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FORM AND ENLARGEMENT OF THE EARTH'S SHADOW DURING THE LUNAR ECLIPSES OF AUGUST 26, 1961, JULY 6, 1963 AND JUNE 24-25 1964

TVAR A ZVĚTŠENÍ ZEMSKÉHO STÍNU PŘI MĚSÍČNÍCH ZATMĚNÍCH Z 26. VIII. 1961, 6. VII. 1963 a 24.—25. VI. 1964

ФОРМА И УВЕЛИЧЕНИЕ ЗЕМНОЙ ТЕНИ ВО ВРЕМЯ ЛУННЫХ ЗАТМЕНИЙ 26 АВГУСТА 1961 ГОДА, 6 ИЮЛЯ 1963 ГОДА И 24–25 ИЮНЯ 1964 ГОДА

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1. INTRODUCTION

During the four past years there were three lunar eclipses observable in Czechoslovakia. At these eclipses the times of entrances of lunar craters into umbra and exits from umbra were determined by various observers. From these observations the enlargement and the ellipticity of the earth's shadow may be derived using KOZIK's method (1940). This method was applied to the moon's eclipses of August 26, 1961, July 6, 1963 and June 24–25, 1964 analogously to the earlier lunar eclipses (BOUŠKA 1947—1960). The sun's and moon's right ascensions and declinations, moon's horizontal parallaxes, sun's selenographic colongitudes and latitudes and position angles of the moon's axis were taken from the Astronomical Ephemeris. The coordinates of observed lunar formations published by BOUŠKA, HŘEBÍK a ŠVESTKA (1953) on the one hand and by KOZIK (1960) on the other were used. The practical computations were, for this time, carried out on a Zuse *Z23* digital computer. The interpolation formula, applied to all the basic data taken from tables for the standard dates, included the differences to the third order. The programme was coded in the Autocode 4.

2. THE ECLIPSE OF AUGUST 26, 1961

This partial lunar eclipse was only partly observable in Czechoslovakia. At the beginning of the partial eclipse the moon's altitude was about 20° only and the moon was setting about half an hour before leaving the umbra. For this reason only the entrances of craters into the shadow could be observed. The eclipse was observed in Prague by three observers as follows:

1. *L. Černý* – 4″ refractor, ×64
2. *O. Hlad* – 7″ refractor Zeiss, ×56
3. *A. Rükl* – 7″ refractor Zeiss, ×56,

and by one observer in Bratislava:

4. *J. Očenáš*– 3″ refractor Busch, ×60.

Weather conditions were very good at both observation places.

Table 1 shows for each observer the names of the observed formations, the ephemeris time of the observed entrances into the umbra and the rectangular (x, y) and polar coordinates (ψ, r) of the points on the umbra boundary. The rectangular coordinates x, y and the radius of the umbra r are expressed in units of the earth's radius. The position angle ψ is computed from the west point of the shadow, negative southwards.

The mean values of ψ and r are for the individual observers:

Observer:	$\bar{\psi}(W)$	$\bar{r}_0$	r_c	Δr	$\Delta r/r_0$	n
1. *L. Černý*	—53°.8	0.7644	0.7426	0.0218	0.0285	23
2. *O. Hlad*	—57 .2	0.7580	0.7424	0.0156	0.0206	39
3. *A. Rükl*	—57 .5	0.7600	0.7424	0.0176	0.0232	44
4. *J. Očenáš*	—46 .2	0.7572	0,7430	0.0142	0.0188	8

Here $\bar{r}_0$ means the mean value of the observed radius of the umbra, r_c the theoretical value of this radius, Δr the difference between the observed and computed radius, $\Delta r/r_0$ the enlargement of the shadow and n the number of observed entrances. The theoretical radius of the umbra was computed from the geometrical conditions using the formula

$$r_c = 0.7447 - 0.0033 \sin^2 \psi .$$

The enlargement of the umbra at this eclipse, according to all the 114 observed entrances of craters, was 2.31%.

Dividing the observed values of shadow radius according to position angles we obtain for individual observers mean points, shown in Fig. 1. From these mean points the oblateness of the umbra may be computed using the formulae

$$a\,n - c \sum \sin^2 \psi - \sum r = 0$$

$$- a \sum \sin^2 \psi + c \sum \sin^4 \psi + \sum r \sin^2 \psi = 0 .$$

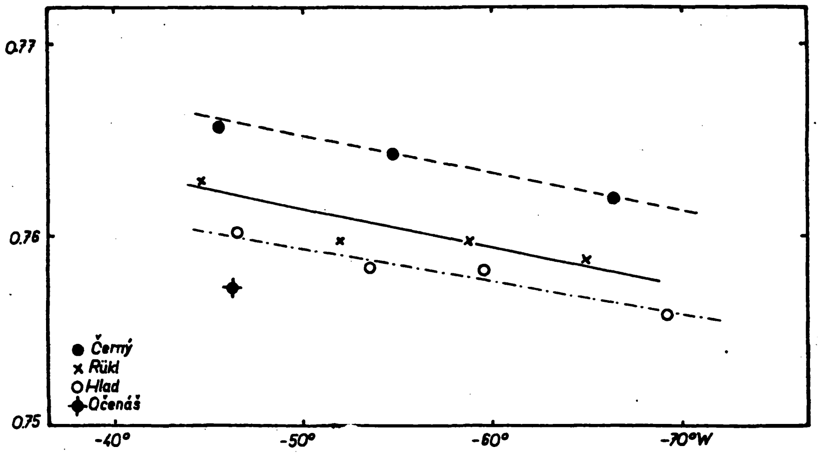

Fig. 1. Lunar eclipse of August 26, 1961. Mean points of umbra radius.

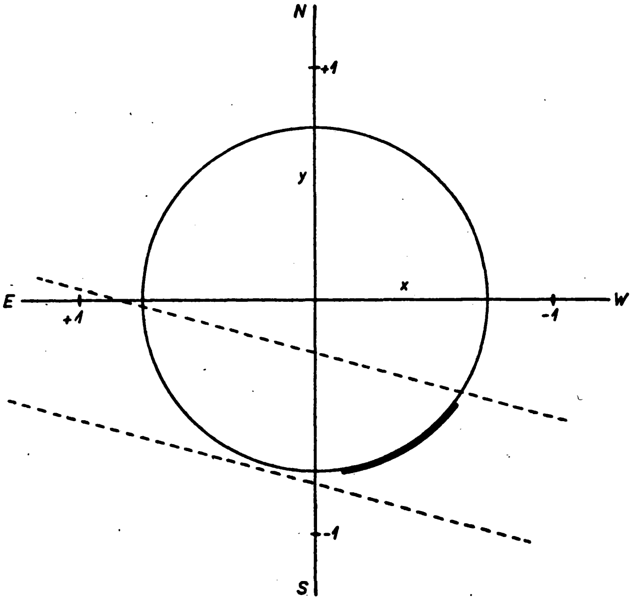

Fig. 2. Lunar eclipse of August 26, 1961. Moon's path through the earth's umbral shadow.

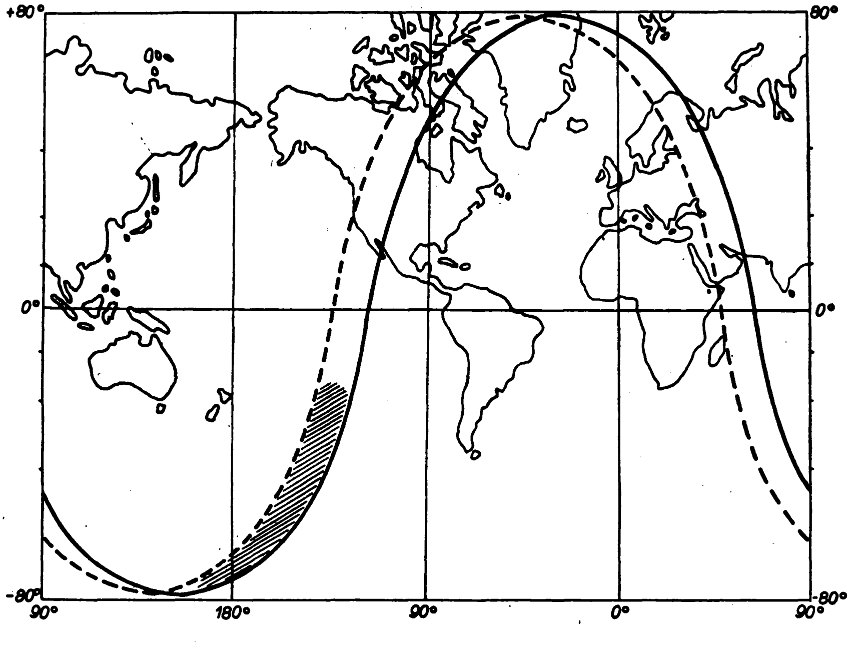

Fig 3. Lunar eclipse of August 26, 1961. Position of the earth's terminator.

For the three first observers the polar equations of the observed umbra boundary are, respectively:

1. *L. Černý:*	$r_0 = 0.7727 - 0.0128 \sin^2 \psi$	$\omega = 1/78$
2. *O. Hlad:*	$r_0 = 0.7656 - 0.0108 \sin^2 \psi$	$\omega = 1/92$
3. *A. Rükl:*	$r_0 = 0.7690 - 0.0127 \sin^2 \psi$	$\omega = 1/79$

ω means the oblateness of the earth's shadow. The mean value of ω from all the 106 observed entrances into the umbra is $\bar{\omega} = 1/83$.

Fig. 2 illustrates the lunar path through the earth' s umbral shadow during this eclipse. The part of the boundary in which the entrances into umbra were observed is represented by a thick arc. In Fig. 3 the positions of the earth's terminator for the beginning (solid curve) and for the end (dashed curve) of observation are plotted. The stripped area between the two curves indicates those regions on the earth's surface over which the sun light, having been refracted, was falling on the moon's disc.

3. THE ECLIPSE OF JULY 6, 1963

This partial eclipse of the moon was observed by Professor E. BUCHAR, Director of the Department for Astronomy and Geophysics, Technical University, Prague. By means of a 5″ refractor Merz, 10 entrances into umbra and 9 exits of lunar formations from umbra were observed. Weather conditions during the first half of the eclipse were not favourable, the observation was interrupted by clouds. During the second half of the phenomenon the sky was bright. The umbra boundary seemed to be completely vague and the shadow was very dark so that the eclipsed part of the moon's disc was nearly invisible.

Table 2 contains the names of the observed lunar craters, the ephemeris time of entrances into umbra and exits from umbra, and further the coordinates x, y and r, ψ. The mean values of ψ and of the observed radius of umbra are:

	$\bar{\psi}$	$\bar{r}_0$	r_c	Δr	$\Delta r/r_0$	n
Entrances:	+55°.3 *W*	0.7462	0.7288	0.0174	0.0233	10
Exits:	+56 .7 *E*	0.7413	0.7288	0.0125	0.0169	9

Here r_c again means the theoretical value of the umbra radius, computed from the equation

$$r_c = 0.7308 - 0.0029 \sin^2 \psi,$$

and further $\Delta r \doteq r_0 - r_c$. The enlargement of the earth's shadow computed from the entrances was 2.33% and from the exits 1.69%. The mean value from all 19 observed contacts of the lunar craters with the umbra gives the enlargement of the shadow 2.03%. Since the number of the observed entrances and exits was small the oblateness of the umbra could not be determined as to this lunar eclipse.

Fig. 4 shows the moon's path through the earth's shadow during this eclipse. The thick arcs represent the regions of position angles in which the entrances (*EN.*) of craters into umbra and exits (*EX.*) from the umbra were observed. Fig. 5 shows the positions of the earth's terminator at the beginning (solid curve) and at the end (dashed curve) of the observed entrances (*EN.*) into the umbra and at the beginning (solid curve) and at the end (dashed curve) of the observed exits (*EX.*) from the umbra. The eclipsed moon's regions illuminated by the sun light refracted over the terminator correspond to the stripped areas between the curves.

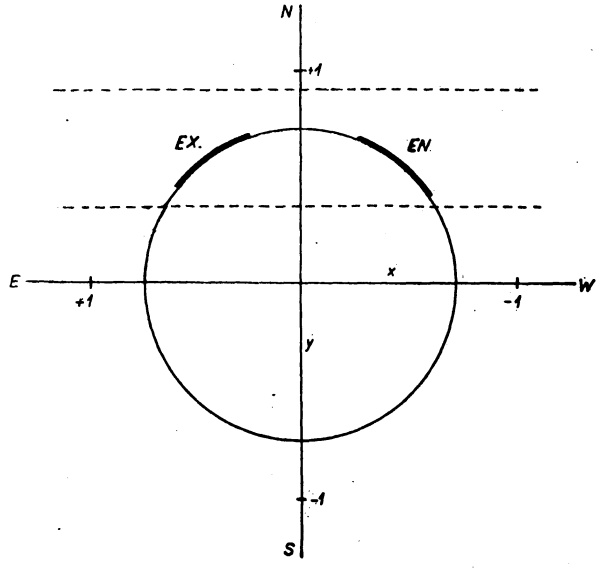

Fig. 4. Lunar eclipse of July 6, 1963. Moon's path through the earth's umbral shadow.

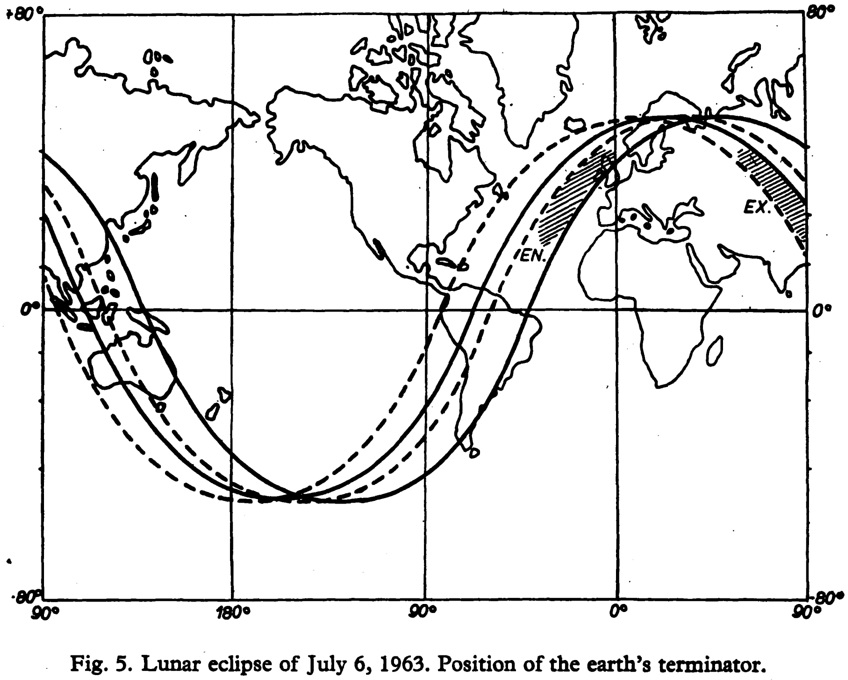

Fig. 5. Lunar eclipse of July 6, 1963. Position of the earth's terminator.

4. THE ECLIPSE OF JUNE 24–25, 1964

This total eclipse of the moon was only partly observable in Czechoslovakia. The observation conditions were not very favourable as the moon was at the time of entrance into the umbra only 16°.5 above the horizon. The moon left umbra a few minutes after the moonset. The weather conditions were quite good, the sky was nearly bright and some high thin cloudiness could not disturb the observation of entrances of the moon's craters into the umbra.

At the observation participated following observers:

1. Prof. *E. Buchar* (Prague) – 5″ refractor Merz, ×44
2. *O. Hlad* (Prague) – 4″ refractor, ×50
3. *K. Mrzílek* (Prague) – 2,5″ refractor, ×40
4. *P. Příhoda* (Prague) – 4″ double-refractor Binar, ×50
5. *A. Rükl* (Prague) – 4″ refractor, ×50
6. Miss *I. Mikešová* (Vích, North Bohemia) – 4″ refractor Monar, ×25
7. Mrs. *D. Šolcová* (Vích) – 4″ refractor Monar, ×25
8. *M. Vinš* (Kozákov, North Bohemia) – 2,5″ refractor, ×35.

Table 3 contains the names of observed lunar formations, *E.T.* of observed entrances into the umbra and the coordinates x, y and r, ψ for each observer. The mean values of position angle and radius of the shadow are:

Observer	$\bar{\psi}(W)$	$\bar{r}_0$	Δr	$\Delta r/r_0$	n
1. Prof. *Buchar*	—6°.1	0.7334	0.0212	0.0289	22
2. *O. Hlad*	—6.2	0.7275	0.0153	0.0210	52
3. *K. Mrzílek*	—7.7	0.7309	0.0187	0.0256	12
4. *P. Příhoda*	—6.9	0.7287	0.0165	0.0226	47
5. *A. Rükl*	—6.7	0.7295	0.0173	0.0237	57
6. Miss *Mikešová*	—2.1	0.7331	0.0209	0.0285	4
7. Mrs. *Šolcová*	—5.9	0.7386	0.0264	0.0357	9
8. *M. Vinš*	—2.2	0.7314	0.0192	0.0262	5

Here Δr again means the difference between the observed and computed radius of the umbra, $\Delta r/r_0$ the enlargement of the shadow and n the number of observed entrances into the umbra. The theoretical radius of the shadow is given by the formula

$$r_c = 0.7122 - 0.0028 \sin^2 \psi$$

and owing to a negligible dispersion in $\bar{\psi}$ the theoretical radius of umbra for all the observers is $r_0 = 0.7122$. The mean enlargement of the earth's shadow is 2.41 % as derived from all the 208 observed contacts.

Dividing the observed values of umbra radius according to position angles we get the mean points shown for different observers in Fig. 6. From this figure it is evident that the form of the umbra boundary was exceptional. In the position angle $\psi = +5^\circ$ *W* the mean radius of umbra was about 0.74, in $\psi = -5^\circ$ *W* about 0.73 and in $\psi = 15^\circ$ *W* about 0.72 in units of the earth's radius. The enlargements of the shadow in these position angles are 4.2 %, 2.8 % and 1.4 % respectively. It seems that as to this lunar eclipse the umbra boundary was not elliptical but quite irregular.

Fig. 7 shows the path of the moon through the earth's shadow, Fig. 8 the earth's terminator for the beginning (solid curve) and for the end (dashed curve) of observation periods.

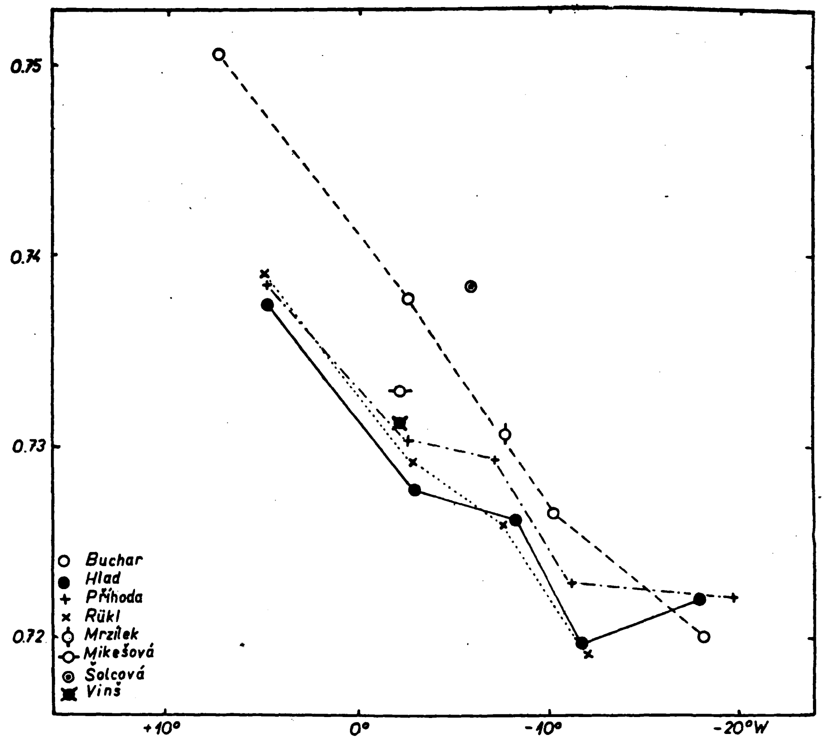

Fig. 6. Lunar eclipse of June 24–25, 1964. Mean points of umbra radius.

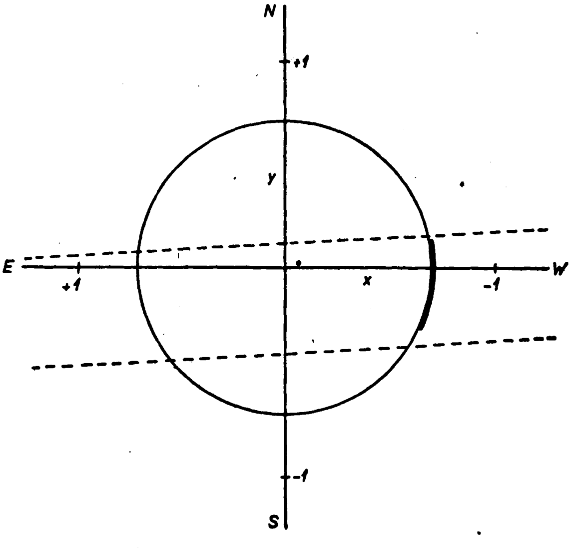

Fig. 7. Lunar eclipse of June 24–25. 1964. Moon's path through the earth's umbral shadow.

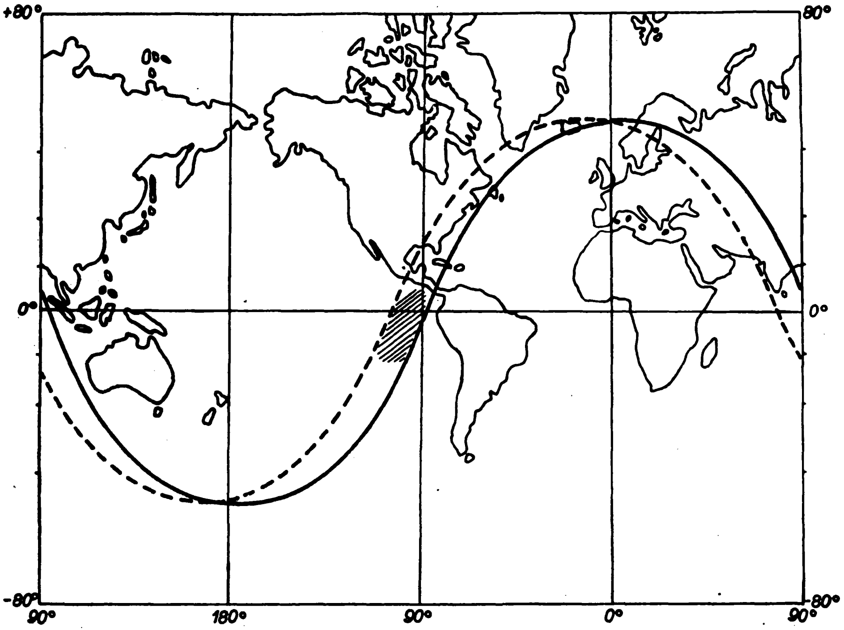

Fig. 8. Lunar eclipse of June 24–25, 1964. Position of the earth's terminator.

5. DISCUSSION OF RESULTS

The mean enlargement of the earth's shadow observed during lunar eclipses is about 2%. For example, **Bouška and Švestka** (1950—1951) found the mean value of umbra enlargement from 33 lunar eclipses to be 2.06%.

The enlargement of the umbra radius at the lunar eclipse of August 26, 1961 was 2.31%, i.e. somewhat larger than the mean value. The mean observed radius of the shadow was thus at the distance of 56.007 earth radii from the earth 112 km larger than the calculated. The polar radius of the umbra was 97 km, the equatorial 152 km larger than the theoretical value, calculated from the geometrical conditions neglecting the influence of the earth's atmosphere. The influence of the terrestrial atmosphere is the same as if the earth's polar radius were by 131 km and the equatorial by 204 km greater, or as if the earth's atmosphere block the sunlight up to these altitudes.

The enlargement of the shadow computed from the entrances of craters into umbra is, as a rule, somewhat larger than the enlargement determined from the exits of craters from umbra. Since during this eclipse only the entrances were observed the true value of umbra enlargement may be somewhat less than the value found.

The umbra boundary was an ellipse. The mean oblateness of the shadow was 1/83, i.e. it was about 3.5 times larger than the oblateness of the earth.

Since the sun rays falling in the earth's shadow near the boundary of umbra are refracted in great heights of the earth's atmosphere, the reasons for the umbra enlargement and ellipticity must be searched principally in upper atmospheric heights, especially in the absorbing layer of meteoritic or volcanic dust, supposed in the height of about 100 km. Refraction and molecular diffusion in such a layer may cause the mentioned enlargement of the umbral shadow.

The part of the earth's terminator, over which the sunbeams falling into the umbral shadow near the observed umbra boundary were refracted, was lying in the South Pacific Ocean.

The enlargement of the umbral shadow found during the eclipse of July 6, 1963 was quite average. At the distance of 61.312 earth's radii (from the earth) the observed radius of umbra was about 132 km larger than the theoretical radius, computed neglecting the terrestrial atmosphere. The enlargement of the umbral shadow determined from the timings of craters entering umbra was, as expected, somewhat larger than the enlargement from timings of formations leaving the shadow. This phenomenon probably is of physiological origin. Experience shows that the observer determines both the time of entrance into umbra and the time of exit from shadow somewhat earlier than the contacts take place in fact.

The shadow was very dark during this eclipse. The exceptionally large density of the umbra, however, caused no substantial enlargement of the shadow, at least in the region of position angles $34° < \psi\,(W) < 69°$ and $37° < \psi\,(E) < 69°$. The fact must be taken into consideration that the number of observed entrances and exits was small. This is just the reason why it was impossible to determine the form of the umbra boundary during this eclipse.

The part of the terrestrial terminator over which the sunrays, falling into the umbra near the observed shadow boundary, were refracted, was during entrances into umbra placed in the east part of the North Atlantic Ocean, during exits from umbra in the north part of Central Asia. If we suppose that the large density of the umbra was caused by an absorbing dust layer of volcanic origin from eruptions of Mount Agung on Bali early in the year 1963 (Brooks 1964) it is evident that this layer must disappear northwards to the latitudes of 34°*N*.

The form of the umbra boundary during the eclipse of June 24–25, 1964 was quite exceptional. The observed radius of umbra at the distance of 63.532 earth's radii from the earth was in the position angle $\psi(W) = +5°$ about 191 km, in $\psi\,(W) = -5°$ about 128 km and in $\psi\,(W) = -15°$ about 64 km larger than the theoretical radius, computed neglecting the influence of terrestrial atmosphere. The influence of the earth's atmosphere is the same as if the earth's radius in the geocentric latitude of 5°*N* were by 269 km greater, or if the terrestrial atmosphere were quite opaque up to this altitude. For the latitudes of 5°*S* and 14°*S* the corresponding values of the enlargement of the earth's radius are 180 km and 90 km, respectively.

The extraordinary enlargement of the umbra near the west point of the shadow may be caused by the mentioned layer of volcanic dust from Mt. Agung. On this assumption the absorbing layer had to be localised only over the equator. The part of the earth's terminator over which the sunbeams falling into the shadow near the observed umbra boundary were refracted was in the equator region placed in the eastern part of the Pacific Ocean near the northern coast of South America. Also the photometrical measurements made by Bouška and Mayer (1965) showed that the density of the umbral shadow was during this eclipse very large. This phenomenon may be also in connection with the presence of volcanic dust in the earth's atmosphere over the equatorial regions. The dust particles of volcanic origin which is the dust layer probably composed of must be of very small dimensions. The time of fall of these particles from the heights of about 100 km to the earth's surface must be very long, approximately a few years. In the view of it we can suppose that during the following lunar eclipses some anomalies in the form, enlargement and density of the umbral shadow might be observed as well.

SUMMARY

From the moments of lunar craters entering or leaving the earth's shadow made during the three last eclipses of the moon visible in Czechoslovakia, the authors determined the enlargement, and the oblateness of the umbral shadow, when possible. During the lunar eclipse of August 26, 1961, the enlargement of the umbra was found to be 2.31% and the umbra boundary was of an elliptical form; the oblateness was 1/83. During the eclipse of July 6, 1963, the enlargement of the shadow was 2.03%. The average of the umbra enlargement, found during the lunar eclipse of June 24–25, 1964, was 2.41%. The form of the umbra boundary was not elliptical, but irregular.

SOUHRN

Z časových okamžiků vstupů kráterů do zemského stínu, resp. výstupů ze stínu, určených při posledních třech měsíčních zatměních, viditelných v Československu, bylo určováno zvětšení a příp., zploštění stínu. Při zatmění z 26. srpna 1961 bylo nalezeno zvětšení stínu o 2,31 % a stín měl eliptický tvar; jeho zploštění bylo 1/83. Zpracováním pozorování zatmění ze 6. července 1963 bylo zjištěno zvětšení stínu o 2,03%. Průměrná hodnota zvětšení stínu, zjištěná při zatmění z 24.—25. června 1964 byla 2,41%. Tvar zemského stínu nebyl však při tomto zatmění eliptický, ale nepravidelný.

РЕЗЮМЕ

По моментам вступления в земную тень и выхода из нее кратеров, отмеченных во время последних трех лунных затмений наблюдаемых в Чехословакии, определены увеличение и сжатие тени. Во время затмения 26 августа 1961 г. было найдено увеличение тени на 2,31 % и контур тени эллиптический; его сжатие было 1/83. Обработка наблюдений затмения 6 июля 1963 привела к увеличению тени на 2,03 %, в то время, как средняя величина увеличения тени, вытекающая по наблюдениям затмения 24—25 июня 1964 г., равна 2,41 %. Форма земной тени для этого затмения не являлась эллиптической, а неправильной.

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Tables 1–3 on pp. 11–20

Table 1

Partial lunar eclipse of August 26, 1961

No.	*Formation*	*E.T.*	*x*	*y*	*ψ (W)*	*r*
Černý						
1	Brayley	1.759$^{\mathrm{h}}$	—0.5393	—0.5372	—44.9°	0.7612
2	Milichius *A*	1.786	—0.5126	—0.5859	—48.8	0.7785
3	Hansteen α	1.809	—0.4052	—0.6532	—58.2	0.7686
4	Milichius	1.816	—0.5041	—0.5809	—49.1	0.7691
5	Pytheas	1.838	—0.5520	—0.5502	—44.9	0.7794
6	Pico	1.911	—0.6060	—0.4704	—37.8	0.7671
7	Gambart *A*	1.959	—0.4507	—0.6163	—53.8	0.7635
8	Darney *C*	1.978	—0.3877	—0.6684	—59.9	0.7727
9	Agatarchides *A*	2.049	—0.3294	—0.6944	—64.6	0.7685
10	Eudoxus *A*	2.089	—0.5940	—0.4789	—38.9	0.7630
11	Bullialdus *β*	2.096	—0.3281	—0.6854	—64.4	0.7598
12	Mösting *A*	2.109	—0.4171	—0.6354	—56.7	0.7600
13	Chladni	2.119	—0.4522	—0.6137	—53.6	0.7623
14	Manilius *E*	2.151	—0.4871	—0.5775	—49.9	0.7555
15	Alpetragius *B*	2.178	—0.3516	—0.6738	—62.4	0.7600
16	Possidonius *A*	2.188	—0.5635	—0.5306	—43.3	0.7740
17	Birt	2.214	—0.3132	—0.6961	—65.8	0.7633
18	Macrobius *B*	2.361	—0.4976	—0.5663	—48.7	0.7539
19	Macrobius *A*	2.361	—0.4950	—0.5719	—49.1	0.7564
20	Abulfeda *F*	2.368	—0.3272	—0.6840	—64.4	0.7582
21	Proclus	2.428	—0.4752	—0.5859	—51.0	0.7544
22	Tycho	2.411	—0.1711	—0.7430	—77.0	0.7624
23	Picard	2.448	—0.4837	—0.5986	—51.1	0.7696
Hlad						
1	Aristarchus	1.708	—0.5449	—0.5220	—43.8	0.7545
2	Grimaldi *C*	1.719	—0.4420	—0.6125	—54.2	0.7553
3	Marius *A*	1.729	—0.5066	—0.5622	—48.0	0.7567
4	Brayley	1.753	—0.5430	—0.5383	—44.7	0.7646
5	Milichius *A*	1.813	—0.4977	—0.5818	—49.5	0.7656
6	Milichius	1.819	—0.5022	—0.5804	—49.1	0.7675
7	Hansteen α	1.839	—0.3883	—0.6485	—59.1	0.7559
8	Darney *C*	2.013	—0.3681	—0.6630	—61.0	0.7584
9	Darney	2.031	—0.3667	—0.6663	—61.2	0.7605
10	Agatarchides *A*	2.076	—0.3144	—0.6902	—65.5	0.7585
11	Eudoxus *A*	2.099	—0.5884	—0.4773	—39.1	0.7577
12	Bullialdus *β*	2.103	—0.3244	—0.6843	—64.6	0.7573

No.	*Formation*	*E.T.*	*x*	*y*	*ψ (W)*	*r*
13	Mösting *A*	2.114^{h}	—0.4143	—0.6346	—56.9°	0.7579
14	Chladni	2.133	—0.4447	—0.6117	—54.0	0.7562
15	Manilius *E*	2.143	—0.4918	—0.5788	—49.6	0.7595
16	Alpetragius *B*	2.178	—0.3516	—0.6738	—62.4	0.7600
17	Possidonius *A*	2.214	—0.5486	—0.5265	—43.8	0.7604
18	E. Pickering	2.219	—0.4095	—0.6391	—57.4	0.7590
19	Birt	2.246	—0.2955	—0.6912	—66.9	0.7517
20	Plinius *β*	2.261	—0.4860	—0.5813	—50.1	0.7577
21	Dionysius	2.283	—0.4288	—0.6230	—55.5	0.7563
22	Janssen *B*	2.304	—0.4676	—0.6003	—52.1	0.7610
23	Macrobius *B*	2.351	—0.5032	—0.5678	—48.5	0.7587
24	Macrobius *A*	2.359	—0.4959	—0.5722	—49.1	0.7572
25	Moltke	2.361	—0.4073	—0.6374	—57.4	0.7564
26	Cauchy	2.399	—0.4572	—0.6088	—53.1	0.7614
27	Proclus	2.424	—0.4771	—0.5864	—50.9	0.7560
28	Censorinus	2.433	—0.4008	—0.6392	—57.9	0.7545
29	Tycho	2.439	—0.1553	—0.7386	—78.1	0.7547
30	Isidorius *D*	2.459	—0.3837	—0.6542	—59.6	0.7584
31	Picard	2.466	—0.4734	—0.5957	—51.5	0.7609
32	W.H.Pickering	2.533	—0.3907	—0.6510	—59.0	0.7592
33	Messier	2.534	—0.3921	—0.6512	—58.9	0.7601
34	Polybius *A*	2.559	—0.2629	—0.7054	—69.6	0.7528
35	Rosse	2.568	—0.2956	—0.6947	—66.9	0.7550
36	Bellot	2.614	—0.3258	—0.6837	—64.5	0.7574
37	Biot *A*	2.684	—0.2623	—0.7106	—69.7	0.7575
38	Biot	2.709	—0.2529	—0.7109	—70.4	0.7546
39	Stevinus	2.776	—0.1905	—0.7328	—75.4	0.7572
Rükl						
1	Seleucus	1.616	—0.5485	—0.5285	—43.9	0.7617
2	Aristarchus	1.698	—0.5505	—0.5235	—43.6	0.7596
3	Grimaldi *C*	1.709	—0.4476	—0.6140	—53.9	0.7599
4	Brayley	1.738	—0.5514	—0.5406	—44.4	0.7722
5	Milichius *A*	1.811	—0.4986	—0.5820	—49.4	0.7664
6	Milichius	1.816	—0.5041	—0.5809	—49.1	0.7691
7	Hansteen α	1.819	—0.3996	—0.6516	—58.5	0.7644
8	Pytheas	1.863	—0.5380	—0.5463	—45.4	0.7668
9	Pico	1.926	—0.5976	—0.4681	—38.1	0.7591
10	Darney *C*	2.003	—0.3737	—0.6646	—60.6	0.7625
11	Darney	2.038	—0.3630	—0.6652	—61.4	0.7578

No.	*Formation*	*E.T.*	*x*	*y*	*ψ (W)*	*r*
12	Agatarchides *A*	2.073^{h}	—0.3163	—0.6908	—65.4°	0.7597
13	Bullialdus *β*	2.091	—0.3309	—0.6861	—64.3	0.7618
14	Eudoxus *A*	2.098	—0.5893	—0.4776	—39.0	0.7586
15	Mösting *A*	2.109	—0.4171	—0.6354	—56.7	0.7600
16	Chladni	2.124	—0.4494	—0.6130	—53.8	0.7600
17	Manilius *E*	2.136	—0.4955	—0.5798	—49.5	0.7627
18	Alpetragius *B*	2.183	—0.3488	—0.6730	—62.6	0.7580
19	Possidonius *A*	2.219	—0.5458	—0.5257	—43.9	0.7578
20	E. Pickering	2.224	—0.4067	—0.6383	—57.5	0.7569
21	Birt	2.231	—0.3039	—0.6935	—66.3	0.7572
22	Plinius *β*	2.251	—0.4916	—0.5828	—49.9	0.7625
23	Dionysius	2.278	—0.4316	—0.6238	—55.3	0.7585
24	Janssen *B*	2.306	—0.4667	—0.6001	—52.1	0.7602
25	Macrobius *B*	2.353	—0.5023	—0.5676	—48.5	0.7579
26	Macrobius *A*	2.358	—0.4969	—0.5724	—49.0	0.7580
27	Moltke	2.361	—0.4073	—0.6374	—57.4	0.7564
28	Abulfeda *F*	2.366	—0.3281	—0.6842	—64.4	0.7588
29	Cauchy	2.399	—0.4572	—0.6088	—53.1	0.7614
30	Proclus	2.423	—0.4780	—0.5866	—50.8	0.7567
31	Censorinus	2.429	—0.4026	—0.6397	—57.8	0.7559
32	Tycho	2.436	—0.1571	—0.7391	—78.0	0.7556
33	Isidorius *D*	2.453	—0.3874	—0.6552	—59.4	0.7612
34	Picard	2.471	—0.4706	—0.5950	—51.7	0.7586
35	W.H.Pickering	2.529	—0.3925	—0.6515	—58.9	0.7606
36	Messier	2.533	—0.3930	—0.6514	—58.9	0.7608
37	Polybius *A*	2.549	—0.2685	—0.7070	—69.2	0.7562
38	Rosse	2.566	—0.2965	—0.6950	—66.9	0.7556
39	Bellot	2.608	—0.3295	—0.6847	—64.3	0.7599
40	Nicolay *A*	2.679	—0.1325	—0.7443	—79.9	0.7560
41	Biot *A*	2.681	—0.2642	—0.7111	—69.6	0.7586
42	Biot	2.701	—0.2576	—0.7122	—70.1	0.7573
43	Stevinus	2.759	—0.1998	—0.7354	—74.8	0.7621
44	Janssen *K*	2.814	—0.0958	—0.7528	—82.7	0.7589
Očenáš						
1	Grimaldi	1.704	—0.4348	—0.6225	—55.1	0.7593
2	Kepler	1.811	—0.4756	—0.5782	—50.6	0.7487
3	Copernicus	1.926	—0.4810	—0.5814	—50.4	0.7546
4	Plato	1.929	—0.6058	—0.4521	—36.7	0.7559
5	Archimedes	1.987	—0.5496	—0.5179	—43.3	0.7552

No.	*Formation*	*E.T.*	*x*	*y*	*ψ (W)*	*r*
6	Aristoteles	2.069^{h}	−0.5987	−0.4643	−37.8°	0.7576
7	Eudoxus	2.089	−0.5813	−0.4796	−39.5	0.7536
8	Delambre	2.272	−0.4262	−0.6444	−56.5	0.7725

Table 2

Partial lunar eclipse of July 6, 1963

No.	*Formation*	*E.T.*	*x*	*y*	*ψ*	*r*
Entrances into umbra						
1	Tycho	20.810^{h}	−0.6345	+0.4291	+34.1°W	0.7659
2	Grimaldi	20.845	−0.3947	+0.5884	+56.1 W	0.7085
3	Fracastorius	21.279	−0.5429	+0.5101	+43.2 W	0.7449
4	Copernicus	21.335	−0.3084	+0.6653	+65.1 W	0.7333
5	Goclenius	21.470	−0.5121	+0.5673	+47.9 W	0.7642
6	Censorinus	21.536	−0.4387	+0.6131	+54.4 W	0.7539
7	Langrenus	21.554	−0.5085	+0.5707	+48.3 W	0.7644
8	Manilius	21.668	−0.2691	+0.6855	+68.6 W	0.7364
9	Menelaus	21.733	−0.2648	+0.6928	+69.1 W	0.7417
10	Proclus	21.886	−0.2979	+0.6870	+66.6 W	0.7487
Exits from umbra						
1	Grimaldi	22.315	+0.3794	+0.6094	+58.1 E	0.7178
2	Copernicus	22.508	+0.3084	+0.6726	+65.6 E	0.7383
3	Manilius	22.711	+0.3583	+0.6919	+62.6 E	0.7792
4	Menelaus	22.753	+0.2671	+0.6913	+68.9 E	0.7411
5	Proclus	23.045	+0.3076	+0.6790	+65.6 E	0.7455
6	Tycho	23.090	+0.5830	+0.4293	+37.0 E	0.7299
7	Censorinus	23.175	+0.4226	+0.6054	+55.1 E	0.7383
8	Goclenius	23.365	+0.4892	+0.5552	+48.6 E	0.7399
9	Langrenus	23.445	+0.4919	+0.5550	+48.5 E	0.7416

Table 3

Total lunar eclipse of June 24–25, 1964

No.	*Formation*	*E.T.*	*x*	*y*	*ψ (W)*	*r*
Buchar						
1	Billy	23.303ʰ	—0.7140	—0.1009	— 8.0°	0.7211
2	Mersenius	23.335	—0.7047	—0.1380	—11.1	0.7181
3	Aristarchus	23.341	—0.7471	0.0635	4.9	0.7498
4	Kepler	23.350	—0.7472	—0.0104	— 0.8	0.7473
5	Fourier	23.376	—0.6793	—0.1737	—14.3	0.7011
6	Cap Heraclides	23.473	—0.7567	0.1113	8.4	0.7648
7	Campanus	23.506	—0.6933	—0.1944	—15.7	0.7201
8	Copernicus	23.510	—0.7389	—0.0263	— 2.0	0.7394
9	Mercator	23.536	—0.6880	—0.2060	—16.7	0.7182
10	Pitatus	23.631	—0.6880	—0.2168	—17.5	0.7214
11	Plato	23.678	—0.7360	0.1225	9.4	0.7461
12	Tycho	23.700	—0.6665	—0.2747	—22.4	0.7209
13	Manilius	23.784	—0.7334	—0.0328	— 2.6	0.7342
14	Eudoxus	23.821	—0.7373	0.0871	6.7	0.7424
15	Menelaus	23.835	—0.7379	—0.0285	— 2.2	0.7384
16	Arago	23.873	—0.7413	—0.0783	— 6.0	0.7455
17	Plinius	23.898	—0.7377	—0.0365	— 2.8	0.7386
18	Censorinus	23.998	—0.7240	—0.1137	— 8.9	0.7329
19	Proclus	0.078	—0.7307	—0.0402	— 3.1	0.7318
20	Goclenius	0.096	—0.7145	—0.1629	—12.8	0.7328
21	Langrenus	0.181	—0.7168	—0.1612	—12.7	0.7347
22	Condorcet	0.185	—0.7329	—0.0623	— 4.9	0.7355
Hlad						
1	Grimaldi *C*	23.230	—0.7263	—0.0356	— 2.8	0.7272
2	Damoiseau *E*	23.250	—0.7217	—0.0511	— 4.1	0.7235
3	Byrgius *A*	23.285	—0.6936	—0.1424	—11.6	0.7081
4	Hansteen α	23.311	—0.7097	—0.0943	— 7.6	0.7160
5	Marius *A*	23.323	—0.7402	0.0170	1.3	0.7404
6	Aristarchus	23.350	—0.7427	0.0629	4.8	0.7453
7	Mersenius *C*	23.363	—0.6975	—0.1362	—11.0	0.7107
8	Gassendi α	23.378	—0.6972	—0.1326	—10.8	0.7097
9	Encke *B*	23.390	—0.7245	—0.0408	— 3.2	0.7257
10	Bessarion	23.405	—0.7306	0.0151	1.2	0.7308
11	Brayley	23.408	—0.7406	0.0406	3.1	0.7417
12	Euklides	23.456	—0.7124	—0.0962	— 7.7	0.7189
13	Vitello ξ	23.466	—0.6805	—0.1964	—16.1	0.7083

No.	*Formation*	*E.T.*	*x*	*y*	ψ (*W*)	*r*
14	Darney *C*	23.490$^{\mathrm{h}}$	—0.7077	—0.1323	—10.6°	0.7199
15	Agatharchides *A*	23.503	—0.6913	—0.1733	—14,1	0.7127
16	Darney	23.508	—0.7088	—0.1373	—11.0	0.7220
17	Pytheas	23.531	—0.7377	0.0213	1.7	0.7380
18	Gambart *A*	23.535	—0.7245	—0.0693	— 5.5	0.7287
19	Kies *A*	23.560	—0.6869	—0.2022	—16.4	0.7160
20	Parry *A*	23.576	—0.7099	—0.1227	— 9.8	0.7205
21	Condamine *A*	23.586	—0.7352	0.1417	10.9	0.7487
22	Maupertuis *A*	23.588	—0.7403	0.1296	9.9	0.7516
23	Guericke *C*	23.610	—0.7124	—0.1367	—10.9	0.7254
24	Lassell *D*	23.636	—0.7032	—0.1526	—12.2	0.7196
25	Mösting *A*	23.660	—0.7215	—0.1038	— 8.2	0.7289
26	Birt	23.666	—0.6942	—0.1902	—15.3	0.7198
27	Pico	23.671	—0.7353	0.1051	8.1	0.7428
28	E. Pickering	23.780	—0.7191	—0.1131	— 8.9	0.7280
29	Manilius *ε*	23.796	—0.7270	—0.0331	— 2.6	0.7278
30	Menelaus	23.848	—0.7310	—0.0287	— 2.3	0.7316
31	Eudoxus *A*	23.858	—0.7277	0.0903	7.1	0.7333
32	Dionysius	23.873	—0.7223	—0.0930	— 7.3	0.7283
33	Plinius *β*	23.913	—0.7299	—0.0367	— 2.9	0.7308
34	Dawes	23.930	—0.7321	—0.0290	— 2.3	0.7326
35	Possidonius *A*	23.943	—0.7273	0.0333	— 2.6	0.7281
36	Nicolai *A*	23.960	—0.6653	—0.2913	—23.6	0.7263
37	Hercules *C*	23.966	—0.7218	0.0870	6.9	0.7271
38	Polybius *A*	23.983	—0.6965	—0.2167	—17.3	0.7294
39	Maury	23.986	—0.7297	0.0529	4.1	0.7316
40	Censorinus	0.011	—0.7173	—0.1139	— 9.0	0.7263
41	Rosse	0.036	—0.7022	—0.1962	—15.6	0.7291
42	Macrobius *A*	0.045	—0.7235	—0.0226	— 1.8	0.7239
43	Tralles *A*	0.058	—0.7286	0.0110	0.9	0.7287
44	Proclus	0.088	—0.7256	—0.0404	— 3.2	0.7267
45	W.H.Pickering	0.105	—0.7212	—0.1259	— 9.9	0.7321
46	Messier	0.105	—0.7235	—0.1255	— 9.8	0.7343
47	Bellot	0.120	—0.7111	—0.1753	—13.9	0.7324
48	Picard	0.131	—0.7264	—0.0493	— 3.9	0.7281
49	Stevinus *A*	0.140	—0.6806	—0.2599	—20.9	0.7286
50	Furnerius *A*	0.170	—0.6784	—0.2683	—21.6	0.7295
51	Firmicus	0.188	—0.7226	—0.0852	— 6.7	0.7276
52	Langrenus *M*	0.215	—0.7108	—0.1664	—13.2	0.7300

No.	*Formation*	*E.T.*	x	y	ψ (*W*)	r
Mrzilek						
1	Hansteen α	23.303^h	—0.7139	—0.0936	— 7.5°	0.7200
2	Aristarchus	23.353	—0.7409	0.0626	4.8	0.7435
3	Pytheas	23.518	—0.7447	0.0220	1.7	0.7450
4	Bullialdus *β*	23.536	—0.6995	—0.1679	—13.5	0.7193
5	Pico	23.673	—0.7344	0.1051	8.1	0.7419
6	Tycho	23.713	—0.6604	—0.2753	—22.6	0.7155
7	Menelaus	23.851	—0.7293	—0.0288	— 2.3	0.7298
8	Dionysius	23.865	—0.7265	—0.0928	— 7.3	0.7324
9	Censorinus	0.001	—0.7223	—0.1138	— 9.0	0.7312
10	Proclus	0.091	—0.7239	—0.0405	— 3.2	0.7250
11	Stevinus *A*	0.135	—0.6831	—0.2598	—20.8	0.7308
12	Furnerius *A*	0.155	—0.6857	—0.2679	—21.3	0.7362
Příhoda						
1	Grimaldi *C*	23.223	—0.7297	—0.0350	— 2.7	0.7305
2	Hansteen α	23.298	—0.7164	—0.0931	— 7.4	0.7224
3	Marius *A*	23.315	—0.7446	0.0176	1.4	0.7448
4	Aristarchus	23.343	—0.7462	0.0634	4.9	0.7489
5	Mersenius *C*	23.355	—0.7016	—0.1355	—10.9	0.7145
6	Gassendi α	23.371	—0.7005	—0.1321	—10.7	0.7128
7	Encke *B*	23.380	—0.7296	—0.0400	— 3.1	0.7307
8	Brayley	23.403	—0.7433	0.0409	3.2	0.7444
9	Milichius	23.430	—0.7381	—0.0129	— 1.0	0.7382
10	Euclides	23.446	—0.7174	—0.0956	— 7.6	0.7237
11	Vitello *ξ*	23.461	—0.6829	—0.1960	—16.0	0.7105
12	Darney *C*	23.475	—0.7151	—0.1313	—10.4	0.7270
13	Darney	23.508	—0.7088	—0.1373	—11.0	0.7220
14	Pytheas	23.521	—0.7429	0.0218	1.7	0.7432
15	Gambart *A*	23.531	—0.7262	—0.0692	— 5.4	0.7295
16	Bullialdus *β*	23.540	—0.6978	—0.1681	—13.5	0.7178
17	Condamine *A*	23.593	—0.7315	0.1413	10.9	0.7451
18	Guericke *C*	23.610	—0.7124	—0.1367	—10,9	0.7254
19	Lassell *D*	23.625	—0.7089	—0.1520	—12.1	0.7250
20	Mösting *A*	23.653	—0.7248	—0.1035	— 8.1	0.7322
21	Birt	23.663	—0.6958	—0.1900	—15.3	0.7213
22	Pico	23.668	—0.7371	0.1053	8.1	0.7446
23	Bode	23.686	—0.7267	—0.0598	— 4.7	0.7291
24	Chladni	23.713	—0.7284	—0.0756	— 5.9	0.7323
25	Tycho	23.726	—0.6542	—0.2760	—22.9	0.7100

No.	*Formation*	*E.T.*	*x*	*y*	*ψ (W)*	*r*
26	Maginus *H*	23.758^{h}	—0.6458	—0.3073	—25.4°	0.7152
27	E. Pickering	23.763	—0.7274	—0.1126	— 8.8	0.7361
28	Werner *D*	23.781	—0.6878	—0.2211	—17.8	0.7225
29	Manilius *ε*	23.790	—0.7304	—0.0329	— 2.6	0.7312
30	Hipparchus *C*	23.798	—0.7134	—0.1355	—10.8	0.7262
31	Menelaus	23.846	—0.7319	—0.0287	— 2.2	0.7324
32	Eudoxus *A*	23.860	—0.7268	—0.0903	7.1	0.7324
33	Dionysius	23.870	—0.7240	—0.0929	— 7.3	0.7299
34	Plinius *β*	23.911	—0.7308	—0.0367	— 2,9	0.7317
35	Dawes	23.928	—0.7329	—0.0289	— 2.3	0.7335
36	Possidonius *A*	23.938	—0.7300	0.0334	2.6	0.7308
37	Hercules *C*	23.971	—0.7191	0.0869	6.9	0.7244
38	Polybius *A*	23.985	—0.6957	—0.2167	—17.3	0.7287
39	Censorinus	0.005	—0.7207	—0.1138	— 9.0	0.7296
40	Rosse	0.030	—0.7055	—0.1961	—15.5	0.7322
41	Macrobius *A*	0.045	—0.7235	—0.0226	— 1.8	0.7239
42	Tralles *A*	0.060	—0.7277	0.0109	0.9	0.7278
43	Janssen *K*	0.083	—0.6516	—0.3089	—25.4	0.7211
44	Proclus	0.093	—0.7230	—0.0405	— 3.2	0.7242
45	Furnerius *A*	0.165	—0.6808	—0.2681	—21.5	0.7317
46	Firmicus	0.183	—0.7251	—0.0851	— 6.7	0.7301
47	Langrenus *M*	0.216	—0.7099	—0.1665	—13.2	0.7292
Rükl						
1	Grimaldi *C*	23.231	—0.7254	—0.0357	— 2.8	0.7263
2	Damoiseau *E*	23.246	—0.7234	—0.0508	— 4.0	0.7251
3	Byrgius *A*	23.295	—0.6887	—0.1433	—11.8	0.7035
4	Hansteen *α*	23.310	—0.7106	—0.0941	— 7.5	0.7168
5	Marius *A*	23.328	—0.7376	0.0166	1.3	0.7378
6	Aristarchus	23.346	—0.7444	0.0631	4.8	0.7471
7	Mersenius *C*	23.363	—0.6975	—0.1362	—11.0	0.7107
8	Gasendi *α*	23.370	—0.7013	—0.1320	—10.7	0.7136
9	Encke *B*	23.381	—0.7288	—0.0402	— 3.2	0.7299
10	Besarion	23.391	—0.7376	0.0160	1.2	0.7378
11	Brayley	23.405	—0.7424	0.0408	3.1	0.7435
12	Milichius *A*	23.428	—0.7308	—0.0149	— 1.2	0.7310
13	Milichius	23.438	—0.7338	—0.0135	— 1.1	0.7339
14	Euclides	23.453	—0.7141	—0.0960	— 7.7	0.7205
15	Vitello *ξ*	23.468	—0.6797	—0.1965	—16.1	0.7075
16	Darney *C*	23.490	—0.7077	—0.1323	—10.6	0.7199

No.	*Formation*	*E.T.*	*x*	*y*	*ψ (W)*	*r*
17	Agatarchides *A*	23.496^h	—0.6945	—0.1728	—14.0°	0.7157
18	Darney	23.513	—0.7064	—0.1376	—11.0	0.7197
19	Pytheas	23.525	—0.7412	0.0216	1.7	0.7415
20	Gambart *A*	23.525	—0.7296	—0.0688	— 5.4	0.7328
21	Bullialdus *β*	23.540	—0.6978	—0.1681	—13.5	0.7178
22	Kiess *A*	23.563	—0.6853	—0.2024	—16.5	0.7146
23	Parry *A*	23.571	—0.7124	—0.1225	— 9.8	0.7228
24	Condamine *A*	23.590	—0.7334	0.1415	10.9	0.7469
25	Maupertius *A*	23.591	—0.7385	0.1294	9.9	0.7497
26	Guericke *C*	23.611	—0.7116	—0.1368	—10.9	0.7246
27	Lassell *D*	23.625	—0.7089	—0.1520	—12.1	0.7250
28	Mösting *A*	23.661	—0.7207	—0.1039	— 8.2	0.7281
29	Birt	23.661	—0.6966	—0.1899	—15.3	0.7221
30	Pico	23.675	—0.7335	0.1050	8.1	0.7410
31	Bode	23.690	—0.7250	—0.0599	— 4.7	0.7274
32	Bode *A*	23.695	—0.7297	—0.0502	— 3.9	0.7314
33	Chladni	23.716	—0.7267	—0.0757	— 5.9	0.7307
34	Tycho	23.723	—0.6557	—0.2758	—22.8	0.7114
35	E. Pickering	23.780	—0.7191	—0.1131	— 8.9	0.7280
36	Werner *D*	23.785	—0.6862	—0.2212	—17.9	0.7210
37	Manilius *ε*	23.791	—0.7296	—0.0330	— 2.6	0.7303
38	Hipparchus *C*	23.796	—0.7142	—0.1355	—10.7	0.7270
39	Egede *A*	23.798	—0.7278	0.1126	8.8	0.7364
40	Menelaus	23.851	—0.7293	—0.0288	— 2.3	0.7298
41	Eudoxus *A*	23.856	—0.7286	0.0904	7.1	0.7342
42	Dionysius	23.870	—0.7240	—0.0929	— 7.3	0.7299
43	Plinius *β*	23.911	—0.7308	—0.0367	— 2.9	0.7317
44	Daves	23.933	—0.7303	—0.0290	— 2.3	0.7309
45	Possidonius *A*	23.943	—0.7273	0.0333	2.6	0.7281
46	Nicolai *A*	23.960	—0.6653	—0.2913	—23.6	0.7263
47	Polybius *A*	23.990	—0.6933	—0.2168	—17.4	0.7264
48	Censorinus	0.008	—0.7190	—0.1138	— 9.0	0.7279
49	Macrobius *A*	0.040	—0.7261	—0.0225	— 1.8	0.7264
50	Rosse	0.041	—0.6997	—0.1964	—15.7	0.7267
51	Tralles *A*	0.065	—0.7252	0.0108	0.9	0.7252
52	Proclus	0.085	—0.7273	—0.0403	— 3.2	0.7284
53	Bellot	0.131	—0.7053	—0.1756	—14.0	0.7268
54	Stevinus *A*	0.141	—0.6798	—0.2600	—20.9	0.7278
55	Furnerius *A*	0.166	—0.6800	—0.2682	—21.5	0.7310

No	Formation	E.T.	x	y	ψ (W)	r
56	Firmicus	0.198^h	—0.7175	—0.0854	— 6.8°	0.7226
57	Langrenus *M*	0.220	—0.7083	—0.1665	—13.2	0.7276
Mikešová						
1	Grimaldi	23.193	—0.7295	—0.0422	— 3.3	0.7307
2	Copernicus	23.526	—0.7304	—0.0272	— 2.1	0.7309
3	Plato	23.710	—0.7186	0.1213	9.6	0.7287
4	Langrenus	0.166	—0.7245	—0.1609	—12.5	0.7422
Šolcová						
1	Grimaldi	23.202	—0.7250	—0.0430	— 3.4	0.7263
2	Kepler	23.334	—0.7553	—0.0093	— 0.7	0.7553
3	Copernicus	23.510	—0.7386	—0.0263	— 2.0	0.7391
4	Pitatus	23.610	—0.6983	—0.2156	—17.2	0.7309
5	Plato	23.669	—0.7408	0.1228	9.4	0.7509
6	Tycho	23.685	—0.6735	—0.2739	—22.1	0.7271
7	Aristoteles	23.846	—0.7222	0.1055	8.3	0.7299
8	Theophilus	23.928	—0.7269	—0.1638	—12.7	0.7451
9	Langrenus	0.165	—0.7249	—0.1609	—12.5	0.7426
Vinš						
1	Grimaldi	23.199	—0.7265	—0.0427	— 3.4	0.7278
2	Kepler	23.353	—0.7453	—0.0107	— 0.8	0.7453
3	Copernicus	23.523	—0.7319	—0.0271	— 2,1	0.7324
4	Plato	23.691	—0.7286	0.1220	9.5	0.7388
5	Cyrillus	23.968	—0.6903	—0.1775	—14.4	0.7128