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Photoelectric Photometry of the Lunar Eclipse of August 6, 1971

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The total lunar eclipse of August 6, 1971, was observed at the Observatories Ondřejov and Kleť. The densities of the penumbral and umbral shadow in the spectral regions B and V were determined from photometric measurements. In the penumbra no differences between measured and theoretical densities were found, in the umbra the measured densities were larger than the theoretical ones, especially in the colour V in the middle parts of the shadow. From differences of the densities the properties of the dust layer in the Earth's atmosphere were derived.

1. Observation

At the Ondřejov Observatory the eclipse was observed with the 65-cm reflector of the Department of Astronomy and Astrophysics, Charles University. A photometric photometer with a photomultiplier EMI 6094 was used and the measurements were made with a diaphragm of 52″ in diameter. The measured area on the lunar surface was chosen near the creater Herodotus. The observations were carried out in two spectral regions, in the instrumental colours B' and V'. The measurements were not reduced to the international system but the differences between the instrumental and international systems are very small. The observation was made between 19^h56^m and 22^h07^m U.T. and altogether 74 measurements were obtained, 36 of them in the colour B' and 38 in the colour V'. During the observation the air mass varied within $4.9 > M > 2.5$. All measurements were corrected for the atmospheric extinction.

At the Kleť Observatory the eclipse was observed with the 25-cm Zeiss refractor of the Department of Astronomy and Astrophysics, Charles University. A similar photometer as at the Ondřejov Observatory was used (photomultiplier EMI 6094, diaphragm 104″). The measured area on the lunar surface was situated in Mare Crisium near the crater Picard and the observations were also made in two spectral regions. The measurements were reduced to the international colours B and V. The observation was performed between 20^h03^m and 22^h27^m U.T. and altogether 91 measurements were obtained, 44 of them in the colour B and 47 in the colour V.

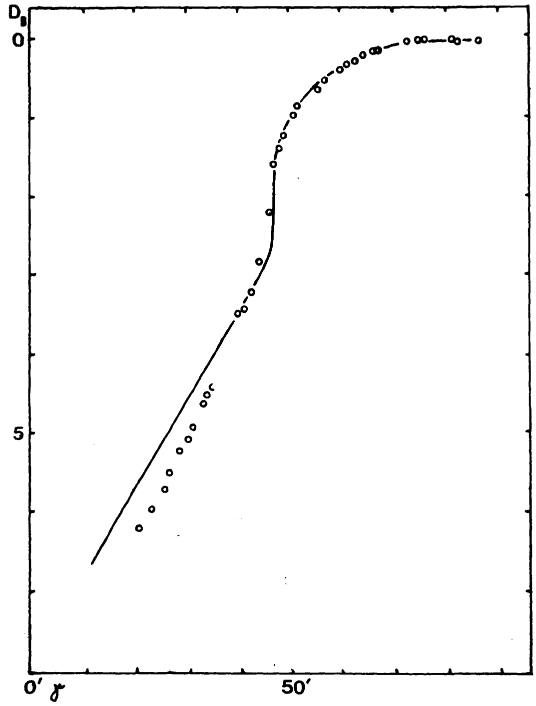

Fig. 1. Observed (o) and computed (—) densities of the shadow in the colour *B* (Observatory Ondřejov).

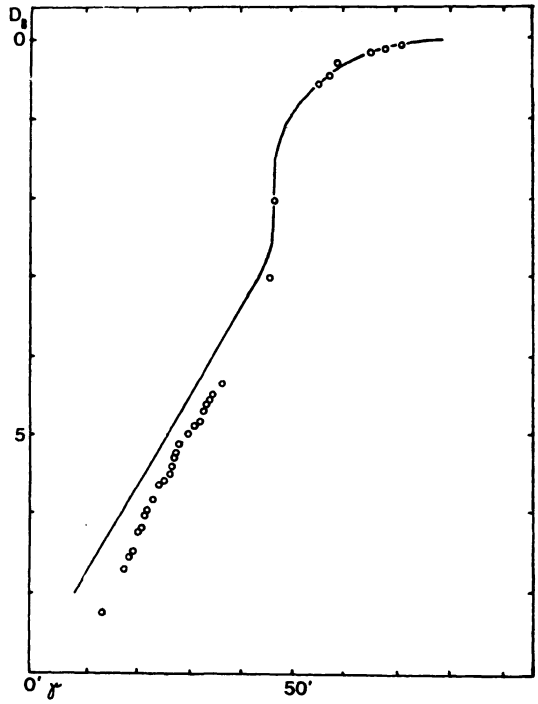

Fig. 2. Observed (o) and computed (—) densities of the shadow in the colour *B* (Observatory Kleť).

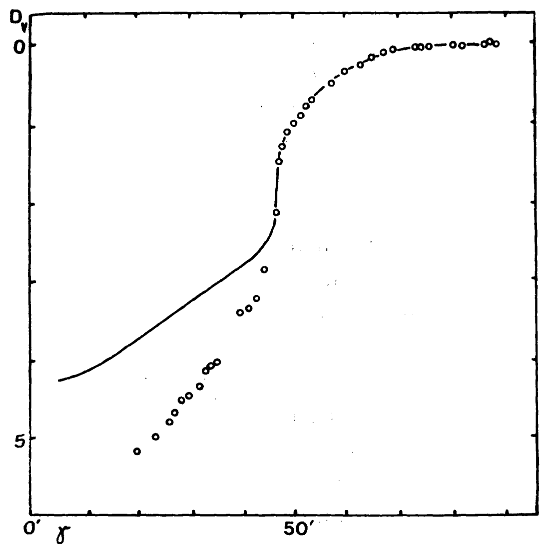

Fig. 3. Observed (o) and computed (—) densities of the shadow in the colour *V* (Observatory Ondřejov).

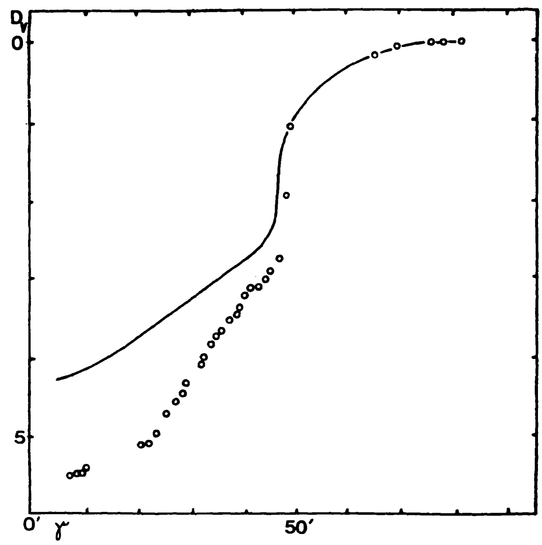

Fig. 4. Observed (o) and computed (—) densities of the shadow in the colour *V* (Observatory Kleť).

Table 1.

γ	h	M_B	M_V	ΔD_B	ΔD_V	ΔA_B	A_B	ΔA_V	A_V
10′	6	37	46	0.70	1.20	0.019	0.131	0.026	0.069
20′	9	26	31	0.55	1.35	0.021	0.133	0.043	0.083
30′	12	18	21	0.40	0.95	0.022	0.134	0.045	0.088
40′	25	13	16	0.15	0.50	0.011	0.122	0.031	0.074

During the observation period the air mass varied within $4.6 > M > 2.4$. All measurements were corrected for the extinction. As a photometric standard the star ϑ Capricorni was observed.

The total lunar eclipse of August 6, 1971, was observable only partly because the Moon was below the horizon at the beginning of the phenomenon. The Moon rose partially eclipsed and at the time of the beginning of the total eclipse the Moon was very low over the horizon in the still bright twilight sky. Consequently, the measurement of the Moon's brightness was very difficult at that time and the first observations were not used for the determination of the umbral densities. The observational conditions were very good at both observatories, the sky was cloudless.

2. Densities of the penumbral and umbral shadow

From the measured intensities of the observed lunar areas the densities of the penumbral and umbral shadow were computed. These densities are shown as functions of the distance γ from the centre of the shadow in Figs. 1 through 4. In these figures the observed penumbral densities are compared with the theoretical densities (e.g. [1]). The theoretical densities of the umbra were computed for the Moon's parallax $\pi = 60'$ and for the wavelengths 4350 Å ($\sim B$) and 5500 Å ($\sim V$), respectively. In Figs. 1–4 the theoretical densities are represented by curves, the observed densities by circles.

From Figs. 1–4 it is evident that there are no differences (within the limits of observational errors) between the observed and computed densities of the penumbral shadow. No brightening in the penumbra, assumed by some authors, was observed.

3. Discussion of results

Table 1 shows the differences ΔD between the observed and computed densities of the umbral shadow for different distances γ from the centre of the shadow; h is the height of the effective beam (in km) and M the mean air mass. The differences ΔD are larger in the central parts than in the outer parts of the shadow, and larger in the colour V than in the colour B. Similar differences have usually been found during all formerly observed lunar eclipses. The theoretical densities were computed under the assumption of an ideal (pure) Earth's atmosphere and therefore the observed densities are larger than the computed ones. The origin of the differences in the densities must be searched for, of course, in the Earth's atmosphere, especially in its lower layers. The densities of the central parts of the shadow ($\gamma < 20' \div 25'$) may be strongly influenced by the meteorological situation in the troposphere. The clouds along the Earth's terminator, particularly in the equatorial regions, may cause a density excess up to $\Delta D = +1.0$. The densities of the shadow at larger distances from the centre are influenced especially by the conditions in the lower stratosphere (10–30 km). At these heights, there are two layers: an ozonic one and a dust one (of volcanic and meteoritic origin). These layers, chiefly the second one, must cause the observed increase of the umbral density.

The absorption coefficient A_0 of the atmosphere is thus composed of the following components:

$$A_0 = A + A' + A''$$

where A is the absorption coefficient of the pure atmosphere, A' is the absorption coefficient of the dust layer and A'' the absorption coefficient of the ozone layer. The influence of the ozone layer on the density of the shadow is, however, very small ($\Delta D \approx 0.1$) and therefore $A'' \ll A'$. The theoretical values of the absorption coefficient A which were used for the determination of the theoretical densities of the shadow, were computed from the well-known Rayleigh-Cabannes formula

$$A_B = 0.112\ (\lambda = 4350\ \text{Å}) \qquad A_V = 0.043\ (\lambda = 5500\ \text{Å})$$

The differences ΔD between observed and computed densities of the shadow, shown in Tab. 1, depend on the mean air mass M and the differences $(A' - A)$ may be expressed by the formula

$$\Delta D = M(A' - A).$$

Using this formula the values $(A' - A)$ of Tab. 1 were computed. The following mean values of the real absorption coefficient A_o of the Earth's atmosphere during the ecplipse of August 6, 1971, were found

$$A_{O,B} = 0.130\ (\lambda = 4350\ \text{Å}) \qquad A_{O,V} = 0.078\ (\lambda = 5500\ \text{Å})$$

The real absorption coefficient A_o depends on the -2.3 power of the wavelength only

$$A_o = (3.20 \times 10^7)/\lambda^{2.3},$$

while the theoretical absorption coefficient A computed according to the Rayleigh-Cabannes formula depends on the -4 power. The real coefficient is not so selective as the theoretical one which is based on the molecular scattering only. The smaller dependence of the real coefficient on the wavelength may be an argument for the absorption in the dust layer in the Earth's atmosphere. From the course of the differences ΔD it may be concluded that during the lunar eclipse of August 6, 1971, the upper limit of the dust layer was at the height of about 30 km and its maximal density at the height of about 10 km (i.e. in the tropopause).

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Enlargement of the Earth's Shadow During the Lunar Eclipse of August 6, 1971

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The enlargement of the umbral shadow was computed from the observed times when the lunar features left the Earth's shadow. During the total eclipse of August 6, 1971, the enlargement of the umbra was found to be 1/52, very close to its mean value determined from many formerly observed lunar eclipses.

1. Introduction

The total lunar eclipse of August 6, 1971, was observable only partially in Central Europe. The moon rose at longitude 15° east from Greenwich and 50° north latitude, at 18^h30^m U.T., shortly before the beginning of the total eclipse. At the beginning of the total eclipse the Moon was very low over the horizon and therefore the entering of the lunar features into the shadow was not observable. Moreover, the twilight sky was still bright.

The eclipse was observed by several observers in Czechoslovakia and Germany (G.D.R.), but only the times of exits of lunar craters from the umbra were determined.

2. Observations of the eclipse

M. Dujnič [1] observed the eclipse at the Urania Observatory, Rožňava ($\lambda = 20°32'$ E Gr., $\varphi = 48°40'$ N) with the small 80-mm binocular telescope. The observational conditions were very good, the sky was clear. During the total eclipse the Moon was relatively very bright (degree 3 in Danjon's luminosity scale) and it was observable during the whole totality. Also the lunar maria and the craters Copernicus and Tycho were visible. The border of the umbral shadow was very sharp and well defined. Dujnič observed exits of 16 lunar features from the shadow and all of them were used for the determination of the enlargement of the shadow in the present paper.

At the Observatory Rokycany ($\lambda = 13°36'$ E Gr., $\varphi = 49°45'$ N) the eclipse was observed under good conditions by three observers [2]. F. Brožík used a small 80-mm Zeiss refractor and 12 exits were observed. These observations were not used for the determination of the enlargement of the shadow because most of them were evidently timed somewhat later. V. Novotný observed with a Newton-type 160-mm reflector and determined the times of 11 exits of lunar features from the shadow. One of the contacts (Langrenus) was omitted, it is probably erroneous. F. Vágner used a small 60-mm refractor for the time determination of 15 contacts, two of which (Fracastorius and Taruntius) were not used for the computation of the enlargement of the shadow. Both these contacts were evidently timed later.

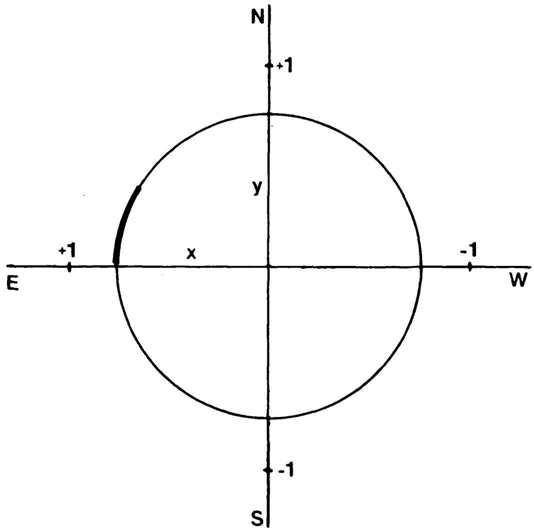

Fig. 1.

The observation at the Sonneberg Observatory ($\lambda = 11°12'$E Gr., $\varphi = 50°23'$ N) was made by a very experienced observer, P. Ahnert [3]. With a 100-mm Zeiss refractor he obtained times of 13 exits all of which were used for the determination of the enlargement of the shadow. Ahnert noted that during the end of the partial eclipse the border of the shadow was diffuse, and the time of Langrenus' exit is therefore not too accurate.

3. Computation of the enlargement of the shadow

Table 1 contains the names of the observed lunar features and the times (in E.T., $\Delta T = +41.5^s$ was accepted) of its contacts with the shadow. Using Kozik's method [4] the rectangular (x, y) and the polar (radii r and position angles ψ) coordinates were computed. These coordinates are also given in Table 1. For the computation the rectangular coordinates of the observed lunar features published by the present writer et al. [5] and Kozik [6] were used. For some lunar features these coordinates were computed by the present author from Neison's monograph [7]. The computation of the values of Table 1 was carried out on the MINSK-22 computer of the Centre for Numerical Mathematics, Charles University. The Sun's and Moon's ephemeris was taken from the Astronomical Ephemeris for the year 1971.

4. Enlargement of the Earth's shadow

Table 2 contains the number N of observed contacts for all observers, the mean values of position angles $\overline{\psi}$ and radii $\bar{r}_0$ of the shadow (together with their mean

Table 1.

Feature	*E.T.*	*x*	*y*	*r*	$\psi(E)$
M. Dujnič, Rožňava					
Grimaldi	20.620^h	+0.7382	+0.1574	0.7548	+12.0°
Aristarchus	.730	.6900	.2925	.7494	23.0
($\lambda = -36°$, $\beta = -17°$)	.777	.7317	.1112	.7401	8.6
Agatharchides A	.830	.7334	.0864	.7385	6.7
Tob. Mayer	.862	.7087	.2693	.7581	20.8
Prom. Laplace	.868	.6410	.3797	.7450	30.6
Plato	.958	.6309	.4000	.7470	32.4
Tycho	.973	.7542	.0198	.7544	1.5
Calippus	21.107	.6528	.3731	.7519	29.8
Eudoxus A	.125	.6331	.3941	.7458	31.9
Manilius	.155	.6990	.2823	.7538	22.0
Menelaus	.185	.6841	.2889	.7426	22.9
Vitruvius	.310	.6895	.3057	.7542	23.9
Mercurius	.338	.6521	.4174	.7743	32.6
Censorinus	.347	.7188	.2289	.7544	17.7
Secchi	.433	.7283	.2518	.7706	19.1
V. Novotný, Rokycany					
Grimaldi	20.613	+0.7347	+0.1559	0.7511	+12.0
Aristarchus	.730	.6900	.2925	.7494	23.0
Gassendi	.787	.7514	.1147	.7601	8.7
Euler	.850	.6895	.2991	.7516	23.5
Pytheas	.915	.6944	.2926	.7535	22.8
Tycho	.970	.7524	.0191	.7527	1.5
Manilius	21.157	.6998	.2827	.7548	22.0
Maskylene	.345	.7246	.2430	.7643	18.5
Colombo	.393	.7293	.1640	.7475	12.7
Picard	.457	.6983	.3038	.7615	23.5
F. Vágner, Rokycany					
Aristarchus	20.733	+0.6917	+0.2932	0.7513	+23.0
Gassendi	.782	.7488	.1136	.7573	8.6
Kepler	.785	.7170	.2301	.7530	17.8
Euler	.847	.6878	.2984	.7497	23.5
Copernicus	.932	.7177	.2486	.7595	19.1
Timocharis	.972	.6837	.3212	.7554	25.2
Plato	.973	.6387	.4033	.7554	32.3
Tycho	.983	.7594	.0220	.7597	1.7
Menelaus	21.203	.6936	.2929	.7529	22.9
Possidonius	.268	.6725	.3694	.7673	28.8
Plinius	.270	.6986	.2944	.7581	22.9
Colombo	.380	.7223	.1611	.7401	12.6
Langrenus	.480	.7242	.1954	.7501	15.1

Feature	*E.T.*	x	y	r	$\psi(E)$
P. Ahnert, Sonneberg					
Grimaldi	20.612	+0.7339	+0.1556	0.7502	+12.0°
Aristarchus	.728	.6891	.2921	.7485	23.0
Gassendi	.773	.7444	.1118	.7528	8.5
Prom. Heraclides	.820	.6503	.3587	.7426	28.9
Prom. Laplace	.873	.6436	.3807	.7478	30.6
Pytheas	.912	.6927	.2918	.7516	22.8
Copernicus	.923	.7134	.2468	.7548	19.1
Plato	.962	.6326	.4007	.7489	32.4
Tycho	.972	.7533	.0195	.7535	1.5
Manilius	21.155	.6990	.2823	.7538	22.0
Possidonius	.255	.6655	.3665	.7598	28.8
Proclus	.392	.6831	.3024	.7470	23.9
Langrenus	.495	.7321	.1986	.7585	15.2

Table 2.

Observer	N	$\overline{\psi}(E)$	$\bar{r}_o$	r_c	$\bar{r}_o - r_c$	$(\bar{r}_o - r_c)/\bar{r}_o$
Ahnert	13	+20.7°	0.7515 ± 0.0013	0.7388	0.0127	1.7 ± 0.1%
Dujnič	16	+21.0	0.7522 ± 0.0024	0.7388	0.0134	1.8 ± 0.3
Novotný	10	+16.8	0.7546 ± 0.0016	0.7389	0.0157	2.1 ± 0.2
Vágner	13	+19.5	0.7546 ± 0.0018	0.7388	0.0158	2.1 ± 0.2

errors), further the theoretical radii r_c of the shadow, the differences between the observed and computed radii $\bar{r}_o - r_c$ and the values of the enlargement of the shadow $(\bar{r}_o - r_c)/\bar{r}_o$ (in per cent together with the mean errors). The theoretical radius of the shadow was computed using the known formula (e.g. [4])

$$r_c = 1 - \frac{\operatorname{tg}(R - \pi)}{\operatorname{tg}\pi'} - 0.00338 \cos^2\delta \sin^2\psi$$

where R is the apparent radius of the Sun, π the horizontal equatorial parallax of the Sun, π' the horizontal equatorial parallax of the Moon and δ the declination of the Sun.

The mean value of the enlargement of the Earth's shadow during the lunar eclipse of August 6, 1971 was $1.91\% = 1/52$, which is very close to the normal value of the enlargement determined from many formerly observed lunar eclipses. This result shows that the transparency of the lower parts of the Earth's upper atmosphere (cca 30 km $< h <$ 70 km) was nearly normal at the moment of the eclipse. In regard to the very small arch of the determined umbral border (Fig. 1, the thick arch) it was not possible to compute the form of the shadow with sufficient accuracy during this eclipse.

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