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ISOPHOTS OF ZODIACAL LIGHT AND ITS TERRESTRIAL COMPONENT

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SUMMARY

The effect of the Moon on the brightness distribution of zodiacal light cones was revealed on the basis of an analysis of zodiacal light isophots obtained under various latitudes, and it was concluded that the zodiacal light contains a terrestrial component due to dust concentrated either in the form of a ring at a certain distance from the Earth, or in the vicinity of the libration points of the Earth-Moon system, or in the vicinity of the lunar orbit.

* * *

In their observation of zodiacal light, the majority of the authors have been investigating brightnesses and polarization only at points located along the ecliptic. Almost all theories on dust matter distribution in the zodiacal cloud are based on this material. However, it is obvious that such an unwarranted limitation, which ignores the possibility of other observations, cannot reliably answer the main question concerning the location of the matter causing zodiacal light. On the other hand, it is clear that analysis of the integral pattern of zodiacal light isophots could yield a more extensive material for developing the theory on dust matter distribution in the interplanetary space. As was shown by V.G. Fesenkov [1] and then by N.B. Divari [2] the position of the brightness maximum of zodiacal light is directly connected with the role of the near-terrestrial dust matter in the formation of zodiacal light. However, to date, the nature of brightness distribution in zodiacal light cones had not yet been accurately determined. In some works, for instance in [3,4], it is tacitly assumed that the zodiacal light is symmetrical to the ecliptic and isophots are produced, identical for the northern as well as southern ecliptic hemispheres. On the other hand, according to available results of observations, the distribution of brightness of zodiacal light is not identical in the northern and southern hemispheres. A difference in the nature of northern and southern zodiacal light isophots is evident from the observations of V.G. Fesenkov [5] who has detected the effect of isophot expansion at the northern horizon. Asymmetry of zodiacal light isophots was clearly manifest in the observations by Elvey and Roach [6], Huruhata [7], Behr and Siedentopf [8] and others. A recent comparison of zodiacal light brightness and polarization near the ecliptic poles [9,10] shows that the brightness of zodiacal light at the South pole is in excess as compared to that at the North Pole. A correct accounting of the tropospheric effect is of major importance for determing the real extraatmospheric brightness of zodiacal light. For instance, Regener [11] succeeded in selecting artificially the parameters for the atmospheric dust layer so as to eliminate the irregularities in the observed distribution of zodiacal light iosophots. The position of the axis of zodiacal light has a direct bearing on the problem of zodiacal light isophot distribution. This problem was investigated in detail in [12,13].

To analyze the brightness distribution in zodiacal light cones we used the photoelectric observations carried out in 1955-1958 and described in [14-17]. Observations were then studied for each individual night, The extraatmospheric zodiacal light brightnesses $\underline{J}$ were obtained by means of the reduction of observed brightnesses J_{app} at the expense of atmospheric glow $A(z)$, of direct light of all the stars σ, of tropospheric sidereal light diffusion G.R., the tropospheric scattering of zodiacal light B, as well as of twilight-sky glow S, according to formula

$$J = [J_{app} - A(z) - \sigma p^{\sec z} - B - G.R. - S]\, p^{-\sec z}$$

Corrections for tropospheric scattering were calculated by the method described in [18] i.e. by way of integration over the entire visible part of the celestial sphere. The brightness used for the analysis are the extra-atmospheric brightness of zodiacal light cones without continuous night sky background. In other words, these are brightness excesses in zodiacal light cones relative to the continuous background far off the cones. To characterize the asymmetry of zodiacal light isophots, we adopted the ratio $R = R(\beta, \lambda_\theta - \lambda)$ of the zodiacal light brightness at a point to the north of the ecliptic with the coordinates $(\beta;, \lambda_\theta - \lambda)$, to the brightness at the point $(-\beta, \lambda_\theta - \lambda)$, to the south of the ecliptic. The values of this ratio

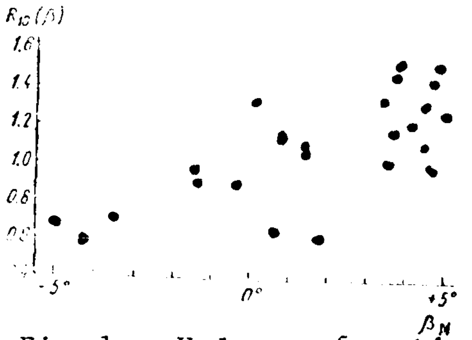

Fig.1. Values of ratio ($R_{10} = I(\beta = 10°)/I(\beta = -10°)$) as a function of Moon's lunar ecliptical latitude β

measured in the $45° \leqslant \lambda_0 - \lambda \leqslant 65°$ range, are compiled in table I for β = 5, 10, 15 and 20°. As may be seen from the Table I these ratios vary considerably from one night to another, i.e. the isophot asymmetry relative to the ecliptic is strongly noticeable. Taking into account the results obtained in [12],

Year	Date	$\beta=5°$	$\beta=10°$	$\beta=15°$	$\beta=20°$	Year	Date	$\beta=5°$	$\beta=10°$	$\beta=15°$	$\beta=20°$
1955	22.9	0.88	0.90	1.09	1.64		31.10	0.77	0.57	0.36	0.26
	23.9	0.90	0.90	0.95	1.11		1.11	0.86	0.70	0.59	0.59
	24.9	0.72	0.65	0.64	0.68	1957	24.10	1.17	1.33	1.12	1.19
	25.9	0.72	0.62	0.58	0.69		25.10	1.08	1.10	1.13	1.19
	27.9	1.06	1.02	1.07	1.33		2.11	1.32	1.44	1.51	1.54
	14.10	0.77	0.68	0.53	0.41		3.11	1.01	1.21	1.37	1.63
1956	8.3	1.21	1.53	2.49	—		4.11	1.19	1.35	1.51	1.48
	9.3	1.08	1.11	1.15	1.17		21.11	1.12	1.15	1.17	1.11
	10.3	1.27	1.53	1.66	2.32		22.11	1.06	1.07	1.12	1.15
	14.3	1.12	1.18	1.03	0.84	1958	12.10	0.93	0.96	0.93	0.98
	13.10	0.92	1.00	1.12	1.14		16.10	1.38	1.47	1.30	1.17
	14.10	1.25	1.27	1.21	1.24		17.10	1.25	1.31	1.24	1.13

<u>TABLE I</u>

Values of R = R(β, $\lambda_\theta - \lambda$) averaged for the 45° $|\lambda_\theta - \lambda|$ < 65° differential longitude range.

we have compared the ratios R with the ecliptical latitude of the Moon. The dependence between R and the Moon's latitude β_M for β = 10° is shown in Fig. I. The correlation factors k_β for various values of β were found to be as follows: $k_5 = 0{,}70$, $k_{10} = 0{,}74$, $k_{15} = 0{,}70$ and $k_{20} = 0{,}64$. No dependence was detected between the ratios $R(\beta, \lambda_0 - \lambda)$ and the inclination of the ecliptic to the horizon, although, according to Weinberg [19] a connection between the zodiacal light brightness and the inclination of the ecliptic does exist.

Besides the ratios $R(\beta, \lambda_\theta - \lambda)$, ratios $R_1 = R_1(\beta - \beta_m, \lambda_\theta - \lambda)$, have also been analyzed. The latter were obtained in the following manner. The latitude β_m of the point of brightness maximum was found on the graph of the dependence of zodiacal light brightness on the ecliptical latitude β for the given cross-section $\lambda_\theta - \lambda = \text{const}$ After that the brightness values for this cross-section were taken down from this graph for the values of $\beta - \beta_m$, equal to ±5, ±10, ±15 and ±20. The quantity $R_1(\beta - \beta_m, \lambda_\theta - \lambda)$, equal to the brightness ratio at two points located at equal distances to the North and to the South of the maximum and characterizes the cross-section symmetry relative to the line of brightness maximum. In this it differs from the quantity $R(\beta, \lambda_\theta - \lambda)$, which characterizes symmetry relative to the ecliptic. Fig.2 shows the values of $R_1(\beta - \beta_m, \lambda_\theta - \lambda)$ for $\beta - \beta_m$ = 10° averaged for the differential longitudes in the $45° \leqslant (\lambda_\odot - \lambda) \leqslant 65°$ interval. As may be seen in the Fig. the quantity $R_1(\beta - \beta_m, \lambda_\odot - \lambda)$ does not depend on the Moon's latitude and is close to the unity. (the correlation factor is 0.48). Hence follows, that the effect of the Moon is manifest in that the zodiacal light cones are so displaced that their symmetry relative to the axis of zodiacal light is not disrupted in the vicinity of the maximum. In other words, a displacement takes place of the brightness line maximum. The connection between the position of the axis of the zodiacal light and the latitude of the Moon was investigated in detail in [12] where it is shown that the basic plane relative to which dust particles of a zodiacal cloud are oriented is the ecliptic plane. The Moon exerts upon its position merely a disturbing effect. Hence it follows, that the lunar component of the zodiacal light cannot be predominant.

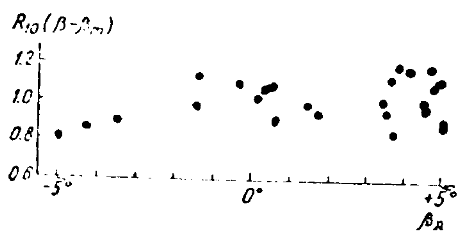

Fig.2. Values of the ratio $R_1(10°) = I(\beta-\beta_m = 10°)/I(\beta-\beta_m = -10°)$ as a function of Moon's latitude β_M.

Inasmuch as the near-terrestrial component can be made apparent owing to the parallactic displacement of the zodiacal light during its observation at different geographical latitudes, we have compared the observations carried out in the region of Alma-Ata (ϕ = 43° N) with those made in Egypt (ϕ = 24° N).

Examination of extraatmospheric brightness of the zodiacal light obtained in 1955-1958 shows that it is not constant but subject to annual variations. Fig.3 shows the course of extraatmospheric brightness variation of the morning zodiacal light averaged with respect to the region of $-20° \leqslant \beta \leqslant +20°$, $40° \leqslant \lambda_\odot - \lambda \leqslant 65°$. As may be seen in the figure, the zodiacal light brightness was apparently minimum in the period of solar activity maximum (1956-1957) and began to increase with the decrease of the latter. This result is in agreement with the data obtained by Well [20] and Asaad [21] on the basis of a more extensive material. In this connection, when comparing the brightnesses of zodiacal light all the brithnesses were reduced to one epoch by means of multiplying them by the respective coefficients determined by way of brightness comparison at different epochs. Thus, with the reduction to a single epoch, the brightnesses of each night varied by an equal number of times, while the relative brightness distribution remained unchanged. The isophots obtained in Egypt on the basis of morning observations on September 24 and November 3, 4 and 22, 1957 for an average inclination of the ecliptic plane to the horizon equal to 88° and mean ecliptical latitude of the Moon β_M = +2°.2 were adopted as standard isophots. After their reduction to the epoch of observations, the brightnesses corresponding to the 1957 standard isophots were subtracted from the brightnesses of each night of observations. The obtained differences Δ were plotted on the graph for each $\lambda_\theta - \lambda$ = const. cross-section. Fig.4 shows three curves $\Delta = \Delta(\beta)$ conveying and idea on the nature of variations in differences Δ as a function of β. The majority of the curves had a clearly expressed maximum whose ecliptical latitudes are shown in Fig.5. Only two curves, for October 16 and 17, 1958 are devoid of a maximum and are characterized by a minimum in the vicinity of the ecliptic (see Fig.4). Taking into account that the mean latitude of the Moon for the epoch of standard isophots is +2°2, the dependence is considered between the position of the curve's maxima and the differences between latitude of the Moon β_M at the time of observation and the mean latitude of the Moon in the epoch corresponding to the standard isophots, namely $\Delta\beta = \beta_M - 2°2$, This dependence is shown in Fig.5 and the correlation coefficient corresponding to it is k = 0.76.

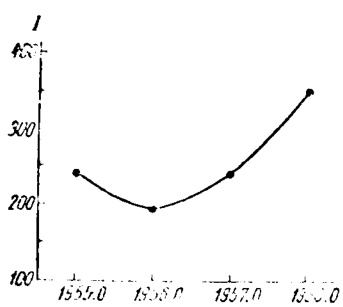

Fig.3

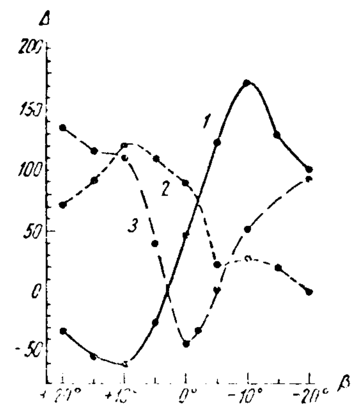

Fig.4

Fig.3. Yearly variations in the morning zodiacal light brightness.

Fig.4. Examples of three curves $\Delta = \Delta(\beta)$ representing the difference Δ between the observed extraatmospheric brightnesses and the brightnesses of standard zodiacal light as a function of the ecliptical latitude β:
1. **November 31**, 1956 $\lambda_\theta - \lambda = 50°$;
2. March 10, 1958 $\lambda_\theta - \lambda = 45°$;
3. October 17, 1958 $\lambda_\theta - \lambda = 50°$.

Therefore comparison of zodiacal light isophots with the standard ones, obtained for an ecliptic plane inclination to the horizon close to 90°, has shown that the distribution of brightness in the zodiacal light cones is highly variable. However, no stable parallax was detected. According to the observations in Alma-Ata and Egypt, the displacement of the maximum of brightness differences is connected with the latitude of the Moon. This may be understood if one considers that a certain part of zodiacal light matter is located in the vicinity of the Earth where the influence of the Moon on the spatial distribution is possible. However, this matter cannot be located in the immediate vicinity of the Earth because no effects of twilight nature were detected in zodiacal light, i.e. there is no dependence of zodiacal light brightness on the azimuth or the solar depression. Analysis of the obtained differences Δ shows that neither their value nor the position of the maximum correlate with the azimuth of solar depression. Moreover, as already mentioned, at solar depressions of at least less than 20°, was not detected in the observed brightnesses [22]. If the zodiacal light were entirely due to a geocentric cloud immediately adjacent to the upper layers of the Earth's atmosphere, the twilight effect would have been detected in the zodiacal light phenomenon, i.e. the brightness of the zodiacal light would have depended on Sun's immersion and azimuth. Since such is not the case, it follows that the dust matter, located in the vicinity of the Earth and contributing to the zodiacal light, cannot be an extension of the dust layer responsible for twilight phenomena and located at altitudes of the order of hundreds of km above the Earth's surface. On the basis of the foregoing, it can be concluded that the matter responsible for the lunar variations of zodiacal light is either located in the form of a ring at a certain distance from the Earth, or constitutes a cluster at the libration points of the Earth-Moon system, or is located on the lunar orbit.

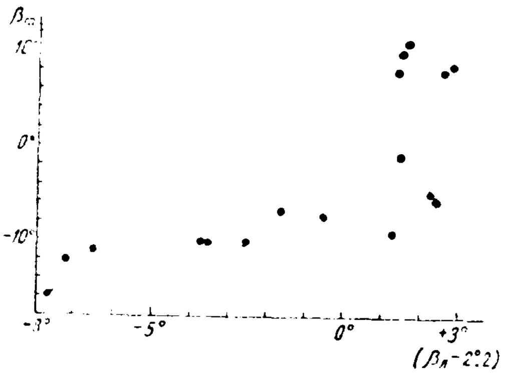

Fig.5. Dependence between the ecliptical latitude β_m of the brightnesses difference Δ maximum and the difference $\Delta\beta_1 = \beta_1 - 2°2$.

The results presented in this work require confirmation before they can be considered absolutely reliable. However, in our opinion, reliable data on isophots of the zodiacal light cones and their variations should be obtained for the development of any theory on the zodiacal light. At the same time one should also take into account the very important and interesting phen - menon of the false zodiacal light sometimes observable simultaneously with the basic zodiacal light cone on the opposite side of the sky. The fact that the false zodiacal light is not always visible and that it can be quite bright as it happened on October 25, 1946 [23] may play a major role in the selection of a model for the distribution of the dust concentration responsible for the phenomenon of zodiacal light.

* * * THE END * * *

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