	1	0	5	1	0
M,	L	1	0	0	2	0	0	2	1	0
G2,	F2	2	1	0	3	1	0	3	1	0
G1,	F1	2	1	0	2	1	0	3	1	0
G,	F	2	0	0	2	1	0	2	1	0
Q,	P	2	0	0	2	1	0	2	1	0
Q1	P1	2	1	0	2	1	0	3	1	0
Q2,	P2	3	1	0	3	1	0	7	1	0
H1,	E1	5	1	0	6	2	0	7	2	0
H,	E	4	1	0	5	1	0	6	2	0
R,	O	4	1	0	5	1	0	6	2	0
R1,	O1	5	1	0	6	2	0	8	2	1

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INSTRUMENTAL PROFILE OF THE BELGRADE SOLAR SPECTROGRAPH

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SUMMARY. The instrumental profile of the Belgrade solar spectrograph is determined using the O_2 telluric lines. The Fourier transform method is applied. A procedure of simultaneous use of several calibration curves has been developed for minimizing the errors, occasioned by the photographic calibration. The telluric line absorption coefficient is approximated by Voigt function. A procedure of normalisation of the natural profile, suitable for computer processing, has been developed. The actual resolving power of the spectorgraph is 106 780 and 134 040 in the 4th and 5th order spectrum, which makes about 37% of its theoretical value.

1. INTRODUCTION

The instrumental profile of the Belgrade solar spectrograph has not up to present been investigated. The prime purpose of the present paper is to provide a preliminary idea of its pattern and to develop method in use at dealing with this subject.

The paper is meant to serve as a contribution to the prospective preparation of the instrument for the investigation of the spectral lines profiles. The whole procedure of data treatment has therefore been elaborated in such a way as to be usable upon minimum modifications, at this task.

2. INSTRUMENTAL PROFILE OF THE SPECTROGRAPH – GENERALITIES

Changes, introduced into the original spectrum by a spectrograph, are a function of the equipment's construction, but equally so of the very nature of electromagnetic radiation. The correct approach to the question of reconstructing the original spectrum implies as complete a quantitative knowledge as possible of these changes. If $F(\lambda)$ is the original spectrum of a real source radiation, $I(\lambda)$ the instrumental profile and $D(\lambda)$ the measured spectrum, then

$$D(\lambda) = \int_{-\infty}^{\infty} I(\lambda - \lambda') F(\lambda') d\lambda' = \int_{-\infty}^{\infty} I(\lambda') F(\lambda - \lambda') d\lambda' \quad (1)$$

where λ – the wave lenght and λ' – the integration variable. These integrals are convolution of the functions $I(\lambda)$ and $F(\lambda)$ The problem now is solving Equ. (1) for $F(\lambda)$ if $D(\lambda)$ and $I(\lambda)$ are known distributions. The methods most used for the solution of this equation are the following: a) Approximation of the spectral lines profiles by Voigt's function. The procedure is described in detail by van de Hulst and Reesinck (1947). b) Iterative method. The modification of this method is outlined by de Jager and Neven (1966). c) Fourier transform method. The method is in some detail described by Gray (1976). The method is distinct by its efficiency in removing the noise and by not imposing any limitation concerning the pattern of the profile under investigation.

The method under c) rests upon the fact that the convolution in the Fourier frequency domain is reduced to a simple multiplication. Namely, on denoting by $f(\sigma)$ the Fourier transform of the function $F(\lambda)$, by $d(\sigma)$ the Fourier transform of $D(\lambda)$ and by $i(\sigma)$ the transform of $I(\lambda)$, the equation (1) may be written in the form:

$$d(\sigma) = f(\sigma) \cdot i(\sigma) \quad (2)$$

As no monochromatic light sources do exist in the nature, spectra with very narrow lines, arising in the known conditions, are used in the actual determination of the instrumental profile. One is thus enabled to theoretically compute their natural profile $F(\lambda)$ and to derive from the measured profile $D(\lambda)$, by solving the equations (1) (by some of the above mentioned methods), the instrumental profile $I(\lambda)$.

In common use as sources producing narrow lines spectra are: lamps with the mercury isotop ^{198}Hg, lasers and the telluric absorption lines of the molecular oxygen O_2. These telluric lines are relatively strong, narrow and distributed over a large spectral range, which makes them suitable for deduction of the instrumental profile. Making them particularly suitable is their being measured under the same conditions as teh spectral lines investigated. On the other hand, these lines are generated in the Earth's atmosphere, thus in the conditions not fully understood. Consequently, their natural profile cannot, in principle, be exactly known either.

The theory of the natural profile of the O_2 telluric lines has been dealt with by van de Hulst (1945) and Allen (1937), while the measurements and comparisons with the theory have been made by Panofsky (1943). Telluric lines for determination of the instrumental profile have been used by Karpinskij (1965), Griffin (1969), Sitnik and Khlystov (1971) and Khetsurijani (1975).

3. METHOD USED AND RESULTS

The properties of the Belgrade solar spectrograph are set forth in detail by Kubičela (1975). The spectrogram measurements have been carried out on MF–2 microphotometer while data processing has been performed on Sinclair ZX Spectrum, 48 K computer.

For the purpose of determining the instrumental profile four telluric lines of O_2 have been photographed: $\lambda = 628.38$ nm, $\lambda = 628.45$ nm, $\lambda = 629.52$ nm and $\lambda = 630.66$ nm. The lines have been chosen so as to be close to those used in the Belgrade researches of the large scale photospheric motions. Another criterion provided for the lines not being blended. Moreover, in view of the spectorgram enclosing a 0.2 nm wide part of the spectrum, it proved possible to obtain the lines $\lambda = 628.38$ nm and $\lambda = 628.45$ nm on the same photography. Since the photographs have been taken in such a way as to have each of these lines at the centre of the spectrogram concerned, it was possible to investigate, to a certain measure, the variation of the instrumental profile depending on the line position on the spectrogram.

The spectrogram taking proceeded by series, any line involving one series. The series embodied two different exposures with entrance slits 155 μm, 55 μm, and 30 μm.

The picture taking was performed conjointly on two different emulsions: the high contrast emulsion ORWO DK–5 and the medium contrast ORWO NP–22 emulsion. In order to bring out which one of them was to be preferred, a spectrogram on both emulsions was measured and complete processing effected. It proved that the results yielded by the ORWO NP–22 emulsion were less dependable, on account of a high level noise appearing in the profile measured. Therefore, further measurements have been carried out on ORWO DK–5 emulsion, which furnished better resutls at the price of a more intricate mode of calibration.

The measuring out of the spectorgrams on the microphotometre was executed using a constant step $\Delta\lambda = 0.2757$ pm (in the fourth order spectrum) and $\Delta\lambda = 0.25$ pm (in the fifth order spectrum). Direct reading was made of the blackening densities $Z_i = (i = \overline{1,N})$, $(N = 256)$.

The calibration was performed by means of a six–step photographic wedge which subsequently was photographed on the same part of the film as the spectrograms, having thus been developed under the same conditions. In order to get many calibration curves, the wedge has been photographed several times using various illuminations. The exposure time with the wedge was the same as that for the spectrogram. Care was also taken that the wedge be illuminated by the light of the same colour as that for the spectrogram.

In parallel with the spectrogram measurements, performed were also the measurements of the blackening densities ${}^kF_n$ of the steps on the calibration photographies. The label n $(n = \overline{1,6})$ denotes the ordering number of the step and the label k denotes the ordering number of the wedge's photography $(k = \overline{1,N_1})$, N_1 is the number of the measured wedge photographies. Thus it was possible to obtain N_1 calibration curves. Each one of the calibration curves is represented by Lagrange interpolation polynomial. Accordingly, the corresponding value of the illumination E_i of the i-th point on the profile resulting from the k–th calibration curve was calculated by the relation

$$ {}^k\log E_i = \sum_{n=1}^{N_2} \left(B_n \cdot \prod_{\substack{m=1\\m\neq n}}^{N_2} \frac{Z_i - {}^kF_m}{{}^kF_n - {}^kF_m}\right) \qquad \begin{matrix} i=\overline{1,N}\\ k=\overline{1,N_1}\end{matrix} $$

where B_n – the logarithm of the ratio of the illumination (E_n)

$$ B_n = \log E_n/E_1 \quad (n = \overline{1,6}) $$

E_n is the illumination of the n–th step and N_2 is the number of the measured steps with the k–th calibration curve.

Due to the accidental errors present in the measured quantities ${}^kF_n$ and B_n the value $\log E_{i+1} - \log E_i$ will not, in principle, be the same for all the calibration curves. For this reason the mean value was calculated

$$ S_i = \frac{\sum_{k=1}^{N_1} \left({}^k\log E_{i+1} - {}^k\log E_i\right)}{N_1} \qquad i=\overline{1,N-1} $$

and the value

$$ \overline{\log E_j} = \sum_{i=1}^{j} S_{i-1} \qquad j = \overline{1,N} $$

where S_0 is an arbitrary constant. Next one calculated

$$ E_j = 10^{\overline{\log E_j}} \qquad j = \overline{1,N} $$

An illustration of the procedure of calibration described above is apparent from Fig. 1.

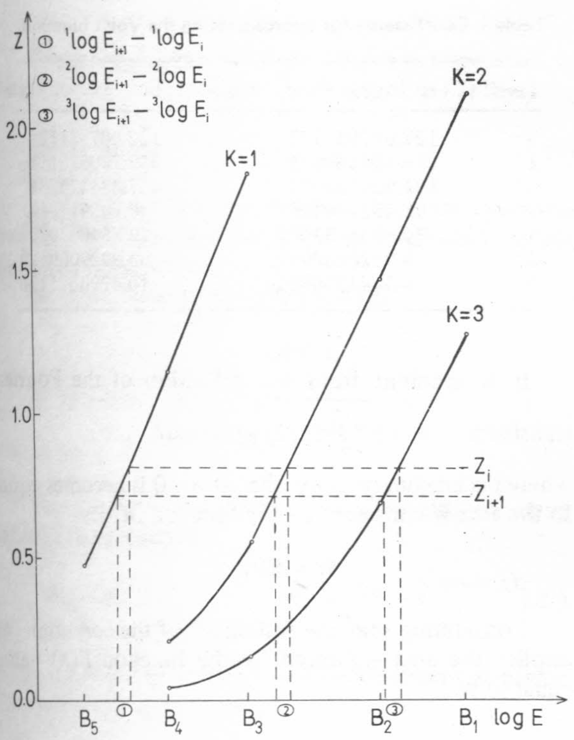

Fig. 1. An example of the calibration procedure for two densities Z_i and Z_{i+1}, measured in succession, using three calibration curves.

The continuum level was determined in the following manner: From N_3 extreme points at the short waves end and N_4 such point at the long waves end we have

$$E_c = \frac{\sum_{i=1}^{N_3} \overline{E_i} + \sum_{j=N-N_4+1}^{N} \overline{E_j}}{N_3 + N_4}$$

Thereupon it was calculated

$$D_i = 1 - \overline{E_i}/E_c \qquad i = \overline{1, N}.$$

The set of equidistant values D_i represents the measured profiles $D(\lambda)$ The observed profile on the illumination scale, together with the continuum level, is shown in Fig. 2.

For the computation of the Fourier transforms and the inverse Fourier transforms in the present work use has been made of FORTRAN programme (N. Brener, IMB Contrib Progr, Library, No. 360D–13.4.002) translated into BASIC.

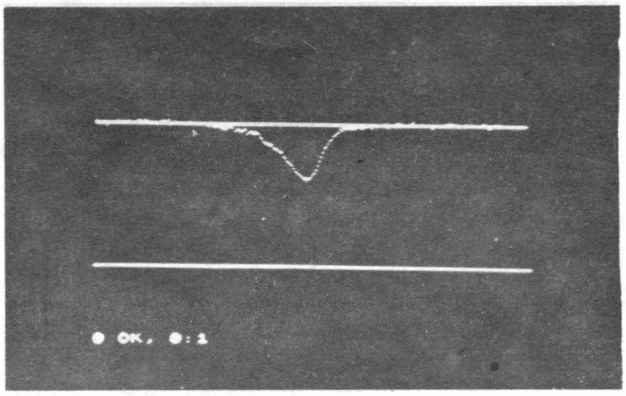

Fig. 2. Intensity of the line λ = 628.38 nm in terms of the wave length. The upper line represents the continuum level D = 0 and the lower one the level D = 1. A spectral range 64 pm wide is shown

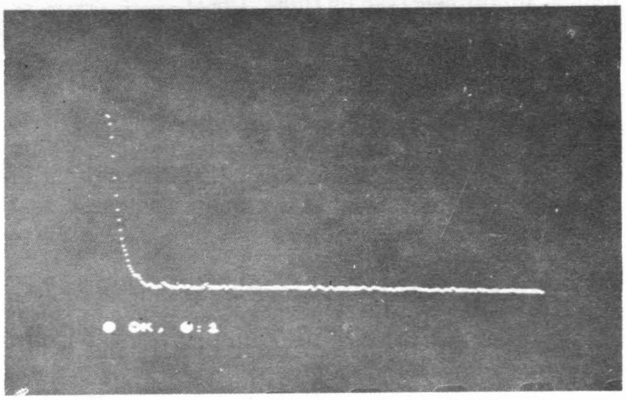

Fig. 3. Fourier amplitudes of the measured profile from Fig. 2. The region from the zero to the Nyquist frequencies is shown.

According to the theory given by van de Hulst (1945) the absorption coefficient $\alpha(\lambda)$ of the natural profile of the telluric line $F(\lambda)$ is represented as a convolution of the Gauss function

$$G(\lambda) = W_G \cdot \frac{1}{\beta_1 \cdot \sqrt{\pi}} \, e^{-\frac{(\lambda-\lambda_0)^2}{\beta_1^2}}$$

and the Lorentz function

$$L(\lambda) = W_L \cdot \frac{1}{\pi} \frac{\beta_2}{\beta_2^2 + (\lambda - \lambda_0)^2} \qquad (3)$$

where λ_0 – the wavelenght of the line centre, W_G and W_L

– the areas under the corresponding distributions and β_1 and β_2 are computed by the relations

$$\beta_2 = \frac{1}{2} b \qquad \beta_1^2 = -\frac{1}{6} b^2 + \delta^2$$

$$\delta^2 = \frac{2RT}{\mu} \left(\frac{\lambda_0}{C}\right)^2$$

Here b is half–width of that portion of the absorption coefficient profile produced solely by the collision of the O_2 molecules, T – absolute temperature, R – Boltzman constant, μ – molecular mase of O_2 in atomic mass units, c – the velocity of light.

For the given values p and T (the pressure and the temperature of the atmosphere) it is possible to determine b, provided b_0 is known for the normal atmosphere (p_0, T_0). The value of b_0 has been determined by a number of authors (a settled list is given by van de Hulst (1945)). From among several values of b_0, given by different authors, which display a noticable divergence, we chose the one due to Allen (1937) reduced to the normal atmosphere (van de Hulst, 1945)

$$b_0 = 2.06 \text{ pm}$$

considering that it was derived from observations at Passadena (Solar Laboratory of the Mount Wilson Observatory) whose altitude is comparable with that of the Belgrade Observatory. It is namely maintained that possible effects of inaccuracies in the Earth's atmosphere modeling will thus be minimized.

The values of this Voigt function $\alpha(\lambda)$ were computed using the same step in λ with which the observed profile has been measured. According to Hui et al. (1977).

$$\alpha(\lambda) = \mathrm{Re}\left\{ \frac{\sum_{i=0}^{p} a_i Z^i}{Z^{p+1} + \sum_{i=0}^{p} b_i Z^i} \right\}$$

where Z is a complex number with coordinates

$$\left(\frac{\beta_1}{\beta_2}, -\frac{\lambda - \lambda_0}{\beta_2}\right).$$

The coefficients a_i and b_i resulting from p = 6 are given in Table I.

The natural profile $F(\lambda)$ of the telluric line was calculated according to the relation

$$F(\lambda) = 1 - e^{-a_w \cdot \alpha(\lambda)}$$

where a_w is a parameter to be determined in such a way as to have fulfilled the condition

$$\int_{-\infty}^{\infty} [1 - e^{-a_w \cdot \alpha(\lambda)}] \, d\lambda = W$$

where W – equivalent width of the measured profile.

Table I. Coefficients for approximating the Voigt function.

i	ai	bi
0	122.607931777	122.607931774
1	214.382388695	352.730625111
2	181.928533092	457.334478784
3	93.1555804581	348.703917719
4	30.1801421962	170.354001821
5	5.91262620977	53.9929069129
6	0.564189583563	10.4798571143

It is apparent from the definition of the Fourier transform $d(\sigma) = \int_{-\infty}^{\infty} D(\lambda) e^{2\pi j \lambda \sigma} d\lambda$

where j is imaginary unity, that at $\sigma = 0$ is becomes equal to the area W embraced by the function $D(\lambda)$:

$$W = d(0)$$

Considering that the fulfilment of the condition (4) implies the area embraced by the funciton $F(\lambda)$ being equal to W

$$f(0) = W$$

and that from the relation (2)

$$i(0)\, f(0) = d(0)$$

there follows $i(0) = 1$, that is the area embraced by the instrumental profile $I(\lambda)$ is equal to unity.

The value of the parameter a_w was determined, using the Newton method, in that the zero was sought of the function

$$\psi(a) = \int_{-\infty}^{\infty} [1 - e^{-a\alpha(\lambda)}] \, d\lambda - W = 0 \tag{5}$$

The n-th and the (n + 1)-th aproximaton are connected by the relation

$${}^{n+1}a = {}^{n}a - \frac{\psi({}^{n}a)}{\psi'({}^{n}a)} \tag{6}$$

The operation is convergent, with the initial value of the parameter ${}^{0}a$, on the condition

$$\psi({}^{0}a) \cdot \psi''({}^{0}a) > 0 \tag{7}$$

The differentiation of the function (5) yields

$$\psi'(a) = \int_{-\infty}^{\infty} \alpha(\lambda)\, e^{-a\alpha(\lambda)} d\lambda \; ;$$

$$\psi''(a) = -\int_{-\infty}^{\infty} \alpha^2(\lambda)\, e^{-a\alpha(\lambda)} d\lambda \qquad (8)$$

Being evident that $\psi''({}^{0}a) < 0$, for the operation to be convergent it is necessary (with regard to (7) that)

$$\psi({}^{0}a) < 0 \qquad (9)$$

In the computing programme a spearate cycle was provided such that, for the initial approximation ${}^{0}a$, the condition (9) is fulfiled.

Next, one calculated by (6) and (8)

$${}^{n+1}a = {}^{n}a - \frac{\int_{-\infty}^{\infty} [1 - e^{-{}^{n}a\alpha(\lambda)}]\, d\lambda - W}{\int_{-\infty}^{\infty} \alpha(\lambda)\, e^{-{}^{n}a\alpha(\lambda)}}$$

The iterative procedure was discontinued upon fulfiling the condition

$$|W_n - W| < \epsilon ; \qquad W_n = \int_{-\infty}^{\infty} [1 - e^{-{}^{n}a\alpha(\lambda)}]\, d\lambda$$

where ϵ being dependent of the measurement accuracy. For the value a_w one took

$$a_w = {}^{n+1}a$$

It was on the basis of a_w determined in this way that the computation of the natural profile of the telluric lines was effected. In Fig. 4. are illustrated both the measured and the natural profiles of the telluric line.

Thereupon one calculated the Fourier transform of the instrumental profile:

$$i(\sigma) = d_1(\sigma)\, \varphi(\sigma)/f(\sigma)$$

where $\varphi(\sigma)$ is a filtration function in the form (Brault and White, 1971)

$$\varphi(\sigma) = \frac{1}{1 + \frac{|n(\sigma)|^2}{|d(\sigma)|^2}} \; ; d_1(\sigma) = d(\sigma) + n(\sigma) \qquad (10).$$

Here, $d_1(\sigma)$ denotes the Fourier transform of the observed profile including the noise, $d(\sigma)$ the Fourier transform of the observed profile without noise and $n(\sigma)$ the Fourier transform of the noise. It could be ascertained throught trials performed that the function $d(\sigma)$ was best represented, in all the profile investigated, by the Fourier transform of the Lorentz function (3)

$$d(\sigma) = W_L\, e^{2\pi j\lambda_0\sigma - 2\pi\beta_2|\sigma|} \qquad (11)$$

The parameters β_2 and W_L were determined in the following manner. N_5 values of $d_1(\sigma)$, within the area of the Fourier frequencies $(0,\ N_5\Delta\sigma)$, where $\Delta\sigma = \frac{1}{N\Delta\lambda}$, were picked up such that the condition is fulfilled

$$d(\sigma) \gg n(\sigma)$$

entailing, according to (10) $d_1(\sigma) \approx d(\sigma)$ Accordingly, the relation (11) may be written in the form

$$d_1(\sigma) = W_L e^{2\pi j\lambda_0\sigma - 2\pi\beta_2|\sigma|}$$

On taking the logarithm of this function we have

$$\ln d_1(\sigma) = \ln|d_1(\sigma)| + (\arg d_1(\sigma) + 2k\pi)\, j = 2\pi j\lambda_0\sigma - 2\pi\beta_2|\sigma| + \ln W_L$$

Now, equating the real terms

$$\ln|d_1(\sigma)| = \ln\sqrt{\mathrm{Re}[d_1(\sigma)] + \mathrm{Im}\,[d_1(\sigma)]} = = -2\pi\beta_2|\sigma| + \ln W_L$$

As a result, one obtained N_5 conditional equations, whose solution by the method of least squares furnished the parameters β_2 and W_L.

The determination of the function $n(\sigma)$ involved the selection of N_6 values of $d_1(\sigma)$ such that within the area of high Fourier frequences $(\sigma_N - N_6 \cdot \Delta\sigma, \sigma_N)$, σ_N – the Nyquist frequency, the condition $n(\sigma) \gg d(\sigma)$ was fulfilled, entailing from (10) $n(\sigma) \approx d_1(\sigma)$. It is apparent from Fig. 3. that the assumption of a constant noise level was justified. Hence, the noise level was computed as a mean of N_6 values $d_1(\sigma)$ within the area of the Fourier frequences $(\sigma_N - N_6 \cdot \Delta\sigma, \sigma_N)$.

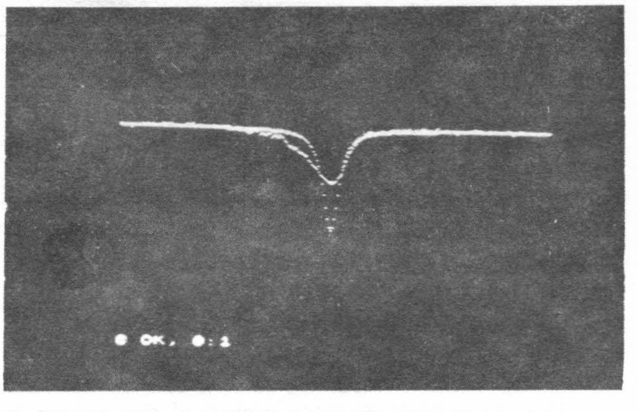

Fig. 4. The natural (the deeper) and the measured (shallow) profile of the line λ = 628.38 nm.

The set of values $i(\sigma)$ thus obtained can be forthrightly used for correcting the profile of some other line in the solar spectrum observed for the instrumental profile. In order to determine the characteristics of the instrumental profile within the range of the wave lenghts $I(\lambda)$, an inverse Fourier transform was performed. In Fig. 5. is shown the instrumental profile of the spectrograph as it resulted from treating the observation of the line in Fig. 4.

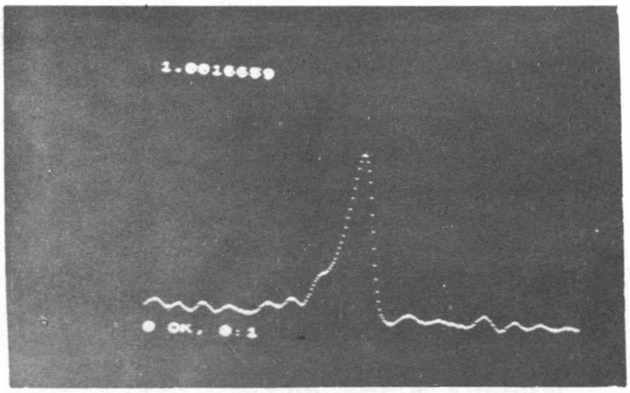

Fig. 5. Instrumental profile of the Belgrade spectrograph (normalized to unity) in the fifth order spectrum. Part of the spectrum, 64 pm wide, is shown. The undulation in the wings is a consequence of noise.

Table II gives an owerview of characteristics of the instrumental profile in the fourth order spectrum with an additional enlargement, as well as in the fifth order spectrum, for different widths of the entrance slit.

$$R_t = m \cdot N_r$$

where m is the spectrum order and N_r the total number of the grating lines. According to Kubičela (1975)

$$N_r = 123\,600$$

consequently, in the fourth order spectrum

$$R_t(4) = 494\,400$$

According to the manufacturer's (Bausch & Lomb) specifications the grating efficiency is 75%, therefore, the effective resolving power of the grating

$${}^{e}R_t(4) = 370\,800$$

According to Zajdel' (1976) the resolving power of a spectrograph with a normal slit is 77% of the theoretical resolving power of the grating:

$${}^{n}R_t(4) = 0.77 \cdot {}^{e}R_t(4) = 285\,516$$

The actual resolving power of the spectrograph is given by the relation (Zeidel' et al., 1976)

$$R_p = \frac{\lambda}{\delta\lambda}$$

$\delta\lambda$ being the width of the instrumental profile at 0.41 of intensity. From the data in Table II the actual resolving power of the spectrograph in the fourth order spectrum, with the entrance slit 30 μm was determined as

Table II. Characteristics of the instrumental profile of the Belgrade spectrograph.

SPECTROGRAM NUMBER	LINE [nm]	WIDTH OF THE ENTRANCE SLIT [μm]	SPECTRE ORDER	HALF–WIDTH OF THE INSTRUMENTAL PROFILE [pm]	WIDTH AT 0.41 INTENSITY [pm]
47109	628.38	155	4th	6.6	7.6
47114	628.38	30	4th	5.2	5.9
47126	629.52	30	4th	5.2	5.9
47116	628.38	155	4th	7.4	8.3
47176	628.38	30	5th	4.0	4.6
47177	628.38	30	5th	4.1	4.9

4. DISCUSSION AND CONCLUSIONS

4.1. Comparison of the theoretical and the actual resolving power

The theoretical resolving power of the grating is specified by the relation

$$R_p(4) = 106\,780$$

As evident, the actual resolving power in the fourth order spectrum with an additional enlargement is 37% of the theoretical resolving power of the spectrograph ${}^{n}R_t(4)$, conditioned solely by the diffraction and the finite width of the entrance slit.

In the fifth order spectrum

$$R_t(5) = 618\,000$$
$$^e R_t(5) = 463\,500$$

$$n\, R_t(5) = 356\,895$$

The actual resolving power, resulting from data in Table II, is

$$R_p = 134\,043$$

Accordingly, the actual resolving power in the fifth order spectrum is 38% of the spectrograph's theoretical resolving power.

4.2. Estimate of effects, produced by various factors, on the spectrograph resolving power.

Preliminary examination showed that there were, besides diffraction and the finite width of the entrance slit, additional factors influencing the width of the instrumental profile. These may be aberational phenomena or finite width of the emulsion profile combined with finite width of the measuring slit of the microphotometer.

According to Mal'shchev (1979), the width of the emulsion instrumental profile is

$$\alpha_f = \frac{1}{N_R}$$

According to the manufacturer's specification (1978) for the ORWO DK–5 emulsion

$$N_R = 220 \text{ lines/mm}$$

Therefore $\alpha_f \approx 4.5\ \mu m$.

The measurements were executed with the width of the microphotometer measuring slit $\ell = 25\ \mu m$ in the film plane. In a fourth order spectrum with additional englargement this corresponds to the values

$$\alpha_f = 0.1 \text{ pm} \qquad \ell = 0.3 \text{ pm}$$

on the wave lenght scale.

The comparison with the results in Table II revealed that the effects of the emulsion instrumental profile and the finite microphotometer measuring slit were negligible.

Thus, optical aberations may be considered as exercizing decisive effect on the width of the instrumental profile.

4.3. Estimate of the pattern of the instrumental profile, depending on the line position on the spectrogram. Assymetry of the instrumental profile.

In table II, with the spectrogram number 47109, are given the characteristics of the instrumental profile of the Belgrade spectrograph for the spectrogram centre and, with the number 47116, those relating to the spectrogram end containing shorter wavelengths. The widening that can be noted is quite a logical one since a stronger aberation was to be expected – in view of the equipment structure – at that end of the field of view.

The results of the present investigation reveal also a noticeable assymetry of the instrumental profile. The assymetry may be a result of defects in the optics, in the grating and also of the uneven illumination of the collimator objective. Therefore, the maximum resolving power of the spectrograph in the future work is to be achieved by covering certain parts of the grating or the collimator.

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SHORT –TERM VARIATIONS OF o AND?

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SUMMARY: Photoelectrical observations of o And revealed this object probably having short–term variations (on a time scale of 0.1 days) of low amplitude (about 0.01 magnitude), superimposed on the variations of longer (on the time scale of 1 day) p riods. These short–term variations, if assumed to be a consequence of a pulsating mechanism in the star and treated as such, furnish a period consistent with the observed one.

1. INTRODUCTION

Most conspicuous of all photometric variations in the Be stars are those having long periods, which usually are associated with the shell phases. In some of these stars short term variations, with stable periods of over one day, have also been observed. Baade (1982) reports that the shortest (1.365 days) among these periods was observed in 28 C Ma. Photometric variations of low amplitude, within intervals under one day, have been observed in several Be stars as well (Percy, 1980). Nevertheless, in the majority of these instances, no stable periodicity could be ascertained, setting appart certain stars, as for instance λ Eri (Bolton, 1982) or LQ And (Harmanec, 1984b) for which such a periodicity has been claimed as observed. The discussion at the Hvar Wokrshop on Rapid Variability of the Early Type Stars (see e.g. Harmanec, 1983) made it clear that due to the very low amplitudes of these variations, in most of the Be stars not only the stability of the periods, but the very reality of the phenomena was questionable.

o And (HR 8762, IDS 23019 + 4219) is a Be star with a very long history of photoelectrical observations. Harmanec (1984b) summarized the basic results to date, infering preliminary that the photometric variations were a result of superposition of the long–term (8.5 years) and the short–term (1.571272 days) variations.

Our observations in Hvar in the course of one (from two in all) night, point to the possibility that this star was having variations within even shorter (on a time scale of the order of 0.1 days) intervals. More specifically, the variations were recognized of an amplitude of about 0.01 magnitude and the quasi–period of about 0.09 days, which, it is belived, might be regarded as real ones.

2. OBSERVATIONS

Photoelectrical UBV measurements of o And, aimed at pursuing the short–term variations, were carried out at the Hvar Observatory in the course of two successive nights, on 20/21 and 21/22 November 1982. The observation was performed on a 65 cm Cassegrain telescope. The comparison star was 2 And (Sp A2) and the check star κ And. The signal integration time was 10 sec, the observations having been executed following the scheme 2 And (U,B,V)–sky–o And (U,B,V). The procedure included occasional observations of the check star.

The extinction coefficients were deduced from the observational material for each night separately. The error of a single measurement on the night oof 20/21 November turned out to be

2 And	o And
$\sigma U = \pm 0\overset{m}{.}014$	$\sigma U = \pm 0\overset{m}{.}022$
$\sigma B = \pm 0.014$	$\sigma B = \pm 0.020$
$\sigma V = \pm 0.014$	$\sigma V = \pm 0.021$

and the one on the night of 21/22 November

2 And	o And
$\sigma U = \pm 0\overset{m}{.}0051$	$\sigma U = \pm 0\overset{m}{.}0073$
$\sigma B = \pm 0.0051$	$\sigma B = \pm 0.0053$
$\sigma V = \pm 0.0058$	$\sigma V = \pm 0.0085$

As evident from these data, the measuring errors pertaining to o And in both instances are larger (although the difference might not be significant statistically) than those involved in the comparison star 2 And. One is induced to the conclusion that there were in existence in o And intrinsic variations, it being unlikely that a considerably brighter star should entail larger measuring errors under equal observing circumstances. The fact is, namely, that the comparison and the programme stars are mutually close both by their positions and the spectral types, while the measurements have rapidly been executed (within a few minutes). Accordingly, the atmospheric effects would have manifested themselves equally on the measurements of both stars.

The differential magnitudes ΔU, ΔB, ΔV, (in the sense 2 And – o And) in the instrumental system are listed in Table I. In figs. 1a. and 1b. are illustrated the differential magnitudes for both observing nights, the horizontal scale representing JD hel. Figs. 2a. and 2b. visualize the behaviour of the comparison star 2 And in the course of observation. The UBV measurements, corrected for extinction, are also given in the instrumental system.

Table I – Differential magnitudes (2 And – o And)
20/21.11.1982.
JD hel = 2445294 + ΔJD

ΔJD	ΔU	ΔJD	ΔB	ΔJD	ΔV
0.2158	–2.200	0.2144	–1.499	0.2137	–1.408
0.2220	–2.193	0.2213	–1.463	0.2206	–1.407
0.2331	–2.237	0.2324	–1.496	0.2436	–1.426
0.2373	–2.223	0.2370	–1.456	0.2491	–1.398
0.2446	–2.235	0.2442	–1.507	0.2571	–1.424
0.2498	–2.202	0.2495	–1.462	0.2613	–1.421
0.2588	–2.183	0.2616	–1.487	0.2689	–1.435
0.2623	–2.215	0.2696	–1.487	0.2717	–1.425
0.2701	–2.228	0.2720	–1.484	0.2790	–1.432
0.2724	–2.223	0.2793	–1.495	0.2817	–1.429
0.2800	–2.239	0.2821	–1.495	0.2988	–1.406
0.2824	–2.232	0.2984	–1.475	0.3010	–1.427
0.2970	–2.235	0.3008	–1.491	0.3048	–1.433
0.3002	–2.228	0.3045	–1.487	0.3062	–1.432
0.3043	–2.239	0.3060	–1.493	0.3100	–1.408
0.3058	–2.244	0.3098	–1.474	0.3115	–1.406
0.3095	–2.232	0.3113	–1.471	0.3151	–1.429
0.3111	–2.230	0.3149	–1.488	0.3165	–1.422
0.3147	–2.250	0.3163	–1.487	0.3225	–1.413
0.3161	–2.238	0.3223	–1.482	0.3240	–1.414
0.3217	–2.247	0.3237	–1.469	0.3556	–1.413
0.3235	–2.229	0.3558	–1.454	0.3574	–1.407
0.3579	–2.212	0.3576	–1.464	0.3622	–1.427
0.3627	–2.209	0.3624	–1.493	0.3639	–1.428
0.3645	–2.186	0.3642	–1.485	0.3765	–1.402
0.3760	–2.207	0.3763	–1.453	0.3792	–1.418
0.3786	–2.221	0.3789	–1.473	0.3836	–1.419
0.3831	–2.215	0.3833	–1.473	0.3854	–1.415
0.3849	–2.223	0.3852	–1.473	0.3912	–1.406
0.3904	–2.217	0.3908	–1.476	0.3935	–1.397
0.3929	–2.219	0.3931	–1.469	0.4006	–1.410
0.4000	–2.214	0.4003	–1.473	0.4024	–1.407
0.4017	–2.201	0.4021	–1.459	0.4131	–1.410
0.4099	–2.208	0.4102	–1.460	0.4183	–1.405
0.4121	–2.205	0.4127	–1.467	0.4204	–1.406
0.4174	–2.205	0.4199	–1.479	0.4290	–1.415
0.4197	–2.225	0.4292	–1.474	0.4308	–1.410
0.4296	–2.219	0.4311	–1.470	0.4377	–1.418
0.4314	–2.214	0.4380	–1.464	0.4395	–1.417
0.4383	–2.210	0.4399	–1.460	0.4452	–1.414
0.4402	–2.207	0.4454	–1.463	0.4471	–1.387
0.4457	–2.205	0.4474	–1.454	0.4523	–1.411
0.4477	–2.204	0.4526	–1.458	0.4545	–1.424
0.4529	–2.192	0.4548	–1.457	0.4595	–1.428
0.4551	–2.198	0.4598	–1.466	0.4612	–1.423
0.4601	–2.211	0.4615	–1.464	0.4724	–1.407
0.4618	–2.216	0.4722	–1.458	0.4747	–1.407
0.4718	–2.198	0.4742	–1.459	0.4799	–1.395
0.4738	–2.196	0.4796	–1.458	0.4823	–1.392
0.4793	–2.192	0.4820	–1.456	0.4877	–1.411
0.4817	–2.180	0.4874	–1.465	0.4896	–1.392
0.4872	–2.187	0.4893	–1.458		
0.4890	–2.186				
0.2289	–2.230	0.2292	–1.478	0.2295	–1.411
0.2306	–2.230	0.2308	–1.478	0.2311	–1.407
0.2345	–2.237	0.2347	–1.481	0.2349	–1.410
0.2361	–2.239	0.2363	–1.484	0.2366	–1.409
0.2448	–2.237	0.2433	–1.481	0.2438	–1.421
0.2468	–2.227	0.2465	–1.484	0.2463	–1.420
0.2511	–2.226	0.2508	–1.479	0.2504	–1.415
0.2527	–2.231	0.2525	–1.482	0.2522	–1.423
0.2568	–2.231	0.2565	–1.486	0.2563	–1.418
0.2586	–2.230	0.2583	–1.486	0.2579	–1.414
0.2627	–2.237	0.2625	–1.484	0.2622	–1.427
0.2643	–2.236	0.2641	–1.489	0.2638	–1.425
0.2719	–2.244	0.2722	–1.481	0.2725	–1.421
0.2736	–2.243	0.2738	–1.486	0.2741	–1.420
0.2790	–2.251	0.2792	–1.487	0.2795	–1.416
0.2808	–2.248	0.2812	–1.489	0.2817	–1.417
0.2872	–2.253	0.2874	–1.491	0.2878	–1.412
0.2891	–2.252	0.2895	–1.487	0.2897	–1.419
0.2945	–2.243	0.2947	–1.486	0.2950	–1.418
0.2956	–2.243	0.2966	–1.486	0.2969	–1.421
0.3065	–2.233	0.3061	–1.496	0.3058	–1.427
0.3091	–2.232	0.3086	–1.500	0.3082	–1.433
0.3154	–2.231	0.3150	–1.489	0.3146	–1.423
0.3174	–2.237	0.3171	–1.490	0.3167	–1.428
0.3225	–2.236	0.3222	–1.488	0.3219	–1.431
0.3250	–2.240	0.3247	–1.493	0.3245	–1.432
0.3302	–2.239	0.3299	–1.494	0.3296	–1.429
0.3324	–2.234	0.3321	–1.494	0.3317	–1.433
0.3389	–2.236	0.3385	–1.497	0.3377	–1.436
0.3415	–2.241	0.3411	–1.495	0.3403	–1.435
0.3492	–2.230	0.3489	–1.487	0.3484	–1.435
0.3522	–2.233	0.3519	–1.496	0.3515	–1.430
0.3627	–2.245	0.3630	–1.496	0.3633	–1.422
0.3652	–2.240	0.3654	–1.498	0.3658	–1.422
0.3706	–2.239	0.3710	–1.488	0.3715	–1.420
0.3735	–2.234	0.3741	–1.488	0.3745	–1.428
0.3800	–2.246	0.3804	–1.488	0.3807	–1.423
0.3822	–2.243	0.3826	–1.486	0.3827	–1.424
0.3883	–2.237	0.3889	–1.480	0.3892	–1.415
0.3906	–2.227	0.3908	–1.483	0.3911	–1.423
0.3976	–2.242	0.3979	–1.495	0.3981	–1.411
0.3995	–2.245	0.3998	–1.498	0.4002	–1.433
0.4044	–2.245	0.4047	–1.488	0.4049	–1.431
0.4063	–2.239	0.4065	–1.498	0.4068	–1.429
0.4174	–2.233	0.4170	–1.487	0.4166	–1.431
0.4206	–2.228	0.4200	–1.494	0.4197	–1.437
0.4258	–2.231	0.4255	–1.487	0.4252	–1.434
0.4280	–2.232	0.4277	–1.485	0.4274	–1.439
0.4337	–2.222	0.4334	–1.497	0.4331	–1.434
0.4359	–2.219	0.4356	–1.492	0.4354	–1.435
0.4470	–2.221	0.4472	–1.481	0.4475	–1.431
0.4488	–2.221	0.4491	–1.475	0.4494	–1.427

It appears from Figs. 1a. and 1b. that variation trends in o And were present on both nights (presumably on a time scale od 1 day). On these variations are superimposed, in the course of night on 21/22 Nov.,

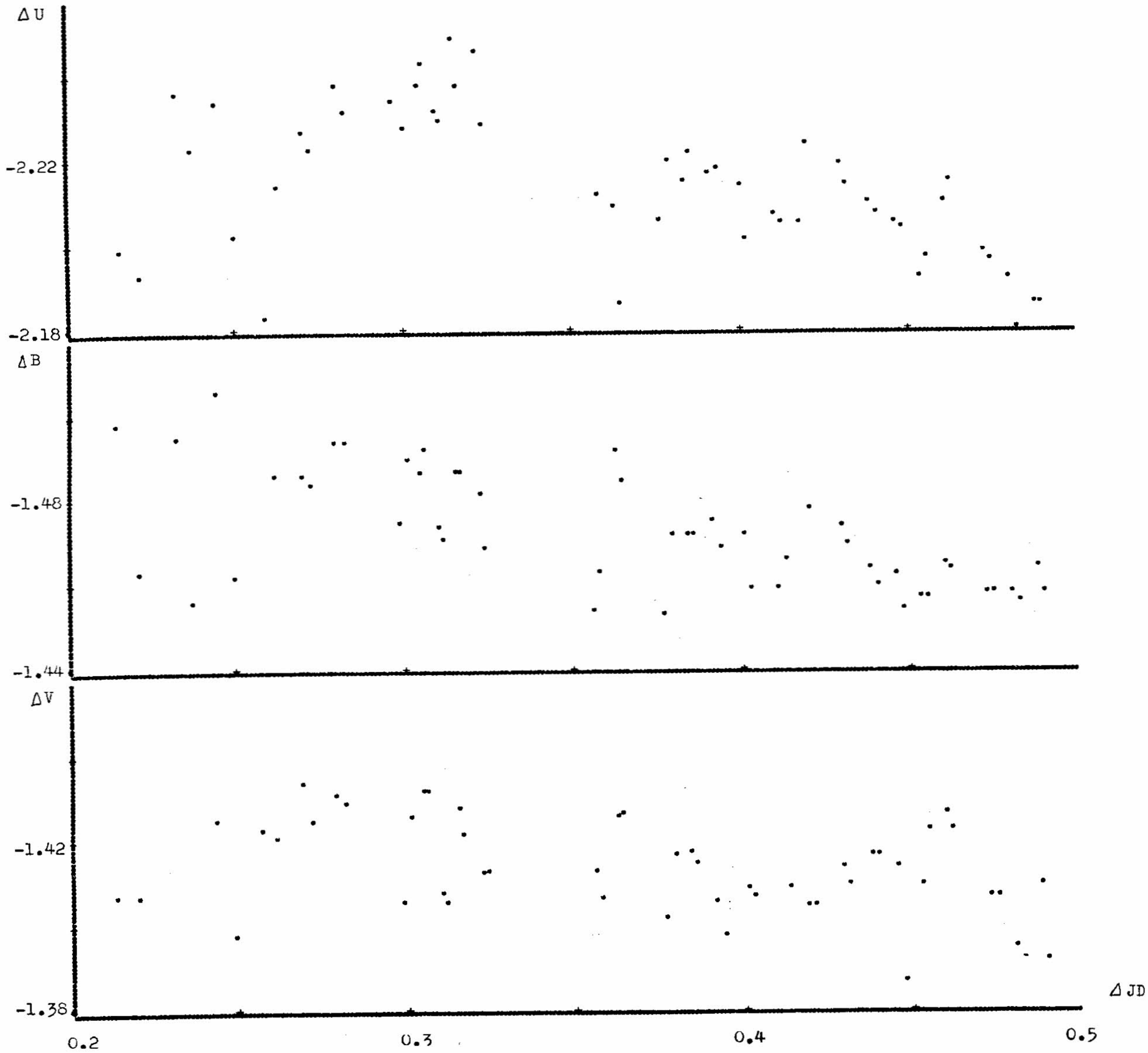

Fig. 1a. Differential magnitudes (2 And – o And) on 20/21.11.1982. (JD hel = 2445294 + ΔJD)

other variations on the time scale of the order of 0.1 days, whose amplitude is estimated at 0.01 magnitude (Fig. 1b.). The rapid variations on 21/22 Nov. (Fig. 1a.) are statistically unrecognisable. While clearly visible in the V and U filters, they almost fail to be distinguishable in the B filter. The light maxima in the V range are very nearly synchronous with the minima in the U range and vice versa. It can be seen from Fig. 3. that the colour indices of o And are behaving in such a way that to the light maxima in the V region there approximately correspond the minima of the U–B and B–V curves and vice versa, which might be regarded as indicating the stars's temperature changes.

The variations on a time scale of 1 day in o And, which have been investigated by various authors, are noticeable in our measurements as well. None the less,

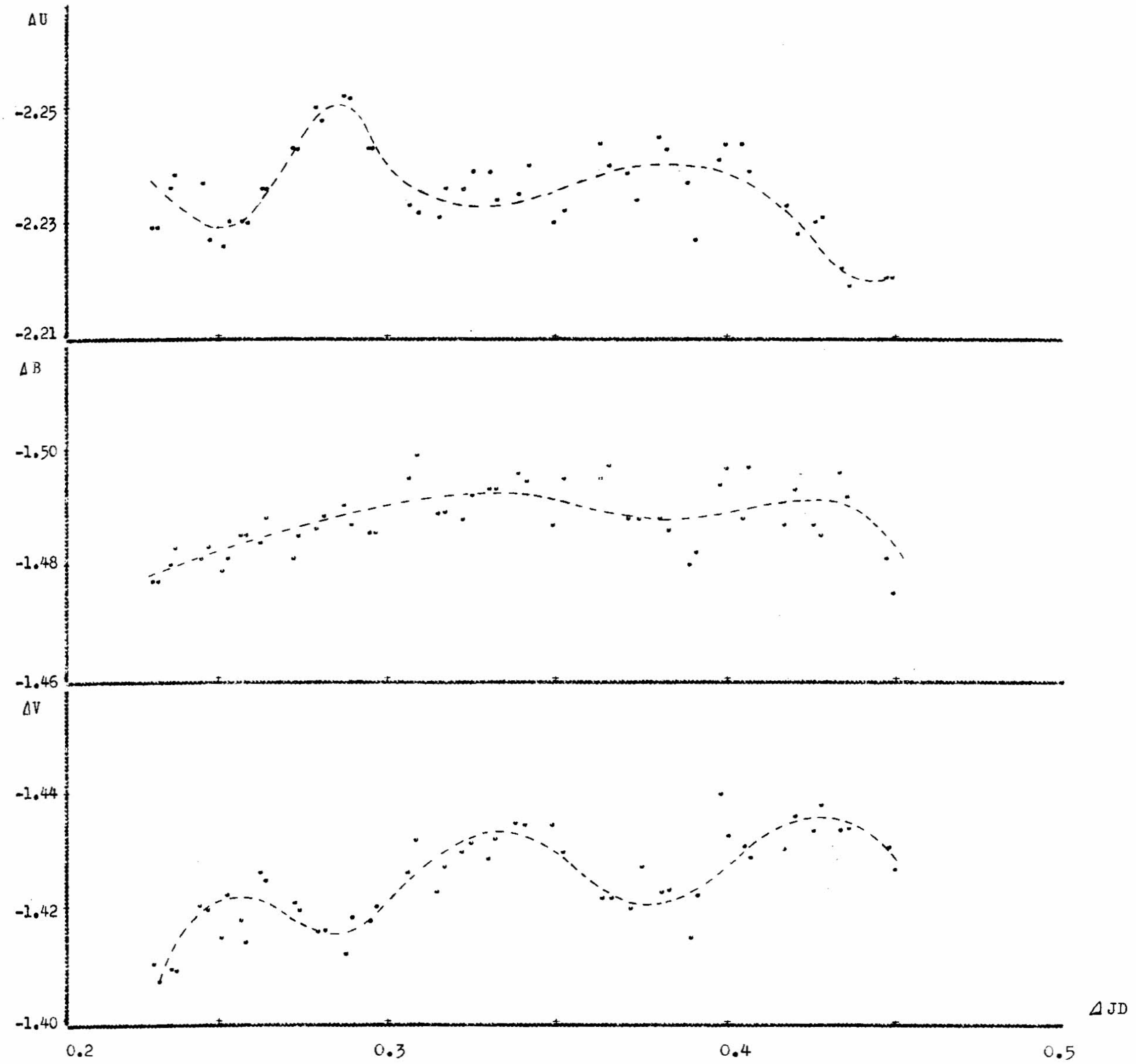

Fig. 1b. Differential magnitudes (2 And – o And) on 21/22.11.1982. (JD hel = 2445295 + ΔJD)

our observational material is unsufficient for a more thorough analysis, all the more so considering the pour quality on the night of 20/21 Nov.

The rapid variations of o And, noted on 21/22 Nov., whose quasi–period is estimated at 0.09 days, in all probability are genuine ones, observing that such variations are missing in the measurements of the comparison star. Whether a permanent or a transient phenomenon is in question cannot be told from our observations, since changes of such low amplitudes are perceptible on high quality nights alone (this, unfortunately, not being the case on 20/21 November). Inasmuch as the described variations are located in an isolated area on the star, the picture observed would be subject to changes induced by the star's rotation.

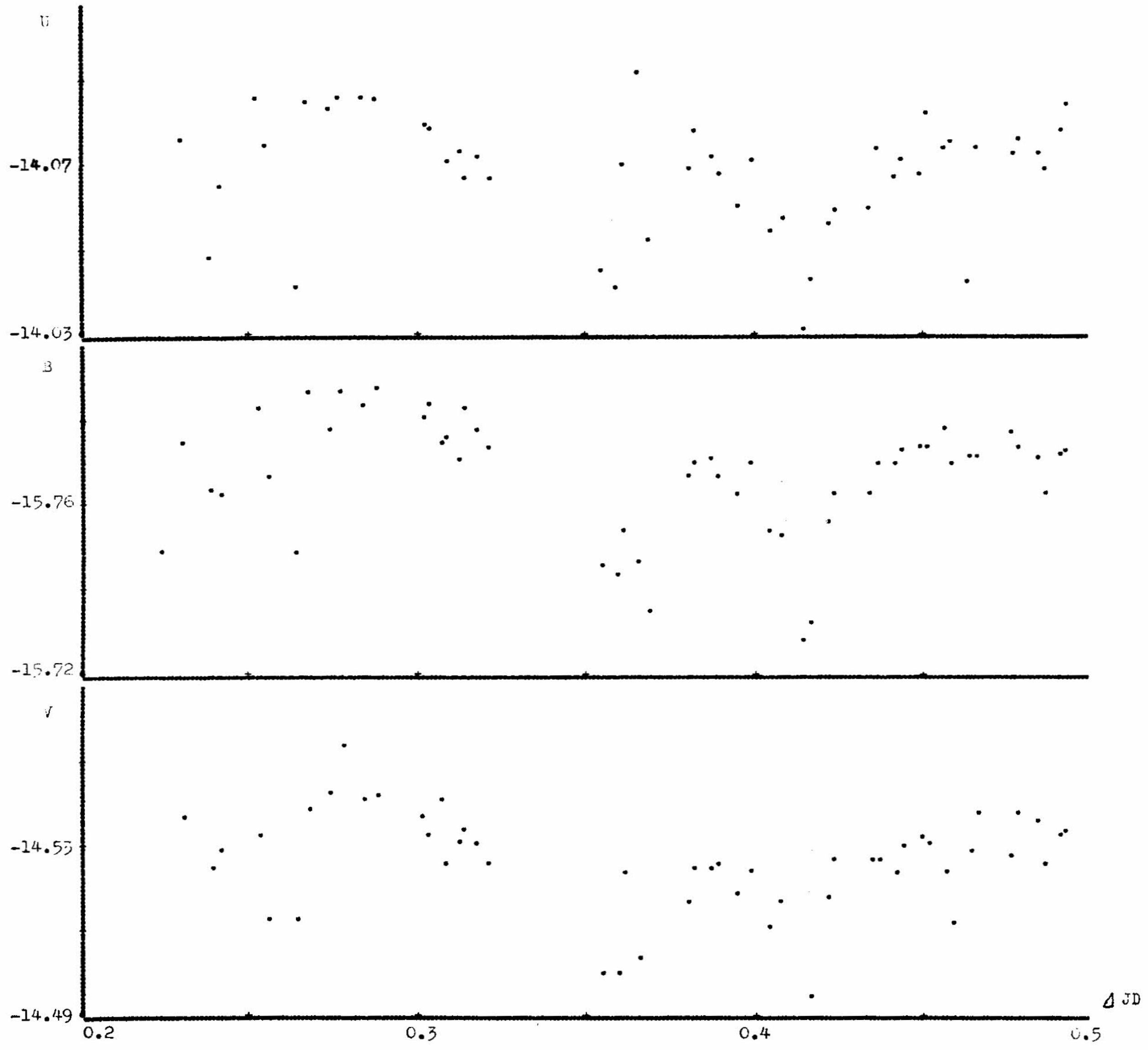

Fig. 2a. Photoelectrical measurements of 2 And on 20/21.11.1982. (JD hel = 2445294 + ΔJD)

3. DISCUSSION

Although the o And is not known to be a pulsating star, we are going to consider the possibility of interpreting the rapid variations noted as being produced by a pulsating mechanism, associated with the ionization of matter in the star's envelope, where the ionized constituent (hydrogen, helium) can bring about the modulation of energy flux variations. As is known (see e.g. Cox, 1980) the ionization regions, as a rule, have low thickness, being located in the outer layers of the star. Such is the modulation that the pulsating regions do absorb the energy at contracting, releasing it at expanding. The absorption of energy in the zone of ionization gives rise to an intensification of the local temperature (and pressure) increase. This heat is being converted, at the subsequent expansion, into work, i.e. into the pulsating energy. The temperature variations conditio-

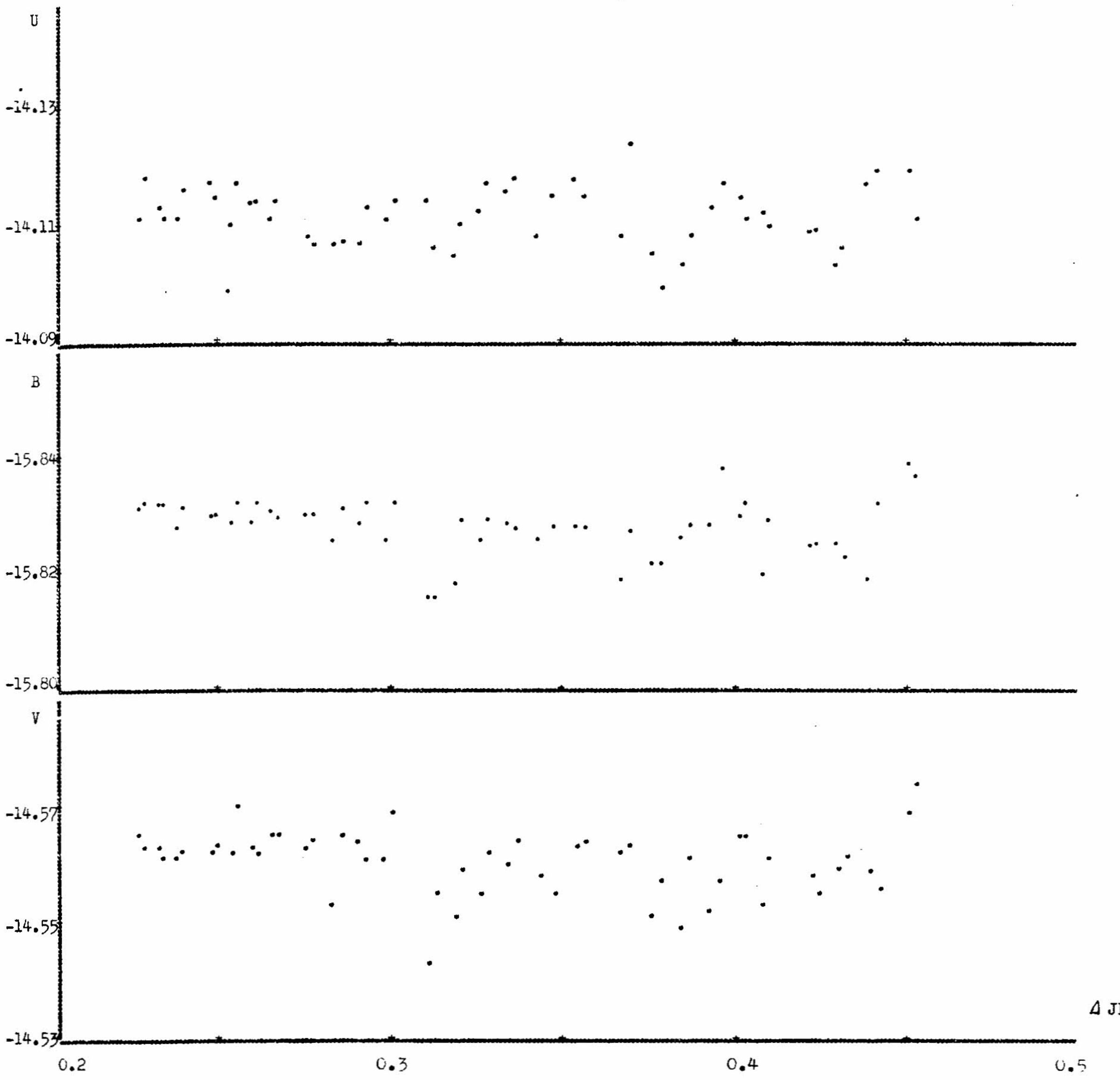

Fig. 2b. Photoelectrical measurements of 2 And on 21/22.11.1982. (JD hel = 2445295 + ΔJD)

ned by the pulsation is manifested through the variations in the star's colour index.

If it is born in mind that variations reminiscent of those observed in o And, with the amplitudes of 0.01 to 0.26 magnitude, are encountered in the βCep type stars, whereby their characteristics at the brightness minima are similar to those of the Be stars (Boyarchuk and Pronik, 1965), one might try employing some of the pulsation theory for treating the data here discussed. Borrowing the relevant parameters of o And from Poeckert (1982) connected with its empirical model, i.e. $m = 6\ m_o$, $R = 5\ R_o$ and using the relation for the pulsation constant, given by Christy (1966):

$$Q_o = 0.022\,(R/R_o)^{\frac{1}{4}}\,(m_o/m)^{\frac{1}{4}}$$

we obtain

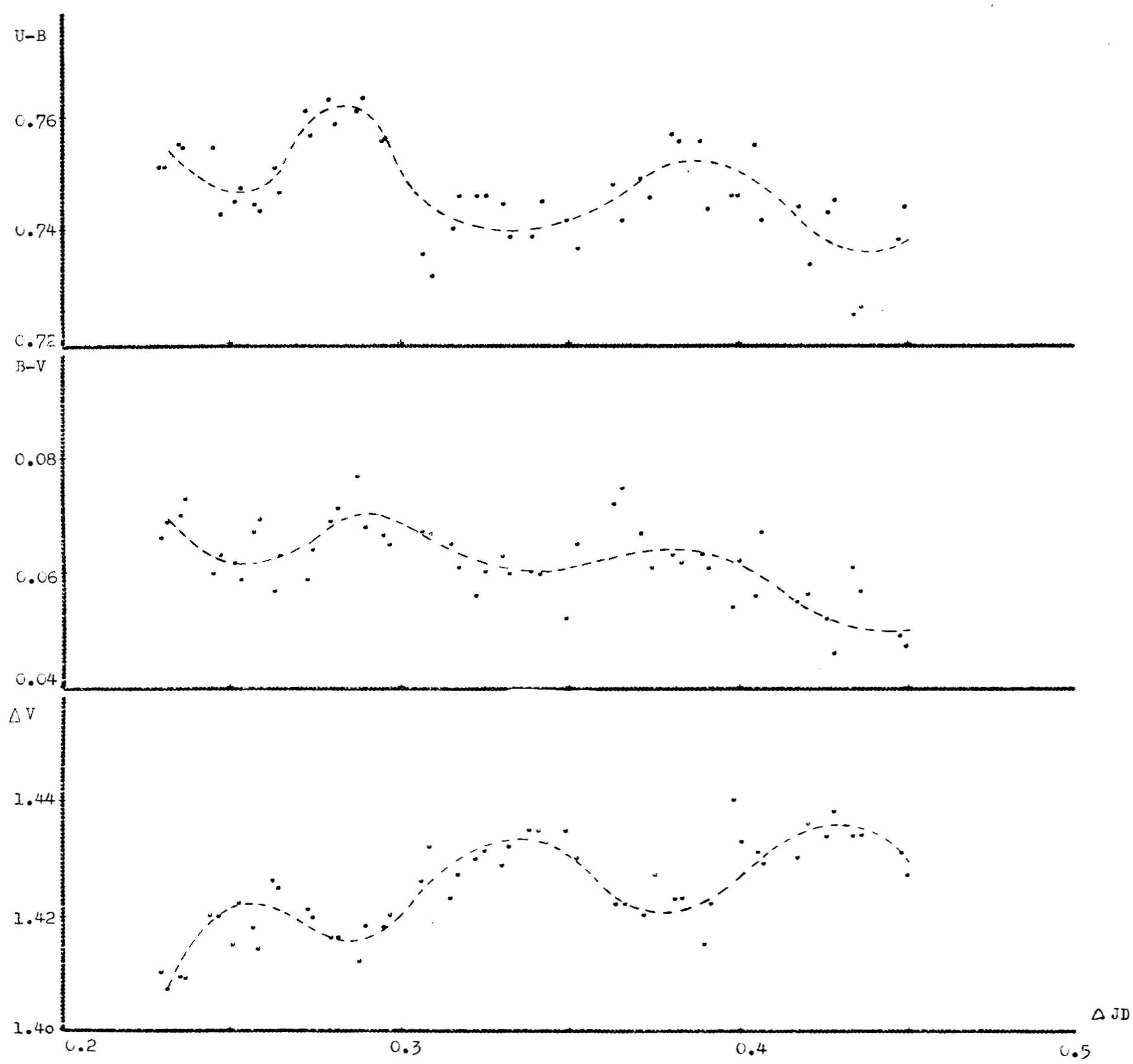

Fig. 3. Color indices U–B, B–V and differential magnitude V of o And on 21/22.11.1982. (JD hel = 2445295 + ΔJD)

$$Q_o = 0^d\!.02102$$

By way of the relation

$$Q_o = P_o\,(\rho/\rho_\odot)^{\frac{1}{2}}$$

we find the basic period of pulsations in o And

$$P_o = 0^d\!.096$$

The above result is quite consistent with our observed quasi–period, suggesting that the short–term variations of o And might well be a consequence of a pulsating mechanism there. These pulsations might be of a damped character, becoming apparent now and then as the necessary conditions combine.

4. CONCLUSION

Although scarce, our results are an indication that o And is probably undergoing short–term variations (on a time scale of 0.1 days) of low amplitude (about 0.01 magnitude), which are superimposed on the variations of longer periods (on a time scale of 1 day), reported formerly too.

However, the UBV measurements are not suitable for the exploration of so rapid, low–amplitude variations. For this reason the observations during the initial stage, where the very reality of the phenomenon and of its time scale is still doubtful, should be made in one single colour, so as to produce as large a number of measurements as possible of the programme and the comparison stars. A more reliable analysis would be assured by measurements of two comparison stars.

We therefore are in favour of Harmanec's (1984b) suggestion conncerning a concentrated international effort aimed at simultaneous observation of o And at various observatories by spectroscopic, photometric and polarimetric methods, with particular attention being paid to variations shorter than 1 day. The results might prove important for better understanding of processes going on o And and the Be stars in general.

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GROWTH OF THE KNOWLEDGE OF STELLAR POSITIONS

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SUMMARY. An analysis is performed of the growth of the number of catalogues of star positions, the number of the catalogue positions, as well as the accuracy of the observational and fundamental catalogues. One of the conclusions is that the accuracy has been increasing faster than the number of catalogue positions and also faster than the number of the stars in the fundamental catalogues (FC–NFK–FK3–FK4 series).

1. INTRODUCTION

Stellar positions determinations is one of the oldest astronomical activities. It can reasonably be assumed that the earliest measurements (not mere descriptions) of the stellar positions have been practicized as far back as 3000 B.C. In the 4th century B.C. we already have stellar catalogues, that is, the lists of positions of quite a number of stars. The most recent Bibliography of the Catalogues of Star Positions (Šavarlić et al., 1978) contains 2087 entries, starting with the Eudoxos' catalogue from the 4th century B.C.

This historically very long activity provides in our view a sufficient amount of elements for making analysis of the course of accretion of knowledge of stellar positions by applying methods of the „Science of Science". A study of this kind may be a contribution not only to the fundamental astrometry, the object of which is the position determination of the celestial bodies, but to the astronomy in general.

In the present study we rely primarily upon the above quoted Bibliography, as well as on two publications dealing with the „Science of Science": Price (1969) and Dobrov (1970).

2. GROWTH OF THE NUMBER OF CATALOGUES AND STELLAR POSITIONS

The Bibliography data are arranged by decades according to years of their publication. In Fig. 1 a graphic presentation is given of the number of catalogues published in the separate intervals since 1600.

The total number of the catalogues registered until the 17th century is 16, never being above 2 in a single decade. The latest decade 1970–1979 is not complete as the data within it cover only two thirds of it.

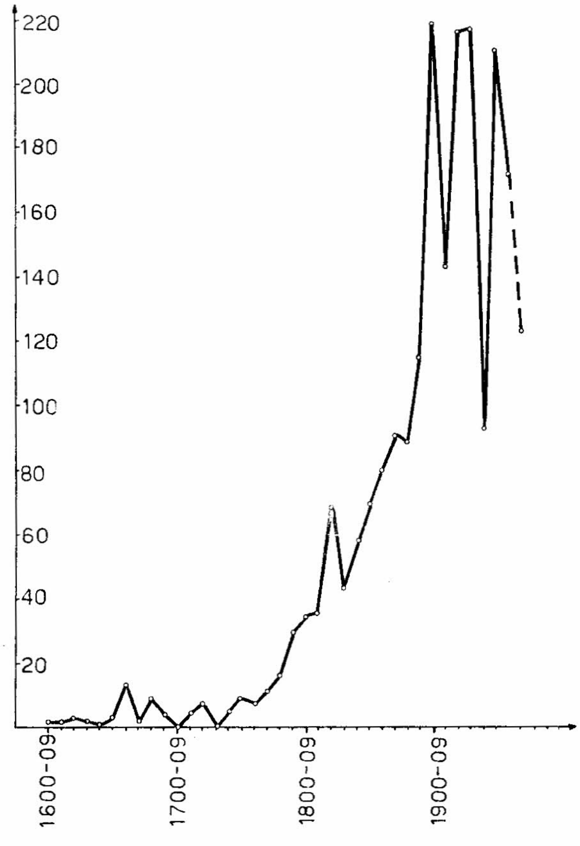

Fig. 1. The number of catalogues published according to decades since 1600. The latest decade 1970–1979 is not complete.

We see the number of the catalogues growing already in the 17th century, that growth becoming particularly intensive at the beginning of the 18th century, when one sees appearing the first modern catalogues in the present–day meaning of the word. Intensive growth is continued until the beginning of the 20th century, whereupon a slow decrease sets in – quite apart from the sharp drops in consequence of two Great Wars.

In analysing the data from Fig. 1 as well as other data in the present study, use will be made of the supposed law of the science development acceleration (Dobrov, 1970), expressed by

$$S = S_0 \exp [k(t-t_0)] \tag{1}$$

where:

S – the number of data (the mass of knowledge) at the time t,

S_0 – the number of data (the mass of knowledge) at the time t_0,

k – the coefficient, characterizing the given science field and its development over the given time interval.

In addition, the time T will also be searched for, within which the number of data (the mass of knowledge) is doubled. Proceeding from (1) the time T will be found by the formula:

$$T = k^{-1} \ln 2 \tag{2}$$

Since the beginning of the 18th century up to the beginning of the 20th century the growth of the number of catalogues follows, very approximately, an exponential pattern. Therefore, it is only natural that we shall apply to this series the expressions (1) and (2). The analysis was carried out using 10, 20 and 50 years intervals respectively for the period 1710–1909. The results obtained are given in Table I.

It can be stated that the number of catalogues, in the period from the beginning of the 18th century up to the beginning of the 20th century, is doubled every 34 years.

Table I. Values of k and T resulting from the analysis of the number of catalogues in the period 1710–1909, according to 10, 20 and 50 years intervals.

Interval	k	T
10	0.021	33
20	0.019	36
50	0.021	33

It can be said that, neglecting the periods 1910–1919 and 1940–1949, when astronomical activities dropped in consequence of World Wars, the number of the catalogues remained virtually unchanged from the beginning of the 20th century up to the end of fifties, whereupon a decline is evident, the rate of which will be established later on.

What is the reason of the culmination at the beginning of the 20th century? What is the cause of stagnation and subsequent decline in the catalogue production during the 20th century? The chief reasons, in our view, are the following:

a/ At the beginning of the twentieth century, as has been the case during the two preceding centuries, most of astronomers were engaged in the stellar catalogue elaboration. However, at the end of the first decade of the 20th century the number of active astronomers decreased (Struve, Zebergs, 1962), causing a general diminishing of astronomical activity together with the working out of stellar catalogues.

b/ The elaboration of catalogues is a time consuming activity, leaving little space for purely creative work (due to the stagnation in the instrumental development, slow growth of data accuracy, great amount of routine work, consevatism etc.). All this resulted in this branch of astronomy becoming less atractive and unrewarding. The astronomical cadres dispersed – continuing their activity in other astronomical fields, or even passing over to other sciences (Boss, 1937; Struve, Zebergs, 1962).

c/ The planing and the working out of catalogues has been conducted, and to a large extent continues to be conducted, as a isolated activity, without due connection with the developments in other disciplines. The catalogues, thus, were constructed for catalogues' sake. This led to further loss of interest in this form of activity.

It can be hoped that the modernization of the existing technics, in combination with the introduction of a new one, would bring with itself a halt to the current recession in the catalogues producing (Tucker, Teleki, 1978).

We analysed also the growth of the total number of the published catalogues. At making sums of all the catalogues, published during a given decade and during the decades preceding it, it could be stated that the growth is a very uniform one. From the beginning of the 18th century up to now that growth is such that the number of catalogues is re–doubled every 69 years. The same tendency, however, can be observed even before the 18th century.

We extended our investigation also to the number of the determined positions of individual stars in a given decade, as well as their sum total. It could thus be disclosed that both the former and the latter are re–doubled in about 33 years. Consequently, their growth is consistent with the growth rate of the number of catalogues according to decades in the interval 1710–1909. It is, otherwise, of interest to record here that all the catalogues in the Bibliography, taken together, comprise 7.5 million star positions, while the number of those, contained in only the observational catalogues amounts to 3.5 million.

3. GROWTH OF THE CATALOGUE ACCURACY

The data from the preceding Section give a picture about the volume growth of the scientific information. There certainly must exist some correlation between these particular information and our knowledge of stellar positions. The question, however, is how close is that correlation.

Another question imposing itself is the following: what is the actual utilization of the scientific information contained in the catalogues?

The two questions look, at first glance, rather identical. This, however, is not true. An information, namely, can be used even though it does not necessarily represent a real contribution to our knowledge because, say, of its low accuracy.

It is hard to give exact answers to these questions, so we are going to restrain, for the time being, our considerations to estimates only. This will be accomplished in the following way.

The basic objective of the fundamental astrometry is the establishment of the celestial reference coordinate system. That system is materialized by the stellar catalogues. As criterions in this analysis of the growth rate of the knowledge of the stellar positions will be taken only: a/ the accuracy of the catalogue data, and b/ the number of stars (reference points) in the catalogues.

The first analysis will be accomplished with the observational catalogues. The data relating to the chosen catalogues, representing particular epochs, are found in Table II.

Table II. Observational catalogues: N° in the Bibliography, author(s), epoch and estimated error of observation (basic data: Bakulin, 1949; Podobed, 1962).

N°	Author(s)	Number of stars	Epoch	Estimated error
5	Ptolemeus	1025	138	±900 "
41	Brahe Tycho	1005	1601	120
55	Hevelius	1564	1661	120
67	Flamsteed	2934	1689	10
104	Bradley	3222	1755	2
840	Gill et al.	3007	1890	0.4
1874	Høg et al.	24900	1970	± 0.2

In using the relations (1) and (2) we first analysed the accuracy growth. The estimated squared error (ϵ^2) has been used with every possible pair of catalogues, listed in Table II. The results obtained are represented in Fig. 2. The mean values T are separated in Table III.

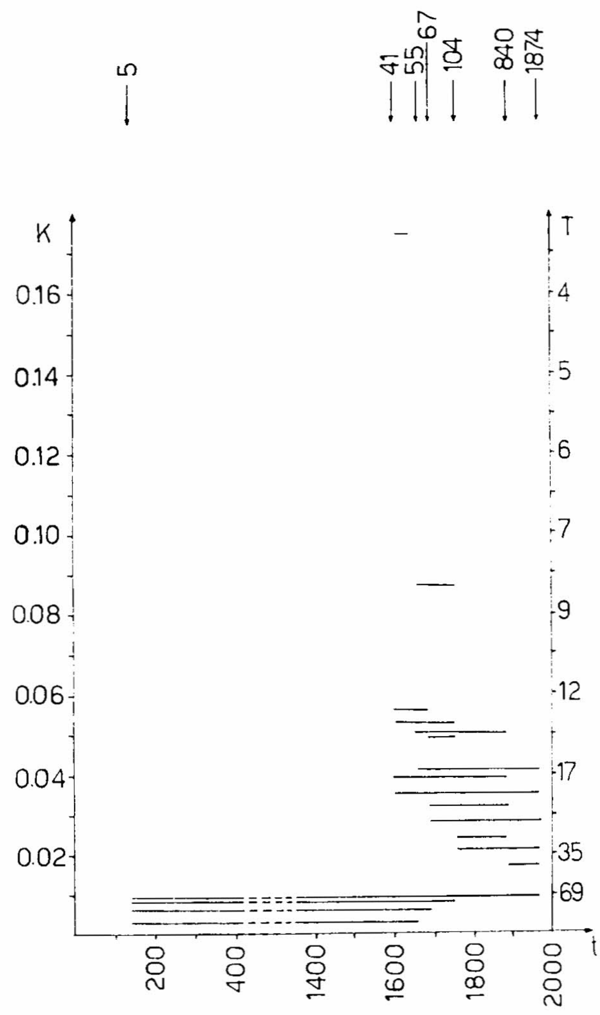

Fig.2. The k and T values for the pairs of observational catalogues. The lines represent the values since the year of the first to the year of the second catalogue. On the top: the N°s of the catalogues according to Table II.

A variety of the accuracy growth rates is evident. It can also be noticed that the time of doubling T decreases with time up to about the middle of the 17th century, resuming thereafter its growth. Mean value T from the pairs of catalogues starting with the Bradley's catalogue – that is from the middle of 18th century – is 34 years.

Table III. Mean values T for the catalogue pairs in the analysis of the accuracy ϵ^2 and the parameter n/ϵ^2 (n is the number of stars).

Catalogues pairs	T	
	Analysis of ϵ^2	Analysis of n/ϵ^2
Mean values from all the catalogue pairs listed in Table II	54	70
Mean values from the pairs of catalogues starting with the catalogue No. 41	19	31
Mean values from the pairs of catalogues starting with the catalogue No. 67	27	39
Mean values from the pairs of catalogues starting with the catalogue No. 104	34	55

It can therefore be said that the accuracy growth since the beginning of the 18th century is the same – perhaps samewhat higher – as that of the growth of the number of catalogues and the catalogue positions in the period 1710–1909.

We find in Table II, among others, the catalogue N° 1874, containing 24900 stars. It should be remarked, however, that this number is not typical of the year 1970, as the average number of stars in the observational catalogues changes very slow. In the 20th century the average number of catalogue positions in the observational catalogues is about 2200. The inclusion of the catalogue N° 1874 in the analysis is, therefore, to be regarded as only an indication of the potentiallities.

We also regard as useful the analysis by way of the parameter n/ϵ^2, where n is the number of stars in the catalogue. Mean values for the catalogue pairs are summarized in Table III. A general conclusion might be the following: granted the number of stars in the observational catalogues is increasing in the way showed in Table II, then T increases slower than that pertaining to the accuracy. However, in so far as it is assumed that n does not vary considerably – at least over the last hundred years – then T, related to $1/\epsilon^2$ is the same as the one related to ϵ^2.

Let us now have a look at the derived (computed) catalogues.

The derived catalogues, the fundamental ones in particular, are relatively young: the earliest of them, compiled from independent observational catalogues, appeared as late as 1830. It is Bessel's "Tabulae Regiomontanae", comprising 38 stars, composed from 3 catalogues.

To get an idea of the growth of knowledge contained in the fundamental catalogues, let us trace the series that led to the present–day fundamental catalogue FK4. There we have first the FC (in 1879), followed by: NFK (in 1907); FK3 (in 1937–38) and finally FK4 (in 1963). Consider the first and the latest catalogue of this series (basic data: Auwers, 1886 and Lederle, 1976). The data considered are given in Table IV. It can be seen that the growth of the number of stars is strongly slowed down as compared with the increase in accuracy. The mean value T=12 years, resulting from the analysis of the parameter n/ϵ^2 will be considered as characteristic of the knowledge growth associated with the family of fundamental catalogues FC–NFK–FK3–FK4. This, as a matter of fact, is but a crude estimate of the subject concerned, as a number of very material facts have been omitted from consideration. For instance: the FC covers only the northern hemisphere (more precisely north of $-10°$ declination), in contrast to the FK4, extending over the whole sky. Nevertheless, T=12 years provides a fair illustration of the markedly faster growth of our knowledge resulting from the formation of the fundamental celestial coordinate systems compared with the growth of the number of catalogues (T = 34 years). This can be accounted for not only by the increase in accuracy of the observational data, but also by the steadily improving organization methods of the observations concerned, by the selection and processing of data in forming the fundamental catalogues.

Table IV. The values k and T from the comparison of corresponding data in the FC and FK4.

Data	k	T
Total number of stars	0.017	41
The number of stars within the zone $-10° < \delta < +90°$	0.009	77
The accuracy (ϵ^2) within the zone $-10° < \delta < +90°$ for the mean epoch:		
– right ascensions		
main stars	0.034	20
supplemental stars	0.069	10
– declinations		
main stars	0.042	16
supplemental stars	0.057	12
The values of the ratio of the number of stars (from FK4 927 are taken into account) and ϵ^2 in the zone $-10° < \delta < +90°$ for the mean epoch:		
– right ascensions		
main stars	0.042	16
supplemental stars	0.077	9
– declinations		
main stars	0.052	13
supplemental stars	0.066	10

We analysed also the rate of the accuracy decrease (due in the first place to errors in the values of the stellar proper motions) of the catalogue positions with time in the FC and FK4. In the FC, in the interval of epochs 1875 and 1900, the accuracy is found to decrease with doubling time (T) of about 15 years. In the FK4, in the interval of 1925 and 2000 epochs, the accuracy decreasing rate is considerably lower, amounting to T ≈ 24 years. It is of interest to note a good agreement of this piece of information with the one given by Fricke (1974): the FK4 cannot profitably be used for more than 20 years after its formation.

4. UTILIZATION OF CATALOGUES

It is hard to tell what is the effective utilization of catalogues. If only fundamental catalogues are considered, the following can be stated: for the formation of the GC 22% of the then available catalogues have been used, while the FK4 has been constructed upon nearly 16%. Obviously, not all the data existing in the catalogues are used. The catalogues used at compiling the GC contain about 40% of all the stellar positions figuring in the observational catalogues of that period taken together. Proceeding from this fact we can assume that overall turning to account of the totality of catalogue positions does not exceed 40% (according to Dobrov (1970) the information loss in the science–technics fields attains 20–80%). Concerning obsolescence, it can be correlated with the time of accuracy doubling of the observational catalogues, amounting to 34 years.

5. CONCLUSIONS

In concluding the following conclusions can be drawn:

a/ The number of catalogues has approximately been increasing exponentially from the beginning of the 18th century up to the beginning of the 20th century, whereafter a stagnation and a certain decline has set in.

b/ The growth of the number of catalogues and the catalogue positions (the time of doubling T = 34 years) is slower than the present–day's growth of scientific–technical information (with T rang from 10 to 20 years).

c/ The accuracy of the observational catalogues incr ses at a rate of T = 34 years, while that of fundamental catalogues (FC–NFK–FK3–FK4) creases at double that rate. But this is still faster th the rate at which the present–day overall scienti knowledge is being doubled (40–50 years).

d/ The accuracy of the FK4 decreases by a factor of t in 24 years (due to the errors of positions at me epoch and due to the errors of proper motions).

e/ The overall utilization of the existing catalog positions is estimated as not surpassing 40%.

It is recommendable to continue these exploratior

Acknowledgement

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ORBITES DE TROIS ETOILES DOUBLES VISUELLES (ADS 3686, IDS 05312S5108, ADS5707AB)

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(Reçu le 4. oct. 1984)

RÉSUMÉ: On donne les éléments orbitaux, les masses, les magnitudes absolues et les parallaxes dynamiques orbitales de trois étoiles doubles visuelles, les éléments étant determinés en utilisant la méthode de Thiele–Innes, Van den Bos.

ORBITE DE ADS 3686 = A 3009

IDS 05013S1403; Mgn.: 8.1–10.4; Type sp. G5

Tableau I. Les éléments orbitaux, les quantités astrophysiques et les constantes.

$P = 168.92$ ans		
$n = 2^\circ.1312$	$A = +0''.6300$	$\pi_{dyn.orb.} = 0''.028$
$T = 1892.90$	$B = +0''.6300$	$M_A = 5.3$
$e = 0.11$	$F = -0''.3850$	$M_B = 7.6$
$a = 1''.033$	$G = +0''.8100$	$\mathbf{M}_A = 1.02 \odot$
$i = 45^\circ.1$	$C = \mp 0''.5226$	$\mathbf{M}_B = 0.73 \odot$
$\Omega = 80^\circ.7$	$H = \pm 0''.5125$	$a = 36.8$ U.A.
$\omega = 314^\circ.4$		
$T_{\Omega,\mho} = 1910.29; 1834.30$		

Tableau II. Les éphémérides

T	θ	ρ
1984.0	235°.2	1''.05
1985.0	236.6	1.06
1986.0	238.0	1.06
1987.0	239.4	1.07
1988.0	240.8	1.08
1989.0	242.2	1.08
1990.0	243.5	1.09
1991.0	244.9	1.09
1992.0	246.2	1.10
1993.0	247.5	1.10

Tableau III. Les observations et les résidus

N.	t	θ_0	ρ_0	Obs.	n	$(0-C)_\theta$	$(0-C)_\rho$
1.	1926.00	109°.5	0''.91	A	2	+0°.5	0''.00
2.	1933.60	127.5	0.88	A	2	+2.9	+0.03
3.	1937.58	133.5	0.79	B	4	–0.2	–0.03
4.	1946.60	158.4	0.64	B	2	+2.2	–0.14
5.	1949.48	163.1	0.80	VBS	4	–0.7	+0.02
6.	1952.66	174.6	0.80	B	3	+2.4	+0.02
7.	1953.02	171.0	1.15	VBS	3	–2.1	+0.37
8.	1958.02	189.6	0.76	B	2	+4.0	–0.05
9.	1959.09	190.8	0.76	B	2	+2.4	–0.05
10.	1959.97	192.4	0.76	B	4	+1.9	–0.06
11.	1963.06	197.4	0.81	KNP	1	–0.2	–0.03
12.	1963.471	201.0	0.86	WOR	3	+2.5	+0.01
13.	1972.073	214.6	0.93	WOR	3	–1.3	0.00
14.	1973.04	215.6	0.96	HEI	3	–2.0	+0.02
15.	1977.923	223.2	1.00	HLN	2	–2.7	+0.01

ORBITE DE IDS 05312S5108 = HU 1566

Mgn.: 9.3–9.6; Type sp. KO

Tableau IV. Les éléments orbitaux, les quantités astrophysiques et les constantes.

$P = 281.29$ ans		
$n = 1^\circ.2798$	$A = -1''.0000$	$\pi_{dyn.orb.} = 0''.024$
$T = 1896.00$	$B = -0''.7675$	$M_A = 6.2$
$e = 0.32$	$F = -0''.5500$	$M_B = 6.5$
$a = 1''.267$	$G = +0''.8425$	$\mathbf{M}_A = 0.90 \odot$
$i = 142^\circ.0$	$C = \mp 0''.1255$	$\mathbf{M}_B = 0.86 \odot$
$\Omega = 44^\circ.8$	$H = \mp 0''.7699$	$a = 51.7$ U.A.
$\omega = 189^\circ.3$		
$T_{\Omega,\mho} = 2023.40; 1892.47.$		

Tableau V. Les éphemerides

t	θ	ρ
1984.0	69°.2	1".44
1985.0	68.5	1.45
1986.0	67.8	1.46
1987.0	67.1	1.47
1988.0	66.4	1.48
1989.0	65.6	1.48
1990.0	65.0	1.49
1991.0	64.3	1.50
1992.0	63.6	1.51
1993.0	62.9	1.52

Tableau VI. Les observations et les résidus

N.	t	θ_0	ρ_0	Obs.	n	$(0-C)_\theta$	$(0-C)_\rho$
1.	1914.98	175°.2	0".76	HU	1	+0°.2	–0".04
2.	1922.38	157.9	0.87	DAW	3	+0.6	+0.07
3.	1928.12	143.6	0.78	B	3	–2.8	–0.05
4.	1928.75	142.9	0.83	VOU	4	+0.3	0.00
5.	1930.14	139.0	0.89	FIN	4	–0.5	+0.05
6.	1932.60	133.4	0.82	FIN	4	–0.8	–0.03
7.	1932.74	132.7	0.93	VOU	4	–1.2	+0.07
8.	1934.08	130.9	0.86	B	4	–0.3	0.00
9.	1936.88	123.7	0.81	VOU	3	–1.9	–0.07
10.	1939.80	120.1	0.98	B	4	0.0	+0.06
11.	1939.82	119.4	0.85	SMW	4	–0.7	–0.07
12.	1942.77	113.0	0.88	VOU	3	–1.9	–0.07
13.	1946.06	111.0	1.06	B	4	+1.4	+0.07
14.	1951.15	102.8	0.99	B	4	+0.7	–0.06
15.	1956.12	96.9	1.05	B	1	+1.3	–0.07
16.	1959.09	95.6	1.07	B	4	+3.6	–0.08
17.	1964.10	87.3	1.22	KNP	2	+0.7	0.00
18.	1966.11	85.8	1.29	B	4	+1.3	+0.05
19.	1967.10	84.3	1.36	KNP	2	+0.8	+0.11
20.	1968.11	82.3	1.29	KNP	2	–0.3	+0.03
21.	1972.079	79.3	1.27	WOR	3	+0.4	–0.04
22.	1975.14	75.7	1.51	HLN	3	–0.5	+0.16
23.	1977.73	73.7	1.41	HEI	3	–0.4	+0.03
24.	1981.22	68.2	1.30	WRH	2	–3.1	–0.11

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Tableau VII. Les éléments orbitaux, les quantités astrophysiques et les constantes

P = 118.31 ans		
n = 3°.0428	A = + 0".1735	$\pi_{dyn.orb.}$ = 0".007
T = 1885.87	B = – 0".1165	M_A = 2.7
e = 0.29	F = + 0".1718	M_B = 3.2
a = 0".247	G = + 0".1495	$\mathbf{M}_A$ = 1.57 ○
i = 40°.9	C = ∓ 0".1311	$\mathbf{M}_B$ = 1.43 ○
Ω = 12°.4	H = ± 0".0948	a = 34.8 U.A.
ω = 305°.9		
$T_{\Omega,\mho}$ = 1895.90; 1854.53		

Tableau VIII. Les éphémérides

t	θ	ρ
1984.0	217°.0	0".22
1985.0	219.9	0.21
1986.0	223.0	0.20
1987.0	226.3	0.20
1988.0	229.9	0.19
1989.0	233.7	0.18
1990.0	237.8	0.18
1991.0	242.3	0.17
1992.0	247.1	0.16
1993.0	252.3	0.16

Tableau IX. Les observations et les résidus

N	t	θ_0	ρ_0	Obs.	n	$(0-C)_\theta$	$(0-C)_\rho$
1.	1922.84	85°.8	0".22	A	2	–9°.2	0".00
2.	1931.15	105.9	0.22	A	2	–10.9	–0.01
3.	1933.16	128.1	0.24	A	1	+6.5	0.00
4.	1936.23	129.9	0.21	B	4	+1.4	–0.04
5.	1936.83	132.9	0.27	VOU	4	+3.1	+0.02
6.	1938.15	134.9	0.26	B	4	+2.3	+0.01
7.	1939.95	138.7	0.26	SMW	1	+2.4	0.00
8.	1944.62	146.9	0.26	B	2	+1.5	–0.01
9.	1944.83	145.6	0.27	VOU	4	–0.2	0.00
10.	1952.08	169.2	0.20	B	1	+10.8	–0.08
11.	1979.19	195.6	0.28	HEI	2	–9.4	+0.04

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OBSERVATIONS OF THE SUN AND PLANETS WITH THE BELGRADE LARGE MERIDIAN CIRCLE

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SUMMARY. Results are presented of the Sun, Mercury, Venus and Mars observations made with Large Meridian Circle of the Belgrade Observatory in the period September 1981 – November 1983.

It is ten years now since systematic observations of the Sun, Mercury and Venus with the Large Meridian Circle of the Belgrade Observatory are going on. These observations are extended, since January 1981, by those of Mars. More about this in Sadžakov et al. (1976), Sadžakov et al. (1981), Sadžakov et al. (1982a), Sadžakov et al. (1982b), Sadžakov et al. (1983), Šaletić (1968).

The observations are relative ones, the reference stars being taken from the FK4. The data treatment involved the circle division corrections as well as corrections for flexure, collimation and refraction (calculated according to the Pulkovo Tables). No account is taken of the „day–hight" corrections and the personal errors. One edge of the planets was observed when these were phased, otherwise both edges have been observed.

The observed right ascensions (α) and declinations (δ) are compared with their ephemeris counterparts, the latter having been caluclated at Pulkovo Observatory.

The number of observations of the Sun and planets in the period September 1981 – November 1983 is presented in Table I, where:

N – the number of reference stars transits;
n – the number of observing tours;
$K = \frac{N}{n}$ – the average number of reference stars transits per observing tours;

Table I. Data on Observations

Object observ.	1981			1982			1983		
	N	n	K	N	n	K	N	n	K
SUN	107	11	10	495	87	6	308	39	8
MERCURY	19	3	7	149	20	7	38	6	6
VENUS	76	8	10	411	48	9	239	32	7
MARS	139	15	9	150	22	7	45	5	9

The temperature inside pavilion has been read off before and after the observation at two places, to the north and to the south of the instrument. Mean temperature has been used at reduction. Data treatment has been performed on a TEXAS 59.

The error of a single observation has been determined according to the formula

$$\epsilon = \pm \sqrt{\frac{\Sigma \nu_i^2}{n-1}}$$

where

ν_i – the deviation (0 – C) of the mean value for a particular period,
n – the number of observations.

Mean yearly differences $(0 - C)_{\alpha,\delta}$ for the Sun and planets, ϵ – mean errors of single observations and n – the number of observations are sumarized in Table II.

Table II. (0 – C) differences and their errors for the observed objects

objects	years	$(0-C)_\alpha$	ϵ_α	$(0-C)_\delta$	ϵ_δ	n
SUN	1981	$-0^s.009$	± 0.022	–0.24	$\pm 0''.27$	11
	1982	–0.004	± 0.026	–0.02	± 0.29	59
	1983	+0.002	± 0.024	–0.08	± 0.23	39
MERCURY	1981	+0.002	± 0.047	+0.11	± 0.14	3
	1982	–0.003	± 0.042	+0.02	± 0.37	20
	1983	+0.045	± 0.024	–0.04	± 0.55	6
VENUS	1981	–0.002	± 0.041	+0.04	± 0.52	8
	1982	+0.004	± 0.046	–0.05	± 0.44	48
	1983	–0.004	± 0.030	+0.06	± 0.43	5
MARS	1981	–0.005	± 0.052	–0.04	± 0.51	15
	1982	–0.002	± 0.033	+0.10	± 0.44	22
	1983	–0.028	± 0.010	–0.09	± 0.56	5

The results of observations in the period 1981–1983 are given in Tables III through VI.

Columns are

Column I – the date of observation,
Column II – observers: Sophia Sadžakov (SS), Miodrag Dačić (MD),
Column III – atmospheric pressure in mm,
Column IV – mean air temperature in the pavilion,
Column V – number of reference stars transits,
Column VI – ephemeris right ascension (α),
Column VII – $(0\text{–}C)_\alpha$ of the right ascensions,
Column VIII – ephemeris declination (δ),
Column IX – $(0\text{–}C)_\delta$ of the declination,
Column X – epoch of observation,
Column XI – clamp position.

Table III. Data on the Sun observations

Date of observ.	ob. serv.	Ba	t°C	n	α			$(o\text{–}C)_\alpha$	δ			$(0\text{–}C)_\delta$	Ep	clamp posit.
1981													1980+	
09.09.	SM.MD.	744.3	22.0	9	11^h	10^m	$52^s.839$	$0^s.002$	05°	16′	01″.90	–0″.16	1.69	E
10.09.	SS.MD.	741.2	22.0	10	11	14	28.452	0.015	04	53	20.20	–0.14	1.69	E
14.09.	SS.MD.	744.6	21.5	12	11	28	49.657	–0.012	03	31	46.42	0.08	1.70	E
21.09.	SS.MD.	745.4	23.5	10	11	53	55.671	0.030	00	39	22.67	0.02	1.72	E
22.09.	SS.MD.	746.7	25.5	10	11	57	31.075	–0.034	00	16	02.20	–0.30	1.73	E
23.09.	SS.MD.	743.2	24.9	12	12	01	06.601	–0.009	–00	07	19.39	–0.30	1.73	E
09.10.	SS.MD.	746.4	19.6	13	12	59	06.214	–0.016	–06	18	43.69	–0.28	1.77	E
02.11.	MD.	747.9	16.2	6	14	30	01.188	–0.046	–14	47	22.23	–0.92	1.84	E
04.11.	SS.MD.	750.9	12.3	5	14	37	54.553	–0.007	–15	24	48.55	–0.12	1.84	W
05.11.	SS.MD.	745.4	13.5	8	14	41	52.441	0.011	–15	43	09.00	–0.12	1.85	W
24.11.	SS.MD.	745.2	13.5	12	15	59	51.621	–0.028	–20	34	34.07	–0.44	1.90	W
1982													1980+	
14.01.	SS.MD.	758.8	–0.5	10	19	43	18.581	–0.044	–21	19	16.86	–0.07	2.04	W
27.01.	SS.MD.	736.0	1.0	12	20	38	18.897	0.025	–18	28	51.94	0.21	2.07	W
17.02.	MD.	748.4	3.3	10	22	02	25.049	0.016	–12	00	58.99	–0.01	2.13	W
08.03.	SS.MD.	749.2	6.3	10	23	14	09.247	–0.006	–04	55	34.02	–0.10	2.18	W
09.03.	SS.MD.	747.1	6.3	8	23	17	50.772	–0.024	–04	32	09.23	–0.07	2.19	W
10.03.	SS.MD.	745.0	8.3	10	23	21	31.938	–0.025	–04	08	41.03	0.24	2.19	W
17.03.	SS.MD.	742.9	9.2	10	23	47	12.060	–0.021	–01	23	17.22	0.08	2.21	W
18.03.	SS.MD.	739.8	9.0	10	23	50	51.197	–0.012	–00	59	34.34	0.00	2.21	W
24.03.	SS.MD.	753.9	6.0	10	00	12	43.353	0.001	01	22	34.42	–0.20	2.23	W
25.03.	SS.MD.	753.0	6.5	10	00	16	21.769	–0.005	01	46	11.01	–0.71	2.23	W
05.04.	SS.MD.	747.1	13.2	8	00	56	25.936	–0.010	06	01	53.80	–0.18	2.26	E
06.04.	SS.MD.	750.2	15.0	5	01	00	05.110	–0.012	06	24	37.36	0.43	2.26	E
08.04.	SS.MD.	746.8	19.0	7	01	07	24.059	0.010	07	09	44.15	–0.63	2.27	E
04.05.	SS.MD.	745.9	20.0	6	02	44	43.448	0.018	15	55	57.02	–0.44	2.34	E
06.05.	SS.MD.	743.0	22.0	7	02	52	25.973	0.002	16	30	13.37	–0.16	2.35	E
17.05.	SS.MD.	744.5	19.0	4	03	35	30.965	0.035	19	18	03.72	–0.12	2.38	E
19.05.	SS.MD.	744.0	23.4	8	03	43	28.535	0.035	19	44	31.18	0.50	2.38	E
24.05.	SS.MD.	737.8	24.2	5	04	03	32.207	–0.025	20	44	43.43	–0.09	2.39	E
01.06.	SS.MD.	750.0	22.0	6	04	36	03.366	0.014	22	02	18.65	–0.23	2.42	E
03.06.	SS.MD.	747.2	24.4	8	04	44	15.269	–0.008	22	17	55.20	0.64	2.42	E
07.06.	SS.MD.	738.5	23.8	7	05	00	43.250	–0.041	22	44	26.34	0.67	2.43	E
09.06.	SS.MD.	743.6	20.4	9	05	08	59.073	–0.024	22	55	18.85	–0.16	2.44	E
16.06.	SS.MD.	742.4	22.6	8	05	38	01.561	–0.020	23	20	37.17	–0.28	2.46	W
21.06.	SS.MD.	743.4	23.6	7	05	58	50.023	–0.019	23	26	22.53	–0.55	2.47	W
22.06.	SS.MD.	741.4	20.8	7	06	02	59.768	–0.002	23	26	17.22	0.01	2.48	W
23.06.	SS MD.	740.4	26.3	8	06	07	09.458	–0.020	23	25	47.12	0.37	2.48	W
24.06.	SS.MD.	742.5	24.7	9	06	11	19.061	–0.016	23	24	52.23	–0.06	2.48	W
29.06.	SS.MD.	742.9	22.5	5	06	32	04.852	–0.030	23	14	07.00	–0.61	2.49	W
02.07.	SS.MD.	746.3	23.0	5	06	44	29.750	–0.017	23	02	45.67	–0.02	2.50	W
06.07.	SS.MD.	744.3	25.2	7	07	00	58.853	–0.024	22	41	59.86	0.08	2.51	W
15.07.	SS.MD.	741.6	23.8	5	07	37	42.064	–0.009	21	32	31.52	–0.71	2.54	W
16.07.	SS.MD.	743.5	25.1	5	07	41	44.640	0.027	21	22	55.58	–0.13	2.54	W

Table III, continued

17.07.	MD.	745.8	25.5	5	07	45	46.725	–0.037	21	12	57.81	–0.11	2.54	W
18.07.	MD.	744.5	26.0	5	07	49	48.303	–0.008	21	02	38.43	–0.19	2.55	W
19.07.	SS.MD.	745.9	26.3	5	07	53	49.357	0.017	20	51	57.67	0.37	2.55	W
20.07.	SS.MD.	747.6	27.0	6	07	57	49.871	–0.014	20	40	55.79	–0.04	2.25	W
21.07.	SS.MD.	746.1	26.9	5	08	01	49.826	–0.040	20	29	33.02	0.03	2.55	W
22.07.	SS.MD.	742.0	27.8	8	08	05	49.206	0.035	20	17	49.62	0.14	2.56	W
23.07.	SS.MD.	740.7	26.4	7	08	09	47.998	–0.002	20	05	45.83	0.18	2.56	W
02.08.	SS.MD.	741.7	22.0	7	08	49	02.224	0.031	17	47	25.81	0.04	2.59	E
11.08.	SS.MD.	743.4	23.9	6	09	23	28.920	0.010	15	18	06.57	0.00	2.61	E
12.08.	SS.MD.	746.8	24.4	6	09	27	15.698	–0.008	15	00	13.55	0.05	2.61	E
06.09.	SS.MD.	742.8	25.8	7	10	59	12.682	0.015	06	28	58.53	0.18	2.68	E
07.09.	SS.MD.	741.8	26.0	8	11	02	48.824	0.003	06	06	35.44	0.24	2.68	E
14.09.	SS.MD.	742.4	24.6	9	11	27	57.996	0.006	03	27	19.36	0.21	2.70	E
11.10.	SS.MD.	746.2	17.7	10	13	05	33.405	0.008	–06	58	36.90	–0.08	2.78	W
19.10.	SS.MD.	745.3	17.9	12	13	35	18.983	0.010	–09	56	16.55	0.16	2.80	W
21.10.	SS.MD.	746.0	17.4	14	13	42	51.297	–0.005	–10	39	22.47	–0.29	2.81	W
22.10.	SS.MD.	743.8	18.2	12	13	46	38.417	0.073	–11	00	41.34	0.11	2.81	W
25.10.	SS.MD.	745.3	18.7	10	13	58	03.791	0.038	–12	03	36.72	0.13	2.82	W
29.10.	SS.MD.	756.1	15.0	12	14	13	27.481	–0.019	–13	24	52.50	0.16	2.83	W
09.11	SS.MD.	746.0	6.8	11	14	56	52.616	–0.011	–16	49	36.66	0.12	2.86	W
11.11.	SS.MD.	751.3	11.5	10	15	04	57.291	–0.048	–17	23	24.48	–0.44	2.86	W
12.11.	SS.MD.	751.0	10.9	12	15	09	00.929	0.031	–17	39	51.83	–0.16	2.87	W
19.11.	SS.MD.	746.3	6.7	14	15	37	50.327	–0.076	–19	26	09.38	0.25	2.88	W
22.11.	SS.MD.	753.0	10.0	13	15	50	23.874	0.037	–20	06	34.64	0.01	2.89	W
23.11.	SS.MD.	754.0	11.3	13	15	54	36.627	–0.016	–20	19	19.18	0.23	2.89	E
24.11.	SS.MD.	749.0	12.5	12	15	58	50.145	–0.015	–20	31	41.16	–0.04	2.90	E
16.12.	SS.MD.	734.6	11.9	10	17	34	28.348	–0.037	–23	18	49.46	0.06	2.96	E
1983.													1980+	
07.01.	SS.MD.	749.6	7.9	12	19	11	49.992	0.040	–22	25	00.48	–0.03	3.02	E
13.01.	SS.MD.	750.6	7.5	12	19	37	56.876	0.055	–19	15	33.22	–0.31	3.04	E
14.03.	SS.MD.	752.1	6.8	10	23	35	20.763	–0.007	–02	40	02.63	–0.01	3.20	E
18.03.	SS.MD.	746.6	12.6	10	23	49	59.019	0.001	–01	05	13.84	–0.26	3.21	E
21.03.	SS.MD.	742.4	13.4	12	00	00	55.648	0.007	00	05	55.71	0.29	3.22	E
28.03.	SS.MD.	736.0	9.5	10	00	26	24.002	0.034	02	51	05.92	–0.13	3.24	E
25.04.	SS.MD.	741.2	20.0	8	02	09	33.466	0.012	13	04	30.19	–0.18	3.32	E
26.04.	SS.MD.	742.2	21.2	8	02	13	19.570	–0.016	13	24	00.65	0.09	3.32	E
28.04.	SS.MD.	743.9	22.1	7	02	20	53.263	–0.004	14	02	21.54	0.17	3.32	E
13.05.	SS.MD.	740.8	22.3	8	03	18	46.333	0.002	18	17	45.05	0.18	3.36	E
14.05.	MD.	743.5	23.7	6	03	22	42.489	0.042	18	32	30.47	0.21	3.37	E
16.05.	SS.MD.	741.4	26.1	6	03	30	36.493	–0.006	19	01	04.71	0.13	3.37	W
17.05.	SS.MD.	742.0	24.7	7	03	34	34.324	0.035	19	14	52.93	0.10	3.38	W
18.05.	SS.MD.	740.7	24.8	7	03	38	32.696	0.033	19	28	21.50	0.07	3.38	W
19.05.	SS.MD.	739.7	22.8	6	03	42	31.601	–0.005	19	41	30.12	0.00	3.38	W
31.05.	SS.MD.	744.4	25.0	8	04	30	58.077	0.002	21	51	50.95	–0.30	3.41	W
01.06.	SS.MD.	746.0	24.5	5	04	35	03.354	0.004	22	00	19.48	–0.46	3.41	W
02.06.	SS.MD.	746.0	24.7	6	04	39	09.049	0.002	22	08	25.07	–0.08	3.42	W
03.06.	SS.MD.	746.2	24.5	8	04	43	15.148	0.006	22	16	07.55	–0.05	3.44	W
09.06.	SS.MD.	748.9	23.5	7	05	07	59.267	0.034	22	54	08.00	0.01	3.49	E
27.06.	SS.MD.	742.3	25.1	4	06	22	46.371	–0.016	23	20	14.63	0.19	3.51	E
05.07.	MD.	745.6	24.8	5	06	55	51.954	–0.051	22	49	10.34	–0.34	3.55	E
19.07.	SS.	745.3	27.2	6	07	52	51.758	–0.024	22	54	35.91	–0.02	3.55	E
20.07.	SS.	742.6	27.0	7	07	56	52.238	–0.020	20	43	39.18	–0.18	3.57	E
27.07.	SS.MD.	744.4	25.2	4	08	24	39.385	–0.016	19	17	31.27	–0.15	3.57	E
28.07.	SS.MD.	742.4	26.9	6	08	28	35.187	0.008	19	03	54.47	0.32	3.59	E
03.08.	SS.	738.8	28.4	6	08	51	57.576	–0.020	17	35	46.81	0.28	3.63	E
18.08.	SS.	744.5	25.5	6	09	48	51.514	–0.010	13	12	43.77	–0.43	3.67	E
01.09.	SS.MD.	745.0	24.3	8	10	40	14.972	–0.015	08	24	33.62	–0.39	3.67	E
02.09.	SS.MD.	743.8	24.4	10	10	43	52.523	–0.025	08	02	47.12	0.03	3.70	E
14.09.	SS.MD.	748.6	19.9	9	11	27	06.074	–0.031	07	10	40.94	–0.06	3.71	E
15.09.	SS.MD.	744.7	22.2	8	11	30	41.257	0.002	03	09	50.47	0.28	3.76	E
03.10.	MD.	750.1	14.0	7	12	35	26.114	0.011	–03	49	18.98	–0.25	3.76	E
05.10.	SS.MD.	748.1	21.2	7	12	42	42.249	–0.018	–04	35	39.42	–0.32	3.76	E
06.10.	SS.MD.	745.9	21.4	8	12	46	20.858	0.019	–04	58	44.89	–0.14	3.78	W
11.10.	SS.MD.	744.8	18.9	10	13	04	39.985	0.000	–06	53	09.24	–0.02	3.78	W
13.10.	SS.MD.	749.7	13.5	10	13	12	02.777	0.005	–07	38	18.27	–0.25	3.78	W
24.10.	MD.	751.1	10.6	12	13	53	17.961	–0.030	–11	37	39.14	–0.46	3.81	W
28.10	MD.	745.0	13.1	12	14	08	38.024	0.037	–12	59	52.27	–0.51	3.82	W

Table IV. Data on the Mercury observations

Date of observ.	ob. serv.	Ba	t°C	n	α			$(0-C)_\alpha$	δ			$(0-C)_\delta$	Ep	clamp posit.
1981.													1980+	
02.11.	MD.	747.9	14.3	6	13^h	21^m	$48^s.945$	$0^s.055$	06°	18'	34".91	0".18	1.84	W
04.11.	SS.MD.	750.9	11.7	5	13	29	35.252	–0.034	07	00	33.85	0.20	1.84	W
05.11.	SS.MD.	745.4	12.2	8	13	33	57.045	–0.015	07	25	50.84	–0.05	1.85	W
1982													1980+	
06.04.	SS.MD.	750.2	16.2	,8	00	41	38.826	0.026	02	50	20.46	0.39	2.26	E
08.04.	SS.MD.	746.8	18.2	7	00	56	06.264	–0.014	04	37	48.42	–0.49	2.27	E
04.05.	SS.MD.	745.9	20.7	7	04	06	31.535	0.005	23	26	57.50	0.29	2.34	E
06.05.	SS.MD.	743.0	23.2	9	04	17	04.285	–0.006	23	56	48.00	–0.39	2.35	E
17.05.	SS.MD.	744.5	18.2	10	04	52	34.760	–0.010	24	12	33.56	–0.34	2.38	E
24.05.	SS.MD.	737.8	24.6	5	04	53	45.102	–0.052	22	37	30.10	–0.45	2.39	E
29.06.	SS.MD.	742.9	22.2	5	04	58	14.944	–0.015	19	49	10.52	–0.44	2.49	W
02.07.	SS.MD.	746.3	22.4	5	05	13	31.814	–0.020	20	43	47.17	–0.02	2.50	W
15.07.	SS.MD.	741.6	23.1	6	06	48	49.586	–0.008	23	21	12.98	0.06	2.54	W
16.07.	SS.MD.	743.5	24.3	5	06	57	43.738	–0.057	23	20	31.93	0.20	2.54	W
17.07.	MD.	745.8	25.0	4	07	06	45.228	0.038	23	17	13.72	0.52	2.54	W
18.07.	MD.	744.5	25.2	5	07	15	52.306	0.045	23	11	13.92	–0.01	2.55	W
19.07.	MD.	745.9	26.0	6	07	25	03.105	–0.068	23	02	30.04	–0.24	2.55	W
20.07.	SS.MD.	747.6	26.5	5	07	34	15.799	0.035	22	51	01.61	–0.51	2.55	W
21.07.	SS.MD.	746.1	26.8	6	07	43	28.592	0.052	22	36	50.13	0.19	2.55	W
22.07.	SS.MD.	742.0	25.3	8	07	52	39.780	–0.049	22	19	58.96	0.26	2.56	W
19.10.	SS.MD.	745.3	17.9	12	12	31	26.654	–0.056	–01	17	40.13	0.50	2.80	W
21.10.	SS.MD.	746.0	17.0	14	12	40	51.773	0.044	–02	11	16.44	–0.02	2.81	W
22.10.	SS.MD.	743.8	16.8	12	12	45	56.362	–0.029	–02	42	00.28	0.16	2.81	W
25.10.	SS.MD.	745.3	16.0	10	13	02	14.166	0.072	–04	25	39.28	0.67	2.82	W
1983													1980+	
27.06.	SS.MD.	742.3	25.0	4	05	21	35.107	0.063	22	36	06.47	–0.65	3.43	E
05.07.	MD.	745.6	26.0	5	06	33	48.956	0.073	24	06	02.17	–0.30	3.51	E
27.07.	SS.MD.	744.4	26.5	4	09	38	52.618	0.032	15	29	30.54	0.51	3.57	E
05.10.	SS.MD.	748.1	20.1	7	11	42	56.300	,0.060	03	44	00.62	0.77	3.76	E
06.10.	SS.MD.	745.9	19.2	8	11	48	18.193	0.030	03	14	26.03	–0.14	3.76	E
11.10.	SS.MD.	744.8	18.4	10	12	17	34.389	0.010	00	13	18.79	–0.40	3.78	W

Table V. Data on the Venus Observations

Data of observ.	ob-serv.	Ba	t°C	n	α			(0–C)$_\alpha$	δ			(0–C)$_\delta$	Ep	clamp posit.
1981.													1980+	
09.09.	SS.MD.	744.3	21.8	9	13^h	35^m	50^{s}806	–0^{s}015	–10°	25′	34″01	–0″86	1.69	E
10.09.	SS.MD.	741.2	22.8	10	13	40	12.382	–0.045	–10	54	31.71	–0.54	1.69	E
21.09.	SS.MD.	745.4	23.8	10	14	28	50.362	0.032	–15	55	57.21	0.49	1.72	E
22.09.	SS.MD.	746.7	26.2	10	14	33	19.981	–0.017	–16	21	30.35	0.48	1.73	E
08.10.	SS.MD.	750.0	21.5	12	15	47	04.479	–0.039	–22	14	11.63	–0.04	1.78	E
04.11.	SS.MD.	750.1	12.5	5	17	55	32.249	0.026	–26	50	11.34	0.30	1.84	W
05.11.	SS.MD.	745.4	15.0	8	18	00	11.528	0.071	–26	51	33.48	0.52	1.85	W
24.11.	SS.MD.	745.2	13.5	12	19	22	18.879	–0.031	–25	23	50.58	–0.07	1.90	W
1982													1980+	
14.01.	SS.MD.	758.8	–0.2	10	20	24	57.032	0.009	–14	14	02.03	–0.64	2.04	W
27.01.	SS.MD.	736.0	0.5	12	19	52	31.137	–0.050	–13	34	28.50	–0.49	2.07	W
17.02.	MD.	748.4	0.5	10	19	39	29.046	–0.015	–14	40	44.22	–0.07	2.13	W
08.03.	SS.MD.	749.2	3.0	10	20	20	41.141	–0.007	–15	03	56.06	–0.39	2.18	W
09.03.	SS.MD.	747.1	2.3	12	20	23	44.353	0.074	–15	01	30.13	0.36	2.19	W
10.03.	SS.MD.	745.0	6.2	12	20	26	51.417	0.008	–14	58	37.62	–0.34	2.19	W
11.03.	SS.MD.	739.4	7.1	12	20	30	02.158	0.010	–14	55	18.09	0.40	2.20	W
17.03.	SS.MD.	742.9	5.5	10	20	50	14.518	0.044	–14	25	35.67	0.58	2.21	W
18.03.	SS.MD.	739.8	7.8	10	20	53	46.431	0.026	–14	18	59.05	–0.01	2.21	W
24.03.	SS.MD.	753.9	4.0	10	21	15	44.238	0.035	–13	29	15.34	0.58	2.23	W
05.04.	SS.MD.	747.1	9.8	8	22	02	23.859	0.026	–10	59	32.13	–0.48	2.26	E
06.04.	SS.MD.	750.2	11.9	7	22	06	23.667	–0.032	–10	44	12.34	0.39	2.26	E
06.05.	SS.MD.	743.0	18.2	7	00	09	39.700	–0.055	–00	29	52.62	0.55	2.38	E
17.05.	SS.MD.	744.5	18.5	10	00	56	01.759	–0.057	03	59	33.18	0.57	2.38	E
19.05.	SS.MD.	744.0	20.3	8	01	04	35.556	–0.081	04	49	08.92	–0.46	2.39	E
24.05.	SS.MD.	737.8	21.0	5	01	26	03.102	0.036	06	52	46.71	–0.09	2.39	E
01.06.	SS.MD.	750.0	19.2	6	02	01	01.615	0.012	10	06	31.73	–0.23	2.42	E
03.06.	SS.MD.	747.2	22.0	8	02	09	54.219	–0.012	40	53	37.15	0.64	2.42	E
07.06.	SS.MD.	738.5	21.5	7	02	27	50.430	0.077	12	25	33.50	0.67	2.43	E
09.06.	SS.MD.	743.6	22.0	9	02	36	54.392	0.044	13	10	13.54	–0.16	2.44	E
21.06.	SS.MD.	743.4	23.0	7	02	32	48.394	0.035	17	14	08.08	0.01	2.47	W
22.06.	SS.MD.	741.4	20.8	7	03	37	35.187	0.005	17	32	12.91	0.37	2.48	W
23.06.	SS.MD.	740.4	26.0	8	03	42	23.110	0.037	17	49	53.75	–0.06	2.48	W
24.06.	SS.MD.	742.5	22.9	9	03	47	12.158	0.040	18	07	09.90	–0.26	2.48	W
29.06.	SS.MD.	742.9	21.0	5	04	11	34.125	0.026	19	26	57.13	0.45	2.49	W
02.07.	SS.MD.	743.3	23.0	5	04	26	24.467	–0.032	20	09	11.90	0.39	2.50	W
06.07.	SS.MD.	744.3	23.4	7	04	46	26.249	0.016	20	58	24.47	–0.42	2.51	W
15.07.	SS.MD.	741.6	22.0	6	05	32	24.024	–0.026	22	16	36.23	–0.47	2.54	W
16.07.	SS.MD.	743.5	22.5	5	05	37	34.282	–0.060	22	22	19.78	0.46	2.54	W
18.07.	MD.	744.5	23.9	5	05	47	56.613	0.011	22	31	55.56	0.69	2.55	W
19.07.	SS.MD.	745.9	24.0	6	05	53	08.587	0.038	22	35	47.17	–0.21	2.55	W
20.07.	SS.MD.	747.6	24.0	5	05	58	21.030	0.028	22	39	00.88	–0.53	2.55	W
21.07.	SS.MD.	746.1	25.7	6	06	03	33.888	0.069	22	41	36.45	–0.54	2.55	W
22.07.	SS.MD.	742.0	25.3	8	06	08	47.108	–0.022	22	43	33.64	–0.19	2.56	W
23.07.	SS.MD.	740.7	25.3	7	06	14	00.637	0.002	22	44	52.23	–0.07	2.56	E
02.08.	SS.MD.	741.7	20.3	7	07	06	21.963	–0.063	22	22	12.65	–0.01	2.59	E
11.08.	SS.MD.	743.4	22.8	6	07	53	11.188	–0.021	21	06	38.41	–0.09	2.61	E
12.08.	SS.MD.	746.8	23.2	6	07	58	20.817	0.015	20	55	06.91	–0.35	2.61	E
06.09.	SS.MD.	742.8	23.7	7	10	02	53.283	–0.030	13	11	03.61	–0.48	2.68	E
07.09.	SS.MD.	741.8	26.0	8	10	07	40.477	–0.007	12	46	34.96	–0.42	2.68	E
14.09.	SS.MD.	742.4	23.5	9	10	40	48.697	–0.006	09	45	49.86	–0.31	2.70	E
19.10.	SS.MD.	745.3	18.0	12	13	22	04.554	0.008	–07	18	09.75	–0.79	2.80	W
21.10.	SS.MD.	746.0	17.0	14	13	31	24.675	0.061	–08	16	05.15	0.16	2.81	W
22.10.	SS.MD.	743.8	17.3	12	13	36	05.769	0.087	–02	42	00.28	–0.47	2.81	W
12.11.	SS.MD.	751.0	10.2	12	15	18	07.478	0.113	–17	42	11.80	0.66	2.87	W
19.11.	SS.MD.	746.3	6.7	14	15	54	01.671	–0.070	–20	01	06.39	–0.66	2.88	W
23.11.	SS.MD.	754.0	11.2	13	16	14	59.109	–0.071	–21	08	23.78	–0.13	2.89	E
24.11.	SS.MD.	749.0	12.2	12	16	20	16.305	–0.067	–21	23	43.49	–0.55	2.90	E

Table V. continued

1983													1980+	
13.01.	SS.MD.	750.6	8.2	12	20	50	18.164	–0.036	–19	15	33.22	–0.31	3.04	E
14.03.	SS.MD.	752.1	8.3	10	01	29	29.310	0.014	09	06	43.59	0.03	3.20	E
18.03.	SS.MD.	746.6	14.6	10	01	47	37.299	–0.001	11	03	27.09	0.52	3.21	E
21.03.	SS.MD.	742.4	15.1	12	02	01	19.622	–0.014	12	28	22.53	–0.58	3.22	E
28.03.	SS.MD.	736.0	9.5	10	02	33	43.402	–0.046	15	35	46.49	0.26	3.24	E
25.04.	SS.MD.	741.2	21.0	8	04	50	05.599	–0.049	24	23	48.87	–0.43	3.32	E
26.04.	SS.MD.	742.2	21.2	8	04	55	07.317	0.035	24	34	21.68	–0.18	3.32	E
28.04.	SS.MD.	743.9	23.4	7	05	05	11.499	0.006	24	53	29.86	–0.33	3.32	E
14.05.	MD.	743.5	24.7	6	06	25	24.217	–0.045	25	50	17.42	–0.21	3.37	W
16.05.	SS.MD.	741.4	26.7	6	06	35	14.903	0.012	25	45	21.00	–0.25	3.37	W
17.05.	SS.MD.	742.0	26.8	7	06	40	08.615	–0.061	25	41	54.16	–0.36	3.38	W
18.05.	SS.MD.	740.7	25.1	7	06	45	01.135	0.007	25	37	48.64	–0.06	3.38	W
19.05.	SS.MD.	739.7	24.7	6	06	49	52.383	–0.006	25	33	04.80	0.77	3.38	W
01.06.	SS.MD.	746.0	23.5	5	07	50	31.857	–0.002	23	36	58.77	0.69	3.41	W
02.06.	SS.MD.	746.0	25.4	6	07	54	58.405	–0.016	23	24	10.61	0.33	3.42	W
09.06.	SS.MD.	748.9	24.3	7	08	25	00.346	–0.055	21	41	13.36	0.01	3.44	E
27.06.	SS.MD.	742.3	26.4	4	09	32	03.040	0.037	15	55	11.15	0.18	3.49	E
05.07.	MD.	745.6	26.1	5	09	56	05.113	–0.020	13	00	42.51	0.63	3.51	E
19.07.	SS.	745.3	28.0	6	10	26	52.456	0.044	07	59	24.36	0.04	3.55	E
20.07.	SS.	742.6	25.1	7	10	28	23.858	0.040	07	39	17.64	0.18	3.55	E
27.07.	SS.MD.	744.4	26.5	4	10	35	57.153	0.036	05	29	11.95	–0.22	3.57	E
28.07.	SS.MD.	742.4	28.4	6	10	36	33.073	–0.020	05	12	30.76	–0.65	3.57	E
03.08.	SS.	738.8	28.5	6	10	37	20.898	–0.016	03	45	40.74	–0.28	3.59	E
18.08.	SS.	744.5	25.6	6	10	37	44.947	–0.018	02	27	58.86	0.43	3.63	E
14.09.	SS.MD.	748.6	18.4	9	09	33	04.587	0.030	07	10	40.94	0.10	3.70	E
15.09.	SS.MD.	744.7	19.8	8	09	33	09.340	0.002	07	20	27.46	0.34	3.71	W
03.10.	MD.	750.1	19.7	7	09	57	34.921	0.011	08	30	38.53	–0.72	3.76	E
05.10	SS.MD.	748.1	18.4	6	10	02	26.769	–0.018	08	25	17.46	0.72	3.76	E
06.10.	SS.MD.	748.4	19.2	8	10	04	59.879	0.019	08	21	39.01	0.49	3.76	E
13.10.	SS.MD.	749.7	10.6	10	10	24	47.460	0.005	07	38	48.53	0.82	3.78	W
24.10.	MD.	751.1	8.0	12	11	01	05.997	–0.030	05	35	11.08	–0.03	3.81	W
28.10.	MD.	745.0	12.3	12	11	15	26.863	0.037	04	35	10.14	–0.26	3.82	W

Table VI. Data on the Mars observations

Date of observ.	ob-serv.	Ba	t°C	n	α			(O–C)α	δ			(O–C)δ	Ep	clamp posit.
1981													1980+	
23.07.	SS.	750.2	26.0	5	06h	14m	44s.195	–0s.056	23°	55'	52".20	0".35	1.56	W
04.08.	SS.	749.4	25.4	6	06	49	39.820	0.032	23	36	44.84	0.77	1.59	W
07.08.	SS.MD.	742.4	24.0	7	06	58	16.334	0.037	23	27	36.22	–0.77	1.60	W
17.08.	MD.	740.6	23.3	7	07	26	32.861	0.071	22	45	18.60	–0.25	1.63	E
19.08.	MD.	744.5	18.5	7	07	32	07.209	–0.012	22	34	46.13	0.39	1.63	E
26.08.	MD.	747.4	16.0	7	07	51	23.650	–0.033	21	52	45.27	0.04	1.65	E
09.09.	SS.MD.	747.4	19.0	9	08	28	46.023	–0.049	20	07	04.42	0.32	1.69	E
10.09.	SS.MD.	744.3	19.4	10	08	31	22.415	0.103	19	58	31.94	0.51	1.69	E
18.09.	SS.MD.	744.6	13.4	12	08	51	55.265	–0.030	18	46	00.25	0.65	1.72	E
21.09.	SS.MD.	745.4	19.8	10	08	59	29.291	–0.063	18	17	00.86	–0.53	1.72	E
22.09.	SS.MD.	746.7	21.7	10	09	01	59.621	–0.056	18	07	09.09	–0.11	1.73	E
23.09.	SS.MD.	743.2	23.4	12	09	04	29.440	–0.056	17	57	11.56	–0.23	1.73	E
08.10.	SS.MD.	750.0	17.0	12	09	40	54.529	0.006	15	17	46.64	–0.73	1.77	E
09.10.	SS.MD.	746.4	15.5	13	09	43	16.073	–0.015	15	06	34.77	–0.48	1.77	E
24.11.	SS.MD.	745.8	18.0	12	11	22	48.330	0.044	06	00	48.26	–0.56	1.90	E
1982													1980+	
09.03.	SS.MD.	747.1	0.2	8	13	09	30.144	–0.025	–03	52	40.29	–0.37	2.19	W
10.03.	SS.MD.	745.0	4.0	10	13	08	43.146	–0.027	–03	47	44.96	0.74	2.19	W
11.03.	SS.MD.	745.0	7.2	12	13	07	53.380	0.025	–03	42	35.96	0.56	2.19	W
18.03.	SS.MD.	739.8	7.6	10	12	59	41.750	–0.009	–02	53	58.63	0.80	2.21	W
25.03.	SS.MD.	753.0	1.0	10	12	50	38.582	–0.032	–02	03	16.49	–0.46	2.23	W
05.04.	SS.MD.	747.1	9.2	8	12	34	45.909	–0.010	–00	40	15.27	0.49	2.26	E
06.04.	SS.MD.	750.2	11.0	5	12	33	19.389	–0.015	–00	33	07.24	–0.55	2.26	E
20.04.	SS.MD.	748.6	18.0	6	12	15	25.413	0.010	00	46	50.19	0.64	2.30	E
04.05.	SS.MD.	745.9	17.0	5	12	05	08.133	0.018	01	13	27.56	0.22	2.34	E
17.05.	SS.MD.	744.5	20.0	4	12	03	57.592	0.030	00	45	54.35	0.55	2.38	E
01.06.	SS.MD.	750.0	22.0	6	12	11	40.459	0.016	–00	39	07.84	–0.15	2.42	E
03.06.	SS.MD.	747.2	22.9	8	12	13	20.132	0.052	–00	54	05.01	0.36	2.42	E
07.06.	SS.MD.	738.5	20.1	7	12	17	02.805	0.040	–01	26	09.88	–0.06	2.43	E
21.06.	SS.MD.	743.4	23.0	7	12	33	39.421	0.030	–03	38	04.98	0.57	2.48	W
22.06.	SS.MD.	741.4	22.8	7	12	35	14.960	–0.048	–03	48	31.29	0.43	2.48	W
28.06.	SS.MD.	742.9	21.4	6	12	43	48.603	0.064	–04	53	31.98	–0.16	2.49	W
05.07.	SS.MD.	744.3	22.4	5	12	55	00.756	–0.026	–06	13	49.22	–0.31	2.51	W
15.07.	SS.MD.	741.6	24.0	5	13	12	37.982	–0.042	–08	14	45.53	–0.46	2.54	W
17.07.	MD.	745.8	25.7	5	13	16	22.291	–0.025	–08	39	37.19	–0.34	2.55	W
19.07.	SS.	745.3	25.6	5	13	20	10.766	–0.033	–09	04	39.65	–0.02	2.55	E
20.07.	SS.	742.6	27.2	6	13	22	06.545	–0.041	–09	17	14.53	–0.18	2.55	E
21.07.	SS.MD.	746.1	27.0	5	13	24	03.339	–0.002	–09	29	51.62	–0.16	2.55	E
1983													1980+	
15.09.	SS.MD.	744.7	20.0	8	09	34	30.192	–0.026	15	41	13.66	–0.81	3.71	E
05.10.	SS.MD.	748.1	18.9	7	10	22	52.249	–0.032	11	30	36.91	0.13	3.76	E
06.10.	SS.MD.	745.9	18.7	8	10	25	13.629	–0.042	11	17	24.88	–0.42	3.76	E
13.10.	SS.MD.	749.7	11.0	10	10	41	34.042	–0.015	09	13	42.40	–0.01	3.78	W
24.10.	MD.	751.1	9.7	12	11	06	44.419	–0.025	07	12	56.05	0.68	3.81	W

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COMET ASTROGRAPHIC POSITIONS OBTAINED AT BELGRADE ASTRONOMICAL OBSERVATORY DURING 1977–1982

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SUMMARY. During the period 1977–1982 the photographic observations of the four bright comets: 1977 m Kohler, 1979 I Bradfield, 1980 u Panther and 1982 f Chyrymov–Gerasimenko were carried out with the Askania astrograph of the Belgrade Astronomical Observatory. 43 astrographic positions for the equinox 1950.0 were obtained.

1. INTRODUCTION

This paper presents 43 astrographic positions of four bright comets observed with 125/1000 mm Askania astrograph of the Belgrade Astronomical Observatory during 1977–1982.

Because of its very favourable position in the sky, the comet Kohler (1977 m) was observed before and after its perihelion passage. As its discovery came to our knowledge with almost a month delay, our observations were begun not earlier than October 3 and the last observation was on 24th November 1977, a 52 day period being thus covered.

Based on these observations and with the aim to check the precision of our observations, a parabolic orbit of the comet Kohler was derived. A good accordance of our orbital elements with those of B.G. Marsden, derived on the basis of 120 observations, covering a considerable longer time interval than ours, was stated (Protitch–Benishek, 1981).

For the comet Bradfield (1970 l) we obtained 7 position only, although it was observed during a longer time interval.

The observations of the comet Panther (1980 u) were carried out over an interval of 11 days, and those of the comet P/Chyrymov–Gerasimenko (1982 f) in the interval from 7 to 26 November 1982.

During this five years period we observed many other periodic and new–discovered comets, but unsuccessfully, as they were much fainter than predicted.

2. OBSERVATIONS, MEASUREMENTS AND DATA REDUCTION

Kodak 103a–0 and OR–WO Zu 2 Spezial plates and Metcalff method of photographical observation were used.

From 3 to 6 reference stars of AGK 3 Catalogue were selected per plate and measured with the two coordinates Zeiss measuring machine (type Pulfrich).

For reduction two methods were used: the dependences method and the least square method with standard coordinates. The accuracy of the positions (including the accuracy of our work: identification, measures, computation) and the precision of the catalogue was, on the whole, within the limits of the precision considered as acceptable with the comets.

All the observations, plate measurements and reductions were performed by the author of this paper.

3. RESULTS

The results of observations are given in Table I where in successive columns are: the ordinal number of each position, the object designation, date in UTC and the topocentric right ascension and declination for the equinox 1950.0.

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Table I: Comet astrographic position

No	Object	Date UTC	h	m	s	o	′	″
1.	1977m Kohler	1977. Oct. 3.80556	16	32	39.10	+18	08	32.2
2.	1977m Kohler	1977 Oct. 4.77469	16	35	39.36	+17	38	44.2
3.	1977m Kohler	1977 Oct. 4.84343	16	35	52.68	+17	36	39.6
4.	1977m Kohler	1977 Oct. 5.75350	16	38	45.49	+17	08	10.7
5.	1977m Kohler	1977 Oct. 6.77921	16	42	03.00	+16	35	23.7
6.	1977m Kohler	1977 Oct. 7.76392	16	45	16.53	+16	03	11.4
7.	1977m Kohler	1977 Oct. 8.77642	16	48	38.61	+15	29	31.1
8.	1977m Kohler	1977 Oct. 17.74864	17	21	08.78	+ 9	56	35.8
9.	1977m Kohler	1977 Oct. 18.74447	17	25	03.19	+ 9	15	41.7
10.	1977m Kohler	1977 Oct. 18.78129	17	25	11.66	+ 9	14	12.5
11.	1977m Kohler	1977 Oct. 19.73337	17	28	59.91	+ 8	34	18.4
12.	1977m Kohler	1977 Oct. 21.72991	17	37	07.95	+ 7	08	08.2
13.	1977m Kohler	1977 Oct. 23.72711	17	45	30.81	+ 5	38	48.6
14.	1977m Kohler	1977 Oct. 27.71600	18	03	00.84	+ 2	30	35.8
15.	1977m Kohler	1977 Oct. 28.72433	18	07	35.45	+ 1	41	09.4
16.	1977m Kohler	1977 Nov. 11.72501	19	17	19.29	–10	35	57.3
17.	1977m Kohler	1977 Nov. 12.70005	19	22	33.88	–11	28	23.6
18.	1977m Kohler	1977 Nov. 24.70212	20	29	57.40	–21	28	29.5
19.	1979 l Bradfield	1980 Jan. 31.77853	3	11	09.46	–10	47	58.5
20.	1979 l Bradfield	1980 Jan. 31.79519	3	11	13.20	–10	43	08.6
21.	1979 l Bradfield	1980 Feb. 4.76915	3	20	52.42	+ 2	38	06.7
22.	1979 l Bradfield	1980 Feb. 7.81394	3	25	22.33	+ 8	22	50.7
23.	1979 l Bradfield	1980 Feb. 7.83200	3	25	23.37	+ 8	24	31.7
24.	1979 l Bradfield	1980 Feb. 9.76672	3	27	39.40	+11	00	10.9
25.	1979 l Bradfield	1980 Feb. 10.84415	3	28	45.57	+12	12	58.0
26.	1980 u Panther	1981 Feb. 25.95005	19	34	08.20	+74	49	49.5
27.	1980 u Panther	1981 Feb. 28.93338	19	38	31.67	+77	55	18.0
28.	1980 u Panther	1981. Feb. 28.96463	19	38	37.20	+77	57	32.9
29.	1980 u Panther	1981 Mar. 5.92088	19	50	32.52	+83	19	17.4
30.	1980 u Panther	1981 Mar. 5.95283	19	50	40.40	+83	21	21.4
31.	1980 u Panther	1981 Mar. 7.94866	20	01	09.93	+83	34	36.1
32.	1980 u Panther	1981 Mar. 8.90769	20	10	23.62	+86	38	51.4
33.	1982 f Chyrymov– Gerasimenko	1982 Nov. 7.94450	6	08	24.38	+26	29	41.1
34.	1982 f Chyrymov– Gerasimenko	1982 Nov. 8.91672	6	10	54.05	+26	49	13.0
35.	1982 f Chyrymov–	1982 Nov. 9.94311 Gerasimenko	6	13	29.93	+27	09	43.7
36.	1982 f Chyrymov– Gerasimenko	1982 Nov. 11.92436	6	18	23.73	+27	49	34.4
37.	1982 f Chyrymov– Gerasimenko	1982 Nov. 13.91499	5	23	09.35	+28	29	22.5
38.	1982 f Chyrymov– Gerasimenko	1982 Nov. 15.94659	6	27	49.07	+29	09	40.9
39.	1982 f Chyrymov– Gerasimenko	1982 Nov. 20.91325	6	38	20.44	+30	47	11.8
40.	1982 f Chyrymov– Gerasimenko	1982 Nov. 21.93756	6	40	20.69	+31	06	58.4
41.	1982 f Chyrymov– Gerasimenko	1982 Nov. 22.92020	6	42	12.92	+31	25	46.4
42.	1982 f Chyrymov– Gerasimenko	1982 Nov. 23.94867	6	44	06.32	+31	45	18.4
43.	1982 f Chyrymov– Gerasimenko	1982 Nov. 25.95839	6	47	37.82	+32	22	57.0

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135 PRECISE ASTROMETRIC POSITIONS OF MINOR PLANETS OBTAINED AT THE GPO TELESCOPE OF ESO, LA SILLA

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SUMMARY. 135 precise astrometric positions of minor planets observed at the GPO (F = 4 m, D = 40 cm) of the European Southern Observatory (ESO), La Silla, Chile, during February–March 1984 are presented. The observations have been made by H. Debehogne and G.G. Vieira. ***Two new asteroids were discovered*** **during this mission. The plates were measured on the Ascorecord Zeiss measuring machine of the Observatoire Royal de Belgique. The reductions were performed with the UNIVAC 9200, computer of the Observatioire Royal de Belgique, Institute Royal metéorologique and Institute d' Aeronomie Spatiale, using the Dependence method by means of five reference stars. Data on reference stars, including dependences, are also given.**

1. INTRODUCTION

Here we present the results of photographic observations of minor planets which were carried out in February and March 1984 with the Grand Prism Objective (GPO) (40/400 cm) at the European Southern Observatory (ESO), La Silla, Chile, by H. Debehogne (Observatoire Royal de Belgique) and G.G. Vieira (Observatorio do Valongo, Brasil).

135 precise positions are obtained and two new minor plants: 1984 DV and 1984 DU were discovered.

2. OBSERVATIONS, MEASUREMENTS AND REDUCTIONS

Minor plants observations were performed using the Kodak II–0 plates and three exposures on each plate were done.

5 reference stars of SAO catalogue were selected per plate. All the plates were measured on the Ascorecord Zeiss measuring machine of the Observatoire Royal de Belgique by H. Debahogne.

The method of dependences was used to obtain the precise positions and the Least Square Method was taken to derive the residuals of the star positions.

The computations were performed at the Uccle Computing Center using the program defined by H. Debehogne.

3. RESULTS

The results of observations collected during this mission are presented in two Tables.

Table I contains, respectively: the ordinal number of each position, the object designation, ordinal number of the plate, date in UT the topocentric coordinates α and δ for the equinox 1950.0 and the residuals.

For the new asteroids only the calculated positions are presented.

In the Table II we give also the ordinal number of each position, the star identification – SAO number, the last digit of α and δ of the star (proper motions are included), the residuals on the reference stars, computed for each of three exposures and the dependences.

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Table 1. Positions.

No	Object	Plate	Date UT 1984 Mon.	Day	Alpha 1950 H	M	S	Delta 1950 °	'	"	Residuals M	'
1	1228 SCABIOSA	6702	2	25.037191	9	8	40.430	+15	05	15.39	–.2	+1
2	1228 SCABIOSA	6702	2	25.043424	9	8	40.128	+15	05	16.36	–.2	+1
3	1228 SCABIOSA	6702	2	25.049657	9	8	39.875	+15	05	17.20	–.2	+1
4	1228 SCABIOSA	6724	2	27.055971	9	7	7.262	+15	09	59.77	–.2	+1
5	1228 SCABIOSA	6724	2	27.062204	9	7	6.935	+15	10	00.60	–.2	+1
6	1228 SCABIOSA	6724	2	27.068437	9	7	6.623	+15	10	01.68	–.2	+1
7	1228 SCABIOSA	6773	3	2.090749	9	4	14.812	+15	18	35.00	–.1	+1
8	1228 SCABIOSA	6773	3	2.096982	9	4	14.596	+15	18	35.93	–.1	+1
9	1228 SCABIOSA	6773	3	2.103215	9	4	14.360	+15	18	36.41	–.1	+1
10	1228 SCABIOSA	6798	3	4.057587	9	2	58.442	+15	22	16.03	–.3	+1
11	1228 SCABIOSA	6798	3	4.063127	9	2	58.264	+15	22	16.83	–.3	+1
12	1228 SCABIOSA	6798	3	4.069360	9	2	58.023	+15	22	17.67	–.3	+1
13	1228 SCABIOSA	6814	3	5.061095	9	2	21.448	+15	24	02.04	–.3	+1
14	1228 SCABIOSA	6814	3	5.067328	9	2	21.228	+15	24	02.37	–.3	+2
15	1228 SCABIOSA	6814	3	5.073562	9	2	21.017	+15	24	02.88	–.3	+2
16	1228 SCABIOSA	6830	3	6.061823	9	1	46.009	+15	25	41.60	–.3	+2
17	1228 SCABIOSA	6830	3	6.068056	9	1	45.782	+15	25	42.36	–.3	+2
18	1228 SCABIOSA	6830	3	6.074288	9	1	45.547	+15	25	42.89	–.3	+2
19	1228 SCABIOSA	6846	3	7.062550	9	1	12.125	+15	27	16.00	–.3	+2
20	1228 SCABIOSA	6846	3	7.068783	9	1	11.914	+15	27	16.77	–.3	+2
21	1228 SCABIOSA	6846	3	7.075016	9	1	11.693	+15	27	17.31	–.3	+2
22	1228 SCABIOSA	6855	3	8.073677	9	0	39.076	+15	28	45.66	–.2	+1
23	1228 SCABIOSA	6855	3	8.079217	9	0	38.888	+15	28	46.00	–.2	+1
24	1228 SCABIOSA	6855	3	8.084758	9	0	38.709	+15	28	46.47	–.2	+1
25	1228 SCABIOSA	6873	3	9.140543	9	0	6.00	+15	30	13.29	–.2	+1
26	1228 SCABIOSA	6873	3	9.145391	9	0	5.833	+15	30	14.01	–.2	+1
27	1228 SCABIOSA	6873	3	9.150239	9	0	5.667	+15	30	14.06	–.2	+1
28	1645 WATERFIELD	6702	2	25.037191	9	12	29.429	+14	54	49.26	–.1	+1
29	1645 WATERFIELD	6702	2	25.043424	9	12	29.148	+14	54	50.31	–.1	+1
30	1645 WATERFIELD	6702	2	25.049657	9	12	28.884	+14	54	51.00	–.1	+1
31	1645 WATERFIELD	6724	2	27.055971	9	11	4.316	+15	01	12.52	–.1	+1
32	1645 WATERFIELD	6724	2	27.062204	9	11	4.049	+15	01	13.27	–.1	+1
33	1645 WATERFIELD	6724	2	27.068437	9	11	3.781	+15	01	14.42	–.1	+1
34	1645 WATERFIELD	6737	2	28.072973	9	10	22.725	+15	04	19.80	–.1	0
35	1645 WATERFIELD	6737	2	28.079899	9	10	22.432	+15	04	21.42	–.1	+1
36	1645 WATERFIELD	6737	2	28.086824	9	10	22.143	+15	04	22.53	–.1	0
37	1645 WATERFIELD	6749	2	29.075432	9	9	42.554	+15	07	20.89	–.0	0
38	1645 WATERFIELD	6749	2	29.081665	9	9	42.297	+15	07	21.86	–.0	0
39	1645 WATERFIELD	6749	2	29.087898	9	9	42.047	+15	07	22.83	–.0	0
40	1645 WATERFIELD	6761	3	1.083096	9	9	3.068	+15	10	18.76	–.0	0
41	1645 WATERFIELD	6761	3	1.089329	9	9	2.858	+15	10	19.49	–.0	0
42	1645 WATERFIELD	6761	3	1.095562	9	9	2.634	+15	10	20.49	–.0	0
43	1645 WATERFIELD	6773	3	2.090749	9	8	24.590	+15	13	12.82	–.1	0
44	1645 WATERFIELD	6773	3	2.096982	9	8	24.378	+15	13	13.69	–.1	0
45	1645 WATERFIELD	6773	3	2.103215	9	8	24.166	+15	13	14.50	–.1	0
46	1645 WATERFIELD	6798	3	4.057587	9	7	12.402	+15	18	38.08	–.2	+1
47	1645 WATERFIELD	6798	3	4.063127	9	7	12.206	+15	18	39.08	–.2	+1
48	1645 WATERFIELD	6798	3	4.069360	9	7	12.001	+15	18	40.13	–.2	+1
49	1645 WATERFIELD	6814	3	5.061095	9	6	37.088	+15	21	17.87	–.2	+1
50	1645 WATERFIELD	6814	3	5.067328	9	6	36.848	+15	21	18.68	–.2	+1
51	1645 WATERFIELD	6814	3	5.073562	9	6	36.651	+15	21	19.56	–.2	+1
52	1645 WATERFIELD	6830	3	6.061823	9	6	2.884	+15	23	52.64	–.2	+1
53	1645 WATERFIELD	6830	3	6.068056	9	6	2.674	+15	23	53.59	–.2	+1
54	1645 WATERFIELD	6830	3	6.074289	9	6	2.460	+15	23	54.51	–.2	+1
55	1645 WATERFIELD	6855	3	8.073677	9	4	57.545	+15	28	49.56	–.2	+1
56	1645 WATERFIELD	6855	3	8.079217	9	4	57.393	+15	28	50.25	–.2	+1
57	1645 WATERFIELD	6855	3	8.084758	9	4	57.204	+15	28	50.93	–.2	+1
58	1645 WATERFIELD	6873	3	9.140543	9	4	24.699	+15	31	19.11	–.1	+1
59	1645 WATERFIELD	6873	3	9.145391	9	4	24.507	+15	31	19.26	–.1	+1
60	1645 WATERFIELD	6873	3	9.150239	9	4	24.355	+15	31	19.82	–.1	+1

Table I Positions

No	Object	Plate	Mon.	Date UT 1984 Day	H	Alpha 1950 M	S	Delta 1950 o	'	"	Residuals M	"
61	2707 1981 QS3	6711	2	25.380006	11	20	24.511	+08	27	00.79	–.0	+0
62	2707 1981 QS3	6711	2	25.386239	11	20	24.240	+08	27	02.24	–.0	+0
63	2707 1981 QS3	6711	2	25.392472	11	20	23.968	+08	27	04.55	–.0	+0
64	2730 BARKS	6711	2	25.380006	11	22	25.080	+07	40	05.06	+.0	+0
65	2730 BARKS	6711	2	25.386239	11	22	34.760	+07	50	05.69	+.0	+0
66	2730 BARKS	6711	2	25.392472	11	22	34.415	+07	50	07.49	+.0	+0
67	2795 1979 YM	6731	2	27.233957	11	29	35.313	–04	59	31.86	+.0	–0
68	2795 1979 YM	6731	2	27.240191	11	29	34.967	–04	59	28.92	+.0	–0
69	2795 1979 YM	6731	2	27.246423	11	29	34.614	–04	59	26.87	+.0	–0
70	1984DV	6702	2	25.037191	9	13	6.817	+15	42	57.04		
71	1984DV	6702	2	25.043424	9	13	6.531	+15	42	57.59		
72	1984DV	6702	2	25.049657	9	13	6.256	+15	42	58.03		
73	1984DV	6724	2	27.055971	9	11	32.220	+15	44	37.12		
74	1984DV	6724	2	27.062204	9	11	31.945	+15	44	37.21		
75	1984DV	6724	2	27.068437	9	11	31.665	+15	44	37.55		
76	1984DV	6737	2	28.072973	9	10	46.054	+15	45	21.05		
77	1984DV	6737	2	28.079899	9	10	45.709	+15	45	21.23		
78	1984DV	6737	2	28.086824	9	10	45.413	+15	45	21.53		
79	1984DV	6749	2	29.075432	9	10	1.583	+15	46	00.69		
80	,1984DV	6749	2	29.081665	9	10	1.309	+15	46	00.94		
81	1984DV	6749	2	29.087898	9	10	1.032	+15	46	01.18		
82	1984DV	6761	3	1.083096	9	9	17.888	+15	46	37.13		
83	1984DV	6761	3	1.089329	9	9	17.630	+15	46	37.25		
84	1984DV	6761	3	1.095562	9	9	17.383	+15	46	37.43		
85	1984DV	6773	3	2.090749	9	8	35.255	+15	47	09.86		
86	1984DV	6773	3	2.096982	9	8	34.962	+15	47	10.00		
87	1984DV	6773	3	2.103215	9	8	34.722	+15	47	10.29		
88	1984DV	6798	3	4.057587	9	7	15.428	+15	48	00.19		
89	1984DV	6798	3	4.063127	9	7	15.200	+15	48	00.43		
90	1984DV	6798	3	4.069360	9	7	14.942	+15	48	00.66		
91	1984DV	6814	3	5.061095	9	6	36.306	+15	48	19.73		
92	1984DV	6814	3	5.067328	9	6	36.070	+15	48	19.58		
93	1984DV	6814	3	5.073562	9	6	35.834	+15	48	19.64		
94	1984DV	6830	3	6.061823	9	5	58.562	+15	48	35.00		
95	1984DV	6830	3	6.068056	9	5	58.330	+15	48	35.08		
96	1984DV	6830	3	6.074288	9	5	58.100	+15	48	35.18		
97	1984DV	6855	3	8.073677	9	4	46.468	+15	48	52.93		
98	1984DV	6855	3	8.079217	9	4	46.264	+15	48	53.00		
99	1984DV	6855	3	8.084758	9	4	46.063	+15	48	53.35		
100	1984DV	6873	3	9.140543	9	4	10.138	+15	48	55.62		
101	1984DV	6873	3	9.145391	9	4	9.982	+15	48	55.62		
102	1984DV	6873	3	9.150239	9	4	9.819	+15	48	55.64		
103	1984DU	6702	2	25.037191	9	11	19.632	+14	48	29.15		
104	1984DU	6702	2	25.043424	9	11	19.376	+14	48	31.91		
105	1984DU	6702	2	25.049657	9	11	19.112	+14	48	34.05		
106	1984DU	6724	2	27.055971	9	9	55.149	+15	00	38.77		
107	1984DU	6724	2	27.062204	9	9	54.874	+15	00	41.15		
108	1984DU	6724	2	27.068437	9	9	54.608	+15	00	43.10		
109	1984DU	6737	2	28.072973	9	9	14.255	+15	06	37.19		
110	1984DU	6737	2	28.079899	9	9	13.972	+15	06	39.81		
111	1984DU	6737	2	28.086824	9	9	13.718	+15	06	42.27		
112	1984DU	6749	2	29.075432	9	8	35.125	+15	12	24.07		
113	1984DU	6749	2	29.081665	9	8	34.882	+15	12	26.31		
114	1984DU	6749	2	29.087898	9	8	34.639	+15	12	28.30		
115	1984DU	6761	3	1.083096	9	7	56.937	+15	18	06.37		
116	1984DU	6761	3	1.089329	9	7	56.700	+15	19	08.25		
117	1984DU	6761	3	1.095562	9	7	56.470	+15	18	10.45		
118	1984DU	6773	3	2.090749	9	7	20.046	+15	23	41.75		
119	1984DU	6773	3	2.096982	9	7	19.824	+15	23	43.87		
120	1984DU	6773	3	2.103215	9	7	19.608	+15	23	45.57		

Table I Positions

No	Object	Plate	Date UT 1984 Mon.	Day	Alpha 1950 H	M	S	Delta 1950 °	'	"	Residuals M	'
121	1984DU	6798	3	4.057587	9	6	11.848	+15	34	16.02		
122	1984DU	6798	3	4.063127	9	6	11.642	+15	34	17.83		
123	1984DU	6798	3	4.069360	9	6	11.414	+15	34	19.88		
124	1984DU	6814	3	5.061095	9	5	38.969	+15	39	29.33		
125	1984DU	6814	3	5.067328	9	5	38.751	+15	39	31.14		
126	1984DU	6814	3	5.073562	9	5	38.531	+15	39	32.70		
127	1984DU	6830	3	6.061823	9	5	7.570	+15	44	33.64		
128	1984DU	6830	3	6.068056	9	5	7.364	+15	44	35.51		
129	1984DU	6830	3	6.074288	9	5	7.188	+15	44	37.43		
130	1984DU	6855	3	8.073677	9	4	8.670	+15	54	24.17		
131	1984DU	6855	3	8.079217	9	4	8.501	+15	54	25.44		
132	1984DU	6855	3	8.084758	9	4	8.332	+15	54	27.16		
133	1984DU	6873	3	9.140543	9	3	39.699	+15	59	25.00		
134	1984DU	6873	3	9.145391	9	3	39.577	+15	59	25.92		
135	1984DU	6873	3	9.150239	9	3	39.439	+15	59	26.91		

Table 2. Star residuals. Dependences.

Observations			No SAO	Positions used		Star residuals						Dependences		
				S	"	S	"	S	"	S	"			
1	2	3	98420	+39.068	58.91	+0.005	+0.12	+0.006	–0.06	+0.005	–0.07	+0.260233	+0.261047	+0.261740
			98427	+32.276	03.38	–0.014	–0.32	–0.012	+0.11	–0.013	+0.10	+0.178821	+0.178408	+0.178058
			98439	+25.970	13.57	+0.006	+0.10	–0.001	+0.01	+0.005	+0.10	+0.117462	+0.116053	+0.114862
			98424	+00.257	55.69	+0.002	+0.12	+0.013	–0.12	+0.003	–0.25	+0.174351	+0.174011	+0.173740
			98405	+0.8.543	37.51	+0.000	–0.03	–0.005	+0.05	–0.001	+0.12	+0.269133	+0.270480	+0.271601
4	5	6	98396	+48.118	15.55	+0.022	+0.01	+0.018	+0.21	+0.019	+0.15	+0.441484	+0.442529	+0.443541
			98405	+08.543	37.51	–0.012	+0.02	–0.011	–0.16	–0.011	–0.11	+0.419237	+0.419834	+0.420348
			98439	+25.970	13.57	+0.027	+0.17	+0.014	–0.01	+0.017	+0.04	–0.070528	–0.071671	–0.072831
			98427	+32.276	03.39	–0.030	–0.29	–0.010	+0.17	–0.015	+0.05	+0.051034	+0.050400	+0.049858
			98420	+39.068	58.91	–0.007	+0.09	–0.010	–0.21	–0.009	–0.13	+0.158774	+0.158900	+0.159084
7	8	9	98396	+48.118	15.56	+0.040	–0.28	+0.039	–0.23	+0.035	–0.27	–0.018908	–0.019561	–0.020300
			98392	+36.001	52.63	–0.040	+0.28	–0.039	+0.21	–0.036	+0.24	+0.035042	+0.034715	+0.034232
			98367	+04.346	28.93	–0.022	+0.15	–0.032	–0.09	–0.030	–0.17	+0.409539	+0.410275	+0.411025
			98365	+59.339	04.85	+0.027	–0.19	+0.035	+0.04	+0.033	+0.10	+0.440927	+0.441875	+0.442824
			98381	+22.609	49.85	–0.005	+0.04	–0.003	+0.08	–0.003	+0.10	+0.133400	+0.132606	+0.132218
10	11	12	98345	+19.619	07.26	–0.050	+0.11	–0.044	–0.06	–0.051	+0.04	+0.590750	+0.591290	+0.592021
			98365	+59.339	04.85	+0.066	–0.15	+0.060	+0.02	+0.069	–0.12	+0.397354	+0.397354	+0.397474
			98396	+48.118	15.55	+0.001	+0.00	–0.001	+0.12	–0.000	+0.12	+0.082403	+0.081527	+0.080436
			98412	+41.262	28.18	–0.039	+0.08	–0.032	–0.23	–0.038	–0.14	–0.075434	–0.075712	–0.076089
			98393	+41.452	08.05	+0.022	–0.05	+0.018	+0.14	+0.021	+0.10	+0.005013	+0.005542	+0.006156
13	14	15	98339	+00.972	45.52	–0.003	+0.26	+0.001	+0.23	–0.003	+0.23	+0.708277	+0.709008	+0.709751
			98367	+04.346	28.93	+0.002	–0.42	–0.005	–0.37	+0.004	–0.40	+0.381373	+0.381396	+0.381342
			98396	+48.118	15.55	+0.019	+0.08	+0.019	+0.01	+0.010	+0.21	–0.039007	–0.039620	–0.040235
			98398	+01.454	00.93	–0.033	+0.28	–0.026	+0.35	–0.019	+0.07	–0.060284	–0.060643	–0.060995
			98393	+41.452	08.05	+0.014	–0.20	+0.010	–0.22	+0.009	–0.11	+0.009641	+0.009859	+0.010138
16	17	18	98340	+01.905	28.13	–0.035	+0.14	–0.021	+0.11	–0.043	+0.09	+0.757341	+0.757790	+0.758402
			98361	+25.621	47.35	+0.019	+0.00	+0.012	–0.05	+0.017	–0.06	–0.059051	–0.058662	–0.058417
			98365	+59.339	04.85	+0.035	–0.24	+0.020	–0.11	+0.051	–0.08	+0.554023	+0.554102	+0.554124
			98396	+48.118	15.55	+0.008	+0.18	+0.007	–0.02	–0.007	–0.05	+0.041837	+0.041433	+0.041043
			98398	+01.454	00.93	–0.027	–0.07	–0.018	+0.08	–0.018	+0.09	–0.294149	–0.294663	–0.295151
19	20	21	98340	+01.905	28.13	–0.004	–0.24	+0.001	–0.19	–0.007	–0.35	+0.242570	+0.243187	+0.243933
			98339	+00.972	45.52	+0.003	+0.20	+0.007	–0.16	+0.017	–0.01	+0.649801	+0.650876	+0.651507
			98345	+19.619	07.26	–0.000	–0.01	–0.008	+0.32	–0.012	+0.30	+0.718104	+0.718340	+0.719181
			98363	+35.190	32.26	+0.003	+0.20	–0.004	+0.29	+0.001	+0.43	–0.440795	–0.441569	–0.442818
			98367	+04.346	28.93	–0.002	–0.15	+0.004	–0.27	+0.001	–0.37	–0.169680	–0.170834	–0.171803
22	23	24	98361	+25.621	47.35	+0.004	–0.26	+0.003	–0.25	–0.005	–0.17	–0.149015	–0.149000	–0.148880
			98319	+37.982	45.17	+0.005	+0.50	+0.005	+0.45	+0.021	+0.34	+0.553566	+0.553998	+0.554384
			98339	+00.972	45.52	–0.042	–0.26	–0.035	–0.12	–0.042	–0.20	+0.528513	+0.528658	+0.528829
			98365	+59.339	04.85	+0.057	–0.37	+0.045	–0.51	+0.032	–0.22	+0.267204	+0.267147	+0.266959
			98392	+36.001	52.63	–0.024	+0.39	–0.019	+0.44	–0.006	+0.25	–0.200267	–0.200803	–0.201293
25	26	27	98319	+37.982	45.17	+0.017	+0.02	+0.018	–0.07	+0.017	+0.04	+0.966617	+0.967426	+0.968206
			98345	+19.619	07.26	–0.029	–0.13	–0.032	+0.01	–0.032	–0.15	+0.485892	+0.486012	+0.486264
			98367	+04.346	28.93	+0.025	–0.25	+0.025	–0.40	+0.023	–0.15	–0.136479	–0.136987	–0.137412
			98363	+35.190	32.26	–0.009	+0.45	–0.007	+0.54	–0.004	+0.34	–0.037844	–0.038177	–0.038433
			98361	+25.621	47.35	–0.004	–0.10	–0.005	–0.09	–0.005	–0.08	–0.278186	–0.278273	–0.278625
28	29	30	98427	+32.276	03.38	–0.000	–0.24	+0.003	–0.02	–0.002	–0.15	–0.128232	–0.126927	–0.125750
			98456	+28.250	–00.30	+0.020	+0.07	–0.013	+0.14	–0.005	+0.34	+0.322212	+0.321628	+0.321144
			98461	+07.394	03.04	–0.016	–0.10	+0.011	–0.11	+0.003	–0.29	+0.399073	+0.398332	+0.397539
			98443	+04.952	05.10	–0.000	–0.14	+0.002	–0.01	–0.001	–0.09	+0.330136	+0.329621	+0.329253
			98439	+25.970	13.57	–0.005	+0.41	–0.001	+0.01	+0.005	+0.18	+0.076811	+0.077347	+0.077814
31	32	33	98439	+25.970	13.57	–0.001	+0.33	–0.018	–0.15	+0.005	–0.07	+0.401050	+0.401022	+0.400912
			98427	+32.276	03.39	–0.038	–0.17	–0.017	+0.17	–0.018	+0.09	+0.251437	+0.251800	+0.252172
			98420	+39.068	58.91	+0.031	–0.05	+0.024	–0.05	+0.011	–0.03	–0.038057	–0.037123	–0.036153
			98453	+11.267	45.85	–0.017	+0.10	–0.017	–0.01	–0.005	–0.00	–0.037654	–0.038038	–0.038354
			98456	+28.250	–00.30	+0.024	–0.21	+0.027	+0.03	+0.006	+0.02	+0.423224	+0.422338	+0.421422
34	35	36	98424	+00.257	55.69	–0.013	+0.27	–0.019	+0.01	–0.023	+0.13	+0.309196	+0.309092	+0.309045
			98427	+32.276	03.39	+0.001	–0.61	–0.003	+0.03	–0.011	+0.00	+0.193850	+0.194021	+0.194235
			98420	+39.068	58.91	+0.000	+0.21	+0.002	–0.01	+0.005	–0.01	+0.020982	+0.022191	+0.023257
			98467	+32.103	34.88	–0.005	+0.07	–0.008	+0.01	–0.011	+0.06	+0.193654	+0.192771	+0.191865
			98439	+25.970	13.57	+0.017	+0.05	+0.028	–0.03	+0.040	–0.19	+0.282318	+0.281925	+0.281598

Table 2 (Cont)

Observations			No SAO	Positions used		Star residuals						Dependences		
				S	"	S	"	S	"	S	"			
37	38	39	98396	+48.118	15.55	+0.008	+0.02	+0.012	+0.05	+0.016	–0.00	–0.042211	–0.040919	–0.039662
			98424	+00.257	55.69	–0.009	+0.10	–0.010	–0.11	–0.019	+0.02	+0.185926	+0.186119	+0.186292
			98439	+25.970	13.57	+0.015	+0.35	+0.031	–0.05	+0.028	+0.04	+0.374129	+0.373259	+0.372381
			98427	+32.276	03.39	–0.010	–0.70	–0.033	+0.24	–0.015	–0.10	+0.278871	+0.278407	+0.278018
			98420	+39.068	58.91	–0.004	+0.23	+0.000	–0.13	–0.10	+0.04	+0.203285	+0.203134	+0.202971
40	41	42	98420	+39.068	58.91	+0.021	–0.50	+0.022	–0.34	+0.033	–0.31	+0.029417	+0.028849	+0.028339
			98412	+41.262	28.18	–0.013	+0.34	–0.009	+0.26	–0.032	+0.21	+0.012299	+0.012281	+0.012295
			98398	+01.454	00.93	–0.023	+0.47	–0.032	+0.26	–0.013	+0.29	+0.096695	+0.097188	+0.097670
			98396	+48.118	15.55	+0.020	–0.45	+0.026	–0.38	+0.020	–0.28	+0.266580	+0.267375	+0.268192
			98439	+25.970	13.57	–0.006	+0.14	–0.007	+0.09	–0.008	+0.09	+0.0595009	+0.594307	+0.593505
43	44	45	98420	+39.068	58.91	+0.035	–0.23	+0.021	–0.49	+0.023	–0.41	–0.052272	–0.052532	–0.052911
			98412	+41.262	18.18	–0.033	+0.25	–0.017	+0.53	–0.020	+0.45	–0.106785	–0.106650	–0.106445
			98427	+32.275	03.39	–0.015	+0.08	–0.010	+0.16	–0.011	+0.13	+0.669555	+0.668448	+0.667390
			98396	+48.118	15.55	+0.039	–0.14	+0.033	–0.26	+0.031	–0.20	+0.323791	+0.324347	+0.324863
			98392	+36.001	52.63	–0.026	+0.04	–0.026	+0.05	–0.024	+0.03	+0.165711	+0.166396	+0.167103
46	47	48	98345	+19.619	07.26	–0.050	+0.11	–0.044	–0.06	–0.051	+0.04	–0.139811	–0.139088	–0.138545
			98365	+39.339	04.85	+0.066	–0.15	+0.060	+0.02	+0.069	–0.12	+0.201227	+0.201189	+0.201390
			98396	+48.118	15.55	+0.001	+0.00	–0.001	+0.12	–0.000	+0.12	+0.945733	+0.944647	+0.943593
			98412	+41.262	28.18	–0.039	+0.08	–0.032	–0.23	–0.038	–0.14	+0.346174	+0.346066	+0.345677
			98393	+41.452	08.05	+0.022	–0.05	+0.018	+0.14	+0.021	+0.10	–0.353324	–0.352815	–0.352115
49	50	51	98339	+00.972	45.52	–0.003	+0.26	+0.001	+0.23	–0.003	+0.23	–0.129363	–0.128490	–0.127778
			98367	+04.346	28.93	+0.002	–0.42	–0.005	–0.37	+0.004	–0.40	+0.326468	+0.326356	+0.326278
			98396	+48.118	15.55	+0.019	+0.08	+0.019	+0.01	+0.010	+0.21	+0.603660	+0.602890	+0.602090
			98398	+01.454	00.93	–0.033	+0.28	–0.026	+0.35	–0.019	+0.07	+0.332799	+0.332412	+0.332199
			98393	+41.452	08.05	+0.014	–0.20	+0.010	–0.22	+0.009	–0.11	–0.133564	–0.133167	–0.132789
52	53	54	98340	+01.905	28.13	–0.035	+0.14	–0.021	+0.11	–0.043	+0.09	+0.097928	+0.098360	+0.098772
			98361	+25.621	47.35	+0.019	+0.00	+0.012	–0.05	+0.017	–0.06	–0.140982	–0.140555	–0.140146
			98365	+59.339	04.85	+0.035	–0.24	+0.020	–0.11	+0.051	–0.08	+0.294112	+0.294112	+0.294158
			98396	+48.118	15.55	+0.008	+0.18	+0.007	–0.02	–0.007	–0.05	+0.451979	+0.451542	+0.451067
			98398	+01.454	00.93	–0.027	–0.07	–0.018	+0.08	–0.018	+0.09	+0.296938	+0.296542	+0.296150
55	56	57	98361	+25.621	47.35	+0.004	–0.26	+0.003	–0.25	–0.005	–0.17	+0.020618	+0.020827	+0.020985
			98319	+37.982	45.17	+0.005	+0.50	+0.005	+0.45	+0.021	+0.34	–0.021357	–0.021010	–0.020550
			98339	+00.972	45.52	–0.042	–0.26	–0.035	–0.12	–0.042	–0.20	+0.178350	+0.178408	+0.178528
			98365	+59.339	04.85	+0.057	–0.37	+0.045	–0.51	+0.032	–0.22	+0.339013	+0.338832	+0.338590
			98392	+36.001	52.63	–0.024	+0.39	–0.019	+0.44	–0.006	+0.25	+0.483377	+0.482943	+0.482448
58	59	60	98367	+04.346	28.93	–0.008	–0.24	–0.017	–0.37	–0.022	–0.10	+0.221141	+0.221383	+0.221464
			98363	+35.190	32.26	–0.037	+0.52	–0.043	+0.57	–0.044	+0.44	+0.202717	+0.203127	+0.203408
			98361	+25.621	47.35	+0.003	–0.10	+0.002	–0.12	+0.001	–0.07	+0.147832	+0.148071	+0.148430
			98365	+59.339	04.85	+0.047	–0.25	+0.063	–0.15	+0.071	–0.34	+0.210535	+0.210767	+0.210896
			98392	+36.001	52.63	–0.005	+0.07	–0.006	+0.07	–0.006	+0.06	+0.217775	+0.216652	+0.215801
61	62	63	118857	+35.949	44.30	+0.008	+0.05	+0.009	–0.08	+0.013	+0.13	–0.244406	–0.245080	–0.245766
			118869	+57.492	33.08	–0.005	–0.03	–0.005	+0.05	–0.009	–0.08	–0.692111	–0.693458	–0.694908
			118854	+27.282	03.20	–0.001	+0.01	–0.001	+0.01	–0.004	–0.07	+0.802977	+0.803716	+0.804581
			118823	+40.070	37.87	–0.002	–0.01	–0.003	+0.03	–0.005	–0.07	+0.470838	+0.471467	+0.472014
			118837	+28.316	53.60	+0.000	–0.02	+0.001	–0.01	+0.004	+0.10	+0.662702	+0.663354	+0.664079
64	65	66	118857	+35.949	44.30	+0.008	+0.05	+0.009	–0.08	+0.013	+0.13	+0.164326	+0.163640	+0.162835
			118869	+57.492	33.08	–0.005	–0.03	–0.009	+0.05	–0.009	–0.08	+0.101308	+0.099795	+0.098058
			118854	+27.282	03.20	–0.001	+0.01	–0.001	+0.01	–0.004	–0.07	+0.206980	+0.207664	+0.208588
			118823	+40.070	37.87	–0.002	–0.01	–0.003	+0.03	–0.005	–0.07	+0.291534	+0.292344	+0.293134
			118837	+28.316	53.60	+0.000	–0.02	+0.001	–0.01	+0.004	+0.10	+0.235853	+0.236550	+0.237385
67	68	69	138259	+57.821	29.65	–0.001	–0.04	–0.005	–0.07	–0.007	+0.04	+0.324842	+0.323413	+0.322256
			138267	+20.828	23.51	+0.028	+0.06	+0.035	+0.07	+0.042	+0.09	+0.216457	+0.213979	+0.211524
			138258	+55.890	14.06	–0.047	–0.04	–0.052	–0.03	–0.062	–0.21	+0.052507	+0.051807	+0.050777
			138248	+02.946	06.55	+0.040	+0.02	+0.042	–0.00	+0.049	+0.19	+0.078894	+0.081055	+0.082882
			138246	+47.383	59.60	–0.020	+0.01	–0.020	+0.03	–0.023	–0.11	+0.327300	+0.329747	+0.332561
70	71	72	98453	+11.267	45.85	–0.004	–0.02	–0.010	–0.01	–0.003	+0.09	+0.548090	+0.547767	+0.547472
			98420	+39.068	58.91	+0.009	+0.05	+0.016	+0.03	+0.006	–0.12	–0.055429	–0.054638	–0.053932
			98427	+32.276	03.38	–0.015	–0.07	–0.015	–0.05	–0.006	+0.08	–0.117776	–0.117264	–0.116730
			98456	+28.250	–00.30	+0.024	+0.10	–0.009	+0.09	–0.000	+0.27	+0.258554	+0.258092	+0.257761
			98461	+07.394	03.04	–0.014	–0.06	+0.018	–0.06	+0.004	–0.32	+0.366561	+0.366043	+0.365428

Table 2 (Cont)

Observations			No SAO	Positions used		Star residuals						Dependences		
				S	"	S	"	S	"	S	"			
73	74	75	98439	+25.970	13.57	–0.001	+0.33	–0.018	–0.15	+0.005	–0.07	+0.063735	+0.063698	+0.06371
			98427	+32.276	03.39	–0.038	–0.17	–0.017	+0.17	–0.018	+0.09	+0.056833	+0.057314	+0.05773
			98420	+39.068	58.91	+0.031	–0.05	+0.024	–0.05	+0.011	–0.03	+0.130435	+0.131323	+0.13224
			98453	+11.267	45.85	–0.017	+0.10	–0.017	–0.01	–0.005	–0.00	+0.489689	+0.489154	+0.48867
			98456	+28.250	–00.30	+0.024	–0.21	+0.027	+0.03	+0.006	+0.02	+0.259309	+0.258511	+0.25762
76	77	78	98424	+00.257	55.69	–0.013	+0.27	–0.019	+0.01	–0.023	+0.13	–0.126311	–0.126200	–0.12607
			98427	+32.276	03.39	+0.001	–0.61	–0.003	+0.03	–0.011	+0.00	+0.174708	+0.175070	+0.17528
			98420	+39.068	58.91	+0.000	+0.21	+0.002	–0.01	+0.005	–0.01	+0.529203	+0.530165	+0.53105
			98467	+32.103	34.88	–0.005	+0.07	–0.008	+0.01	–0.011	+0.06	+0.403692	+0.402549	+0.40159
			98439	+25.970	13.57	+0.017	+0.05	+0.028	–0.03	+0.040	–0.19	+0.018709	+0.018416	+0.01813
79	80	81	98439	+25.970	13.57	+0.009	+0.27	+0.022	–0.22	+0.010	–0.00	–0.162414	–0.162778	–0.16297
			98427	+32.276	03.39	–0.013	–0.79	–0.038	+0.12	–0.026	–0.14	+0.040055	+0.040252	+0.04018
			98420	+39.068	58.91	+0.005	–0.25	+0.005	–0.29	–0.005	–0.14	+0.515721	+0.516041	+0.51640
			98396	+48.118	15.55	+0.000	+0.53	+0.009	+0.24	+0.014	+0.18	+0.197972	+0.198468	+0.19902
			98467	+32.103	34.88	–0.001	+0.24	+0.002	+0.15	+0.006	+0.10	+0.408666	+0.408017	+0.40736
82	83	84	98420	+39.068	58.91	+0.021	–0.50	+0.022	–0.34	+0.033	–0.31	+0.742063	+0.741234	+0.74046
			98412	+41.262	28.18	–0.013	+0.34	–0.009	+0.26	–0.032	+0.21	+0.43661	+0.436419	+0.43610
			98398	+01.454	00.93	–0.023	+0.47	–0.032	+0.26	–0.013	+0.29	+0.026285	+0.026727	+0.02738
			98396	+48.118	15.55	+0.020	–0.45	+0.026	–0.28	+0.020	–0.28	–0.405608	–0.404288	–0.40316
			98439	+35.970	13.57	–0.006	+0.14	–0.007	+0.09	–0.008	+0.09	+0.200649	+0.199908	+0.19920
85	86	87	98420	+39.068	58.91	+0.035	–0.23	+0.021	–0.49	+0.023	–0.41	+0.598069	+0.597159	+0.59661
			98412	+41.262	28.18	–0.033	+0.25	–0.017	+0.53	–0.020	+0.45	+0.454333	+0.454446	+0.45446
			98427	+32.275	03.39	–0.015	+0.08	–0.010	+0.16	–0.011	+0.13	+0.099427	+0.098300	+0.09726
			98396	+48.118	15.55	+0.039	–0.14	+0.033	–0.26	+0.031	–0.20	–0.129748	–0.128857	–0.12811
			98392	+36.001	52.63	–0.026	+0.04	–0.026	+0.05	–0.024	+0.03	–0.022081	–0.021048	–0.02022
88	89	90	98345	+19.619	07.26	–0.050	+0.11	–0.044	–0.06	–0.051	+0.04	–0.064991	–0.064342	–0.06360
			98365	+59.339	04.85	+0.066	–0.15	+0.060	+0.02	+0.069	–0.12	+0.050471	+0.050652	+0.05084
			98396	+48.118	15.55	+0.001	+0.00	–0.001	+0.12	–0.000	+0.12	+0.221093	+0.220310	+0.21943
			98412	+41.262	28.18	–0.039	+0.08	–0.032	–0.23	–0.038	–0.14	+0.395298	+0.394902	+0.39447
			98393	+41.452	08.05	+0.022	–0.05	+0.018	+0.14	+0.021	+0.10	+0.398130	+0.398479	+0.39884
91	92	93	98339	+00.972	45.52	–0.003	+0.26	+0.001	+0.23	–0.003	+0.23	+0.043488	+0.044223	+0.04498
			98367	+04.346	28.93	+0.002	–0.42	–0.005	–0.37	+0.004	–0.40	–0.001264	–0.001144	–0.00107
			98396	+48.118	15.55	+0.019	+0.08	+0.019	+0.01	+0.010	+0.21	+0.125330	+0.124815	+0.12428
			98398	+01.454	00.93	–0.033	+0.28	–0.026	+0.35	–0.019	+0.07	+0.301523	+0.301182	+0.30077
			98393	+41.452	08.05	+0.014	–0.20	+0.010	–0.22	+0.009	–0.11	+0.530924	+0.530923	+0.53103
94	95	96	98340	+01.905	28.13	–0.035	+0.14	–0.021	+0.11	–0.043	+0.09	–0.109788	–0.109175	–0.10862
			98361	+25.621	47.35	+0.019	+0.00	+0.012	–0.05	+0.017	–0.06	+0.473324	+0.473361	+0.47343
			98365	+59.339	04.85	+0.035	–0.24	+0.020	–0.11	+0.051	–0.08	–0.049711	–0.049463	–0.04916
			98396	+48.118	15.55	+0.008	+0.18	+0.007	–0.02	–0.007	–0.05	+0.213655	+0.213240	+0.21284
			98398	+01.454	00.93	–0.027	–0.07	–0.018	+0.08	–0.018	+0.09	+0.472520	+0.472037	+0.47151
97	98	99	98361	+25.621	47.35	+0.004	–0.26	+0.003	–0.25	–0.005	–0.17	+0.552690	+0.552580	+0.55261
			98319	+37.982	45.17	+0.005	+0.50	+0.005	+0.45	+0.021	+0.34	+0.013374	+0.013817	+0.01426
			98339	+00.972	45.52	–0.042	–0.26	–0.035	–0.12	–0.042	–0.20	–0.051317	–0.051011	–0.05083
			98365	+59.339	04.85	+0.057	–0.37	+0.045	–0.51	+0.032	–0.22	+0.087855	+0.087739	+0.08765
			98392	+36.001	52.63	–0.024	+0.39	–0.019	+0.44	–0.006	+0.25	+0.397397	+0.396875	+0.39630
100	101	102	98367	+04.346	28.93	–0.008	–0.24	–0.017	–0.37	–0.022	–0.10	+0.003978	+0.004171	+0.00445
			98363	+35.190	32.26	–0.037	+0.52	–0.043	+0.57	–0.044	+0.44	+0.124193	+0.124548	+0.12487
			98361	+25.621	47.35	+0.003	–0.10	+0.002	–0.12	+0.001	–0.07	+0.573693	+0.573833	+0.57400
			98365	+59.339	04.85	+0.047	–0.25	+0.063	–0.15	+0.071	–0.34	+0.087152	+0.087385	+0.08755
			98392	+36.001	52.63	–0.005	+0.07	–0.006	+0.07	–0.006	+0.06	+0.210983	+0.210063	+0.20910
103	104	105	98427	+32.276	03.38	–0.000	–0.24	+0.003	–0.02	–0.002	–0.15	+0.078328	+0.079845	+0.08131
			98456	+28.250	–00.30	+0.020	+0.07	–0.013	+0.14	–0.005	+0.34	+0.153849	+0.153507	+0.15310
			98461	+07.394	03.04	–0.016	–0.10	+0.011	–0.11	+0.003	–0.29	+0.137705	+0.137151	+0.13652
			98443	+04.952	05.10	–0.000	–0.14	+0.002	–0.01	–0.001	–0.09	+0.432464	+0.431336	+0.43044
			98439	+25.970	13.57	–0.005	+0.41	–0.001	+0.01	+0.005	+0.18	+0.197653	+0.198161	+0.19861
106	107	108	98439	+25.970	13.57	–0.001	+0.33	–0.018	–0.15	+0.005	–0.07	+0.412253	+0.412042	+0.41178
			98427	+32.276	03.39	–0.038	–0.17	–0.017	+0.17	–0.018	+0.09	+0.364088	+0.364334	+0.36465
			98420	+39.068	58.91	+0.031	–0.05	+0.024	–0.05	+0.011	–0.03	+0.182746	+0.183880	+0.18494
			98453	+11.267	45.85	–0.017	+0.10	–0.017	–0.01	–0.005	–0.00	–0.181270	–0.181372	–0.18155
			98456	+28.250	–00.30	+0.024	–0.21	+0.027	+0.03	+0.006	+0.02	+0.222182	+0.221115	+0.22017

Table 2 (Cont)

Observations			No SAO	Positions used		Star residuals						Dependences		
				S	"	S	"	S	"	S	"			
109	110	111	98424	+00.257	55.69	–0.013	+0.27	–0.019	+0.01	–0.023	+0.13	+0.322262	+0.321976	+0.321690
			98427	+32.276	03.39	+0.001	–0.61	–0.003	+0.03	–0.011	+0.00	+0.244962	+0.245160	+0.245356
			98420	+39.068	58.91	+0.000	+0.21	+0.002	–0.01	+0.005	–0.01	+0.243842	+0.245244	+0.246521
			98467	+32.103	34.88	–0.005	+0.07	–0.008	+0.01	–0.011	+0.06	–0.026421	–0.027215	–0.027924
			98439	+25.970	13.57	+0.017	+0.05	+0.028	–0.03	+0.040	–0.19	+0.215355	+0.214836	+0.214357
112	113	114	98396	+48.118	15.55	+0.008	+0.02	+0.012	+0.05	+0.016	–0.00	+0.292497	+0.293647	+0.294806
			98424	+00.257	55.69	–0.009	+0.10	–0.010	–0.11	–0.019	+0.02	+0.226176	+0.226046	+0.225977
			98439	+25.970	13.57	+0.015	+0.35	+0.031	–0.05	+0.028	+0.04	+0.137940	+0.137070	+0.136204
			98427	+32.276	03.39	–0.010	–0.70	–0.033	+0.24	–0.015	–0.10	+0.167533	+0.167183	+0.166811
			98420	+39.068	58.91	–0.004	+0.23	+0.000	–0.13	–0.010	+0.04	+0.175845	+0.176054	+0.176201
115	116	117	98420	+39.068	58.91	+0.021	–0.50	+0.022	–0.34	+0.033	–0.31	–0.067996	–0.068313	–0.068505
			98412	+41.262	28.18	–0.013	+0.34	–0.009	+0.26	–0.032	+0.21	+0.047414	+0.047588	+0.047878
			98398	+01.454	00.93	–0.023	+0.47	–0.032	+0.26	–0.013	+0.29	+0.236215	+0.236772	+0.237201
			98396	+48.118	15.55	+0.020	–0.45	+0.026	–0.28	+0.020	–0.28	+0.460423	+0.461009	+0.461535
			98439	+25.970	13.57	–0.006	+0.14	–0.007	+0.09	–0.008	+0.09	+0.323944	+0.322944	+0.321890
118	119	120	98420	+39.068	58.91	+0.035	–0.23	+0.021	–0.49	+0.023	–0.41	–0.042442	–0.042348	–0.042456
			98412	+41.262	28.18	–0.033	+0.25	–0.017	+0.53	–0.020	–0.45	+0.056137	+0.056605	+0.057060
			98427	+32.275	03.39	–0.015	+0.08	–0.010	+0.16	–0.011	+0.13	+0.230492	+0.228975	+0.227632
			98396	+48.118	15.55	+0.039	+0.14	+0.033	–0.26	+0.031	–0.20	+0.407288	+0.407614	+0.407969
			98392	+36.001	52.63	–0.026	+0.04	–0.026	+0.05	–0.024	+0.03	+0.348525	+0.349153	+0.349795
121	122	123	98345	+19.619	07.26	–0.050	+0.11	–0.044	–0.06	–0.051	+0.04	+0.076053	+0.076745	+0.077469
			98365	+59.339	04.85	+0.066	–0.15	+0.060	+0.02	+0.069	–0.12	+0.173543	+0.173539	+0.173585
			98396	+48.118	15.55	+0.001	+0.00	–0.001	+0.12	–0.000	+0.012	+0.371809	+0.370421	+0.368874
			98412	+41.262	28.18	–0.039	+0.08	–0.032	–0.23	–0.038	–0.14	+0.267854	+0.267595	+0.267247
			98393	+41.452	08.05	+0.022	–0.05	+0.018	+0.14	+0.021	+0.10	+0.110741	+0.111700	+0.112825
124	125	126	98339	+00.972	45.52	–0.003	+0.26	+0.001	+0.23	–0.003	+0.23	+0.171381	+0.172264	+0.173135
			98367	+04.346	28.93	+0.002	–0.42	–0.005	–0.37	+0.004	–0.40	+0.126061	+0.125774	+0.125533
			98396	+48.118	15.55	+0.019	+0.08	+0.019	+0.01	+0.010	+0.21	+0.148481	+0.147438	+0.146487
			98398	+01.454	00.93	–0.033	+0.28	–0.026	+0.35	–0.019	+0.07	+0.224023	+0.223664	+0.223276
			98393	+41.452	08.05	+0.014	–0.20	+0.010	–0.22	+0.009	–0.11	+0.330055	+0.330859	+0.331570
127	128	129	98340	+01.905	28.13	–0.035	+0.14	–0.021	+0.11	–0.043	+0.09	+0.059974	+0.060243	+0.060402
			98361	+25.621	47.35	+0.019	+0.00	+0.012	–0.05	+0.017	–0.06	+0.380109	+0.380899	+0.381720
			98365	+59.339	04.85	+0.035	–0.24	+0.020	–0.11	+0.051	–0.08	+0.063978	+0.063776	+0.0635448
			98396	+48.118	15.55	+0.008	+0.18	+0.007	–0.02	–0.007	–0.05	+0.173696	+0.173060	+0.172478
			98398	+01.454	00.93	–0.027	–0.07	–0.018	+0.08	–0.018	+0.09	+0.322243	+0.322022	+0.321852
130	131	132	98361	+25.621	47.35	+0.004	–0.26	+0.003	–0.25	–0.005	–0.17	+0.676202	+0.676657	+0.677332
			98319	+37.982	45.17	+0.005	+0.50	+0.005	+0.45	+0.021	+0.34	+0.100042	+0.100414	+0.100787
			98339	+00.972	45.52	–0.042	–0.26	–0.035	–0.12	–0.042	–0.20	–0.067481	–0.067461	–0.067613
			98365	+59.339	04.85	+0.057	–0.37	+0.045	–0.51	+0.032	–0.22	+0.009179	+0.008817	+0.008492
			98392	+36.001	52.63	–0.024	+0.39	–0.019	+0.44	–0.006	+0.25	+0.282058	+0.281572	+0.281002
133	134	135	98367	+04.346	28.93	–0.008	–0.24	–0.017	–0.37	–0.022	–0.10	–0.094669	–0.094753	–0.094686
			98363	+35.190	32.26	–0.037	+0.52	–0.043	+0.57	–0.044	+0.44	+0.125563	+0.125749	+0.125910
			98361	+25.621	47.35	+0.003	–0.10	+0.002	–0.12	+0.001	–0.07	+0.847644	+0.848123	+0.848658
			98365	+59.339	04.85	+0.047	–0.25	+0.063	–0.15	+0.071	–0.34	+0.042206	+0.042264	+0.042243
			98392	+36.001	52.63	–0.005	+0.07	–0.006	+0.07	–0.006	+0.06	+0.079256	+0.078616	+0.077875

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In the four years period 1980–1983 the researching results of the present and retired associates of the Belgrade Astronomical Observatory were published under 205 titles (articles, notes, abstracts, observations data) in a number domestic and foreigh periodicals and editions. The following tabulation gives the relevant information.

Year	Number of titles appearing in the editions of			Total
	Belgrade Astr. Observatory	other establishments in Yugoslavia	Establishments abroad	
1980	1	6	19	26
1981	19	27	33	79
1982	11	14	32	57
1983	7	3	33	43
Total	38	50	117	205

As evident, most of the papers, 57.1%, were published abroad and no more than 18.5% in the Observatory's own editions.

It is contemplated to regularly publish in the future the bibliography of papers of our researchers.

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