Bull. Astron. Belgrade № 155 (1997), 117 – 125

UDC 523.9:520.86:5211.8
Preliminary report

ASTROMETRIC ASPECT OF 1980 INDIAN TOTAL SOLAR ECLIPSE

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(Received: February 17, 1997)

SUMMARY: During the Total Solar Eclipse of February 16, 1980, observable from India, besides many kinds of research programs, the sequence of eclipse phases was taken photographically for the astrometric purposes. All relevant parameters of this eclipse are derived, including $\Delta T, T_{max}, \Delta R_S$ etc.

1. INTRODUCTION

During their stay in India at the time of the Total Solar Eclipse - February 16, 1980 - the members of an expedition from Belgrade Astronomical Observatory (BAO), J. Arsenijević and I. Vince, photographed among others, following the proposal of the first author, the run of the phases of this interesting phenomenon. The team led by A. Kubičela, also a member of the BAO expedition, was located in the centrality-line region, near Jawalagera, Karnataka District, at the following geographic coordinates

$$\lambda = -5^h 7^m 31^s.5$$

$$\phi = +15°50'57" ,$$

where the altitude above the sea level is $h = 400$ m.

2. OBSERVATIONS

For the purpose of photographing (Kubicela, 1981) an adapted Askania finder refractor from the Small Refractor of BAO was used. The aperture of its objective is 60 mm, the focal length is 85 cm. There were attached a Barlow lens (yielding 1.62 magnification of the solar image), an O 2.8 filter (orange) and a Zenit ES camera on the tape of an FOTOKEMIKA N Mikrofilm. A total of 65 photographs was taken, out of which 6 out of (2 before and 4 after) eclipse. The atmospheric conditions were very good: a cloudless sky without cirri, but hot with a shade temperature of $+36°$ C.

Unfortunately, shortly after the beginning of the photographing the team had problems with the quartz clock put at its disposal by the National Organising Committee of India. Probably due to the too high temperature the clock rate became irregular. For this reason the mode of time registering was changed so that time was measured according to the quartz watch of one of the expedition members (JA). This watch was compared with the IST signals (India Standard Time) emitted by the Indian National Physical Laboratory. It is important to notice that over several days it preserved an unchanged state of -8^s. Nevertheless, for the time data, in view of the applied mode of observing ("eye - ear"), one could not account for any accuracy exceeding 1-2 seconds.

Table 1. Prediction of the Solar eclipse of 1980 February 16 for central line

Ephemeris Time		Latitude		Ephemeris Longitude		Duration		Width of Path	Altitude of Sun
h	m	°	'	°	'	m	s	miles	°
10	00	11	47.0	-63	33.0	3	10.0	84	48
10	05	13	02.4	-70	55.7	3	01.3	82	44
10	10	14	23.3	-73	35.1	2	51.9	80	40
10	15	15	51.3	-76	37.3	2	41.6	78	36
10	20	17	28.8	-80	12.7	2	30.2	75	31
10	25	19	20.7	-84	41.3	2	17.2	72	25
10	30	21	39.0	-90	54.6	2	01.3	68	18

Clearly, this circumstance obliged us to change the concept of our task formulated originally and to use the available observational data only for the purpose of classical-parameters deriving and determining of the times of the main eclipse phases, such as the first and the last contact between the solar and lunar discs, as well as concerning the maximum and the size of the given phase at that instant.

Since the plan of our expedition envisaged astrophysical observations during the totality, the photographing performed at our request were interrupted about 15^m before and after the maximum-phase instant (from 10^{01} - $10^{31} UT$). In this way we got two independent series of photographs containing 35, and 26 items respectivelly.

Based on the experience with Transits of Mercury across the Solar disk we decided to preserve in this paper such a division and to present the obtained results, as well as the conclusions reached by their analysing and comparing with predicted, theoretical, values.

3. OBSERVATIONAL RESULTS. REDUCTION AND INTERPRETATION

The negatives were measured on the Zeiss photometer with an accuracy of ± 0.001 *mm* following the procedure applied at our Observatory in the case of an earlier eclipse (Protić, 1968). The film tape placed between two glass plates, one of them having a device enabling its easy manipulating, is brought by rotating the plate carrier on the photometer into such position that the intersection points for the solar and lunar discs are along one of the wires (in Fig. 1 points m1 and m2 along the thread denoted as $y - y$). By determining the distance between the horns ($m1$ and $m2$) are determined, by fixing the photometer at the position corresponding to the reading $(y1+y2)/2$. Then the width of the solar uneclipsed disc d is measured and by setting on the limbs also its diameter $2R$. Provided negatives are offering a sufficient contrast, these measurements are easily performed with high precision.

The results of our measurements, each one being based on two settings, are presented in Table 1; Fig. 2 contains the corresponding plot - a time function where $\sigma = 10(\sigma/2R)$.

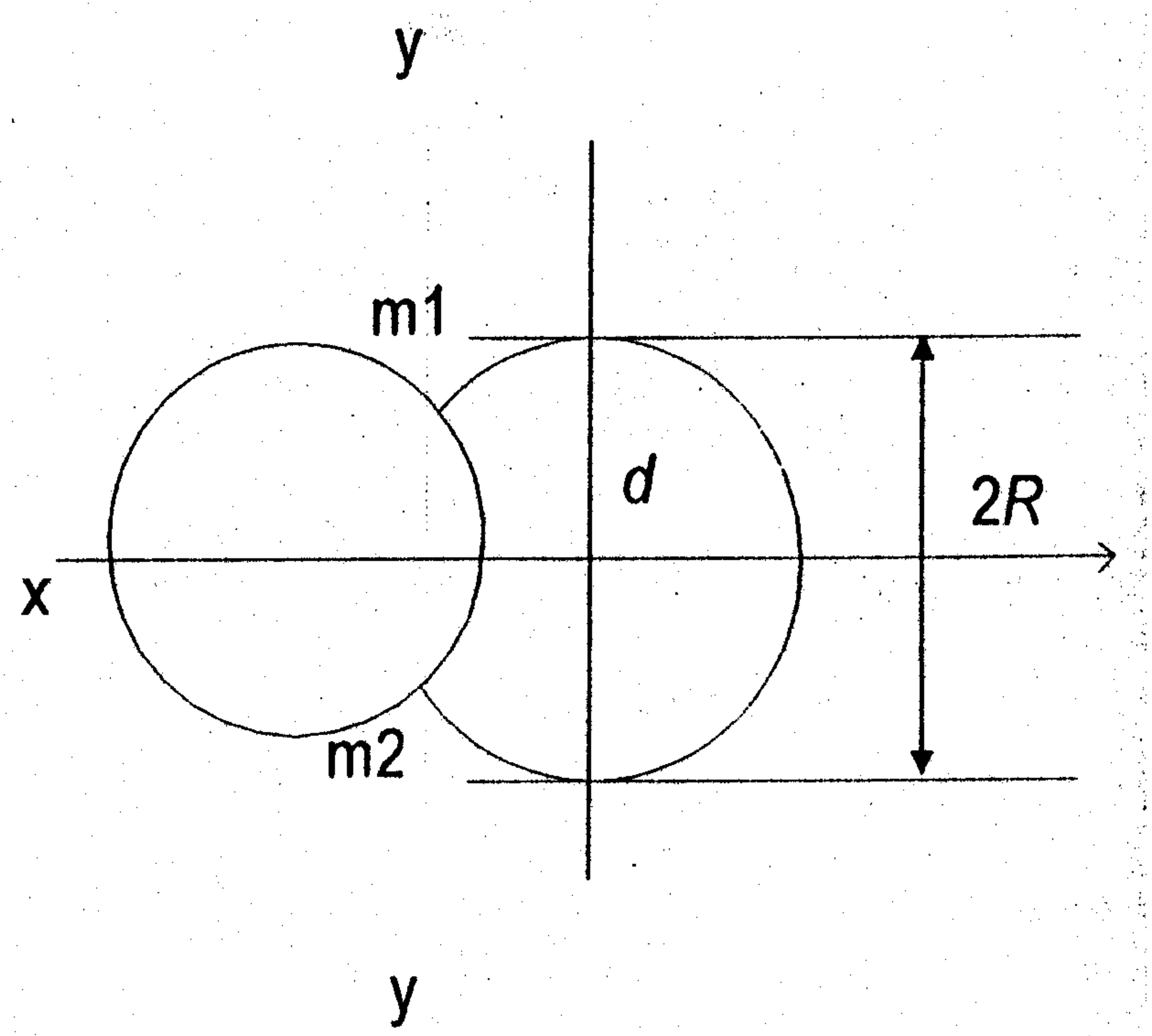

Fig. 1. Practical measurement scheme of the partial eclipse.

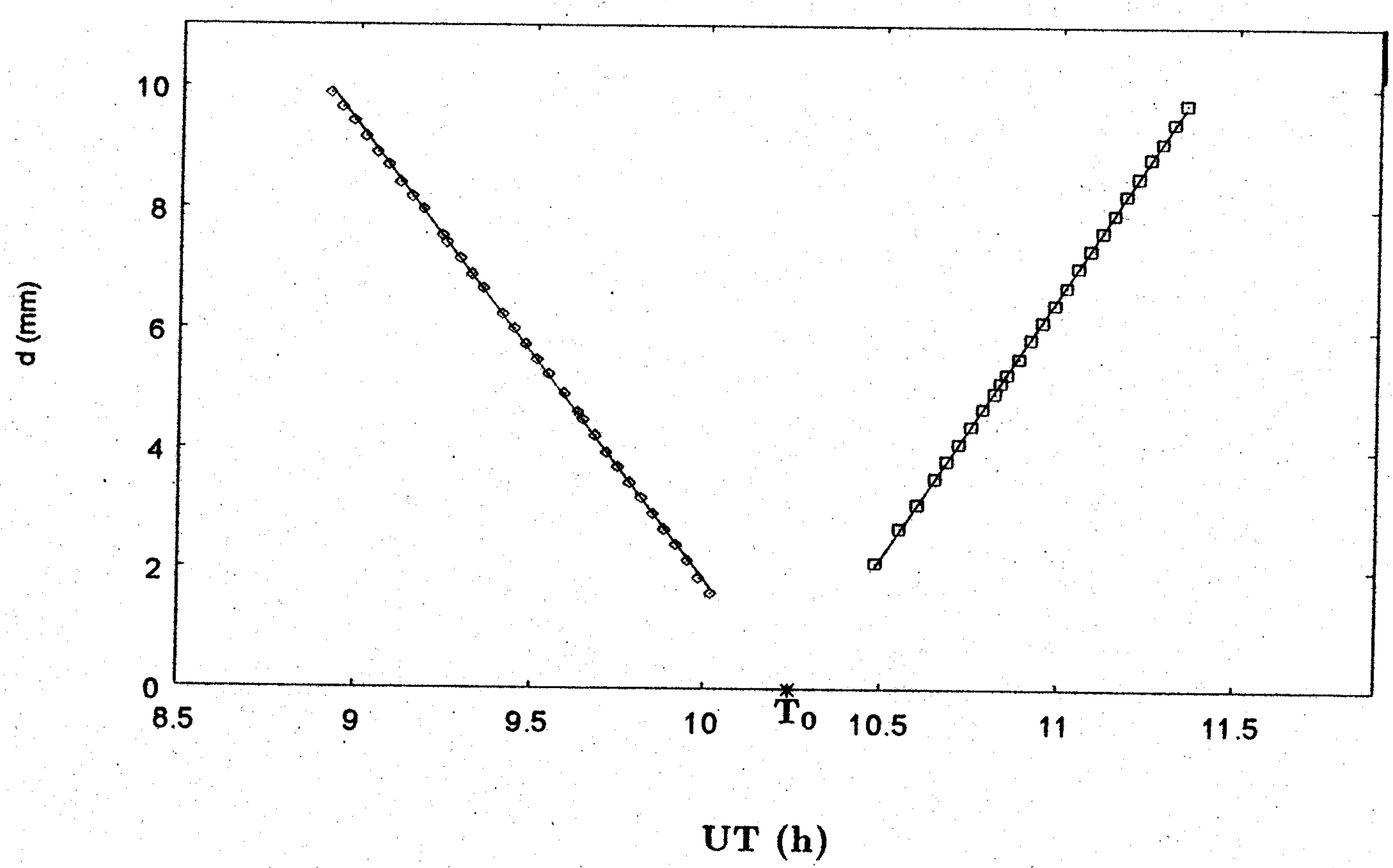

Fig. 2. Eclipse phase variation in time.

Obviously $\bar{\sigma} = f(t)$ is a uniform, but asymmetric, function with an extremum at the instant of the conjunction between the Moon and the Sun (maximum eclipse phase) and it can be very satisfactorily approximated by the following relation

$$\bar{\sigma}_i = A_0 + A_1 \Delta t_i + A_1^2 \Delta t_i^2 + A_1^3 \Delta t_i^3 \qquad (1)$$

(variant I)
where for the sake of brevity

$$\Delta t_i = t_i - t_0$$

or by an inverse one given by M. Protić (1961) which has a simplified form

$$A_{t_i} = B_0 + B_1 \bar{\sigma} + B_2 \bar{\sigma}^2 + B_3 \bar{\sigma}^3 \qquad (2)$$

(variant II)
with t_o is denoted the initial instant chosen arbitrarily.

Bearing in mind the experience concerning an earlier paper (Protić-Benišek, 1984) in the analysing of these results, as already mentioned, each group is treated separately. Though both variants are applied, the second one is preferable as more suitable because it yields explicitely the time data which we want to determine, whereas the purpose of variant I is rather the verification of the results.

Thus, in view of the results from Table 1 and choosing as initial instants:

$$t_{01} = 9^h 27^m 56^s.0 \ UT$$

i.e.

$$t_{02} = 10^h 56^m 52^s.0 \ UT$$

corresponding to the mean times of the observed interval for each group, we determine by using the least-square method the most probable values of the parameters B_k (k=0,1,2,3), namely:

	Group I	Group II
B_0	+44.4615	−40.8961
B_1	−7.14905	+7.12305
B_2	−0.08878	−0.01733
B_3	+0.001995	−0.000754

It is found for the correlation factors within Group I 0.99998 and 0.99997 within Group II. This fact alone proves that the application of (2) is completely justified. Besides, the standard errors also indicate that the estimate concerning the accuracy of registered times is realistic.

If, as usually, the instants of the first and last contacts between the solar and lunar discs are denoted T_1 and T_4 corresponding to the condition $\bar{\sigma} = 10.0$, relation (2) yields after substituting the corresponding values for B_k

$$(T_1 - t_{01}) = -33^m.9128 = -33^m 54^s.77$$

$$(T_4 - t_{02}) = +27^m.8475 = +27^m 50^s.85$$

hence

$$(T_1)_o = 8^h 54^m 01^s.23 \pm 0.55 \ UT$$

$$(T_4)_o = 11^h 14^m 42^s.85 \pm 0.68 \ UT.$$

Table 2. Observational and measured data for the I group of photos

No. of photos	UT			t-t_m	d	2R
	h	m	s	m	mm	mm
				t_m: $9^h\ 27^m\ 56^s$		
1	8	51	00	-	-	13.012
2	8	52	00	-	-	12.985
3	8	55	00	-32.933	9.8788	12.992
4	8	57	00	-30.933	9.6555	12.989
5	8	59	00	-28.933	9.4085	12.993
6	9	01	00	-26.933	9.1532	12.996
7	9	03	00	-24.933	8.8989	13.010
8	9	05	00	-22.933	8.6757	13.007
9*	9	07	16	-20.667	8.3962	13.038
10*	9	09	08	-18.800	8.1708	13.014
11*	9	10	55	-17.017	7.9544	12.962
12*	9	14	25	-13.517	7.5248	13.007
13*	9	15	16	-12.667	7.4200	13.000
14*	9	17	25	-10.517	7.1582	13.000
15*	9	19	31	- 8.417	6.8994	13.007
16*	9	21	25	- 6.517	6.6649	13.006
17	9	24	52	- 3.067	6.2380	12.993
18	9	26	52	- 1.067	5.9898	13.007
19	9	28	52	0.933	5.7290	12.984
20	9	30	51	2.917	5.4792	12.991
21	9	32	52	4.933	5.2360	12.988
22	9	35	22	7.433	4.9159	13.016
23	9	37	52	9.933	4.5995	12.952
24	9	38	52	10.933	4.4699	12.969
25	9	40	52	12.933	4.2100	12.984
26	9	42	52	14.933	3.9459	13.004
27	9	44	52	16.933	3.6929	12.960
28	9	46	52	18.933	3.4277	13.000
29	9	48	52	20.933	3.1762	12.994
30	9	50	52	22.933	2.9041	12.988
31	9	52	52	24.933	2.6464	12.988
32	9	54	52	26.933	2.3924	12.985
33	9	56	52	28.933	2.1275	12.992
34	9	58	52	30.933	1.8483	12.976
35	10	00	52	32.933	1.5836	12.970

Note:

In the case of photographs No 9-16 for which the registered times were unreliable (the clock went out of order as related) a correction is applied based on the curve derived after "five points third degree" by smoothing in five points.

Because of one (or a group of) unsuccessful photograph there is a confusion concerning the identification of photographs No 36-40 on the film tape and consequently in the registered times. The correspondence is established on the basis of the measurements after which they are incorporated in the general run of the curve $\bar{\sigma} = f(t)$.

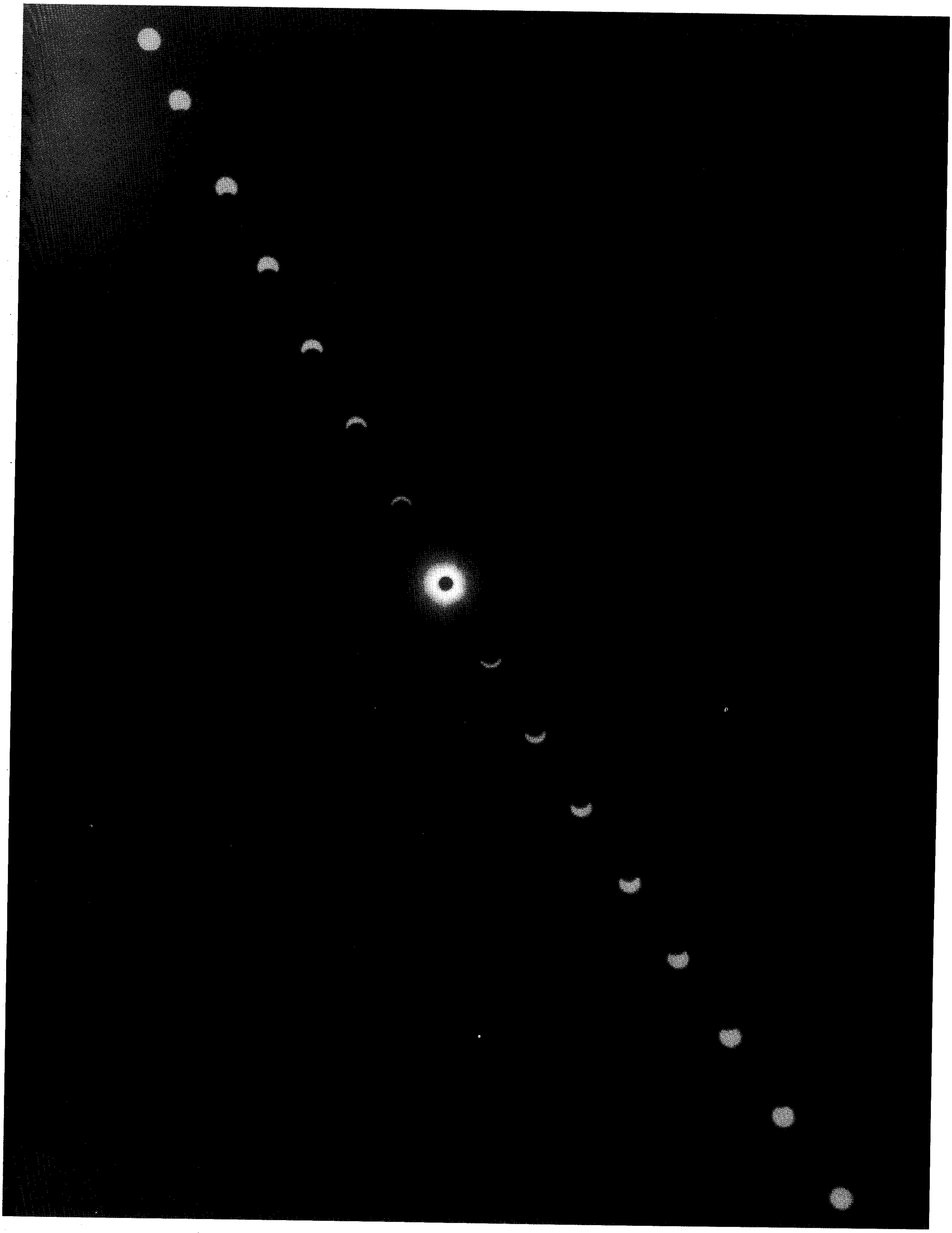

Fig. 3. The progress of the solar eclipse of February 16, 1980. Exposures made every 10 minutes with an ordinary 6x9 cm film camera of Mr. Harrinder Sing. Note the steep afternoon descent of the Sun corresponding to the Jawalagere's low latitude ($\Phi = 12^{\circ}$).

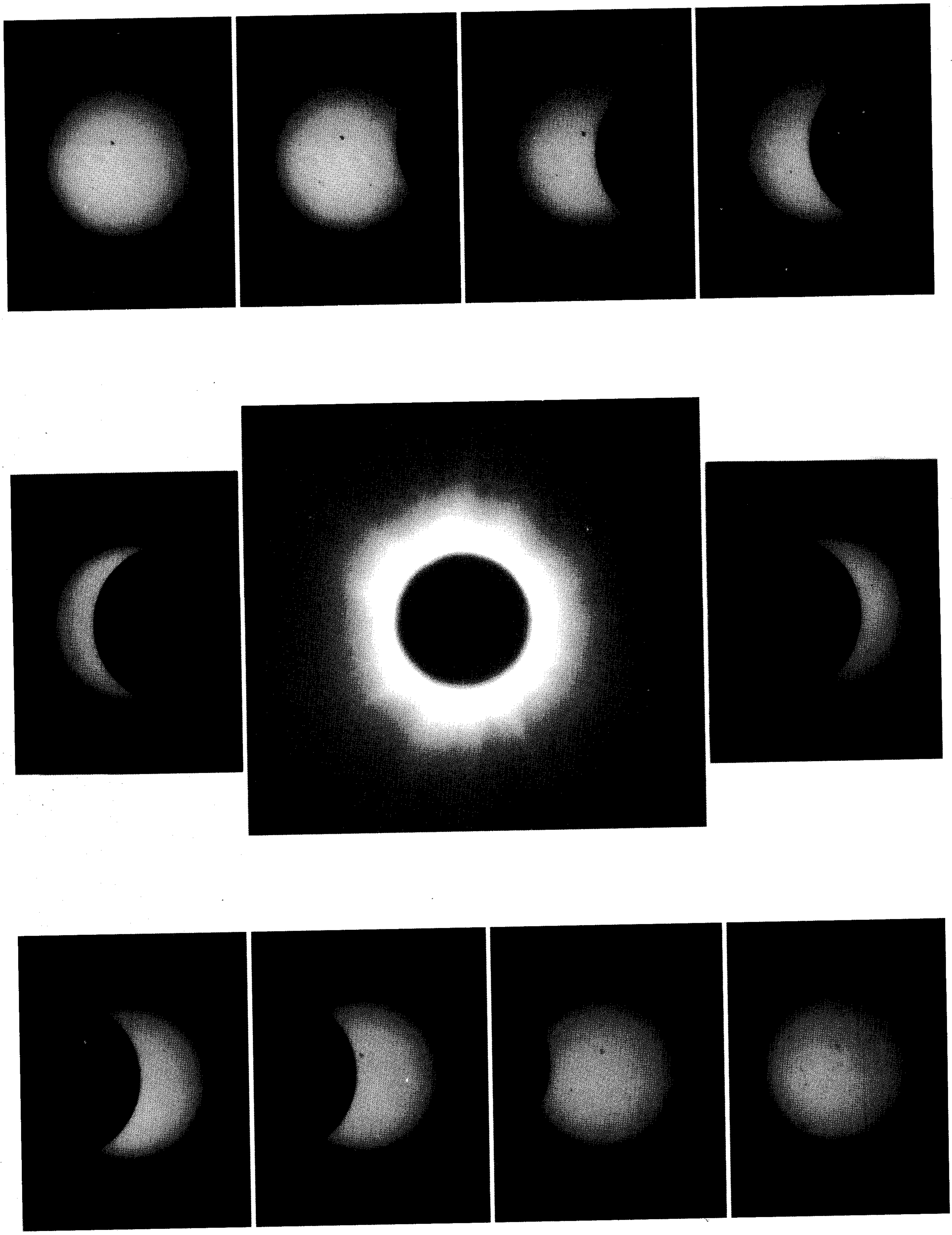

Fig. 4. The partial phases photographed by J. Arsenijević and I. Vince, using a refractor D=60 mm, F=850 mm with a 1.65x Barlow lens, and the corona photographed by N. Uzelac, using a refractor D=66 mm, f=300 mm.

Table 3. Observational and measured data for the II group of photos

No. of photos	UT			t-t_m	d	2R
	h	m	s	m	mm	mm
				t_m: $9^h\ 27^m\ 56^s$		
36*	10	29	00	-26.000	2.0991	12.991
37*	10	33	00	-22.000	2.6713	12.990
38*	10	36	00	-19.000	3.0965	12.994
39*	10	39	00	-16.000	3.5376	12.989
40*	10	41	00	-14.000	3.8292	13.011
41	10	43	00	-12.000	4.1060	12.996
42	10	45	00	-10.000	4.4021	12.987
43	10	47	00	- 8.000	4.6811	12.990
44	10	49	00	- 6.000	4.9600	13.011
45	10	50	00	- 5.000	5.1197	12.991
46	10	51	00	- 4.000	5.2621	12.998
47	10	53	00	- 2.000	5.5419	12.992
48	10	55	00	0.000	5.8427	13.018
49	10	57	00	2.017	6.1286	13.000
50	10	59	00	4.000	6.4385	12.982
51	11	01	00	6.000	6.7177	13.018
52	11	03	00	8.000	7.0264	12.996
53	11	05	00	10.000	7.3291	12.988
54	11	07	00	12.000	7.6164	12.999
55	11	09	00	14.000	7.9028	13.032
56	11	11	00	16.000	8.2144	13.010
57	11	13	00	18.000	8.5145	13.020
58	11	15	00	20.000	8.8206	13.032
59	11	17	00	22.000	9.1018	13.020
60	11	19	00	24.000	9.4133	13.038
61	11	21	00	26.000	9.7167	13.036
62	11	23	00	-	-	13.012

On the other hand substituting $t_1 = T_{max}$ and equaling the two obtained relations solved for $\bar{\sigma}$ we easily find

$$\bar{\sigma}_{max} = -0.2505\bar{\sigma} + 0.0714\bar{\sigma}^2 - 0.0027\bar{\sigma}^3 \quad (2)$$

whence it follows

$$\bar{\sigma}_{max} = -0.2505$$

which after substituting in relations (2) yields the solutions for the instant od setting in of the phase maximum

$$T'_{max} = 10^h14^m10^s.69\ UT$$

$$T''_{max} = 10^h14^m11^s.22\ UT$$

or as a mean value

$$T_{max} = 10^h14^m10^s.96 \pm 0^s.62\ UT$$

where the mean between the errors determined for T_1 and T_4 is assumed as the root-mean-square error.

It is not difficult to conclude that the phase amount at that instant is given by the following expression

$$(10 - \bar{\sigma}_{max})/10 = 1.025.$$

By applying variant II and the least-square method for the found parameters A_i we obtain results almost completely coinciding with those given here (deviations less than $0^s.15$) as was expected.

If as the coordinates of the observing site are taken those of Jawalakhere and the theoretical times as derived, we find by means of the classical Besselian procedure after two approximations

$$T_1 = 8^h53^m56^s.64\ UT$$

$$T_2 = 10^h12^m50^s.97\ UT$$

$$T_0 = 10^h14^m13^s.38\ UT$$

$$T_3 = 10^h15^m35^s.78\ UT$$

$$T_4 = 10^h24^m28^s.80\ UT$$

where the correction $\Delta T = TE - UT$ is assumed to be equal to $+50.^s 60$.

The maximum phase calculated here is

$$M = 1.029.$$

Applying direct calculation (interpolation method, i.e. calculating the topocentric apparent relative positions of the Sun and the Moon, for applying the corrections $\Delta\alpha_m$: $+0^s 014$ and $\Delta\delta_m$: $-0'' 56$ given in AE1980, p.343) with an interval of 1^m around the predicted times for the first and last outer contacts, in two ways, i.e. without taking into account the irradiation and including its amount of $+1'' 54$, it is found:

without irradiation

$$T_{1C} = 8^h 53^m 57^s 06\ UT \quad T_{4C} = 11^h 24^m 28^s 73\ UT$$

with irradiation

$$T_{1C'} = 8^h 53^m 53^s 02\ UT \quad T_{4C'} = 11^h 24^m 31^s 86\ UT$$

The former values agree well with the times calculated classically. Therefore, they are addopted for the comparison with the observed ones so that we find:

	$(O-C)$
ΔT_1	$+\ 4^s 59$
ΔT_0	$-\ 2^s 42$
ΔT_4	$+14^s 05$
ΔT_m	$+5^s 42$

Taking into account the irradiation we obtain

ΔT_1	$+\ 8^s 23$
ΔT_4	$+10^s 99$
ΔT_m	$+9^s 61$

If we omit in the former case the deviation of $-2^s 42$ at the mean instant, it is obtained $(O-C)_m = +9^s 32$, a value different by about $0^s 3$ from the latter one.

Though, most likely, such significant $(O-C)$ should be partly attributed also to the unreliable coordinates of the observing site, it is beyond any doubt that the corrections of the theoretical lunar-solar positions are also concerned and indirectly also the values applied for ΔT. In favour of such a conclusion is also the fact that for the setting in of the first inner contact a retardation of about 3^s is estimated preceding by only $1^m 22^s 4$ the maximum-phase time; besides, the eclipse duration derived observationally is longer by about $9^s 5$ compared to the theoretical one. True, it should be noted that in the calculation the corrections for the lunar limb irregularity are not taken into account again.

Note that in the $(O-C)$ some properties similar to those observed also in the case of the Transits of Mercury are found.

4. CONCLUSION

Since this eclipse took place at the time when the Moon was at its descending node and relatively near the perigee, it would be of interest to examine the behaviour of the residuals if it had been at the apogee and also for the case of the ascending node, perigee or apogee (total and annular eclipses). On the basis of this material one might reach some conclusions concerning the secular and periodical variations in the longitudes of the node and perigee of lunar geocentric orbit. In addition, one might also explain oscillations found in some fundamental constants (nutation and precession, for instance). Therefore, the importance of any further photographic observations of the solar, and lunar eclipses is understandable.

Acknowledgements – After the long period elapsed since the eclipse observation in 1980 in India till the publishing of the present paper some personalities, who at that time contributed exceptionally to the success of our expedition, are no longer with us. Above all this relates to late Dr M. K. V. Bappu, whom we remember today as dearest individual.

A valuable aid was offered to us also by Prof. J. C. Bhattcharyya, Indian National Eclipse Coordinator.

Our sincere gratitude is addressed to the staff of the Indian Institute of Astrophysics, Bangalore, for the exceptional efforts made by them in preparing our camp and their help in solving encountered problems.

Last, but not least, we wish to express our gratitude to all Yugoslav institutions for their sponsoring our expedition.

This work is a part of the project "Astrometrical, Astrodynamical and Astrophysical investigations", supported by Ministry of Science and Technology of Serbia.

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АСТРОМЕТРИЈСКИ РЕЗУЛТАТИ ПОСМАТРАЊА ПОТПУНОГ СУНЧЕВОГ ПОМРАЧЕЊА У ИНДИЈИ 1980. ГОДИНЕ

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УДК 523.9:520.86:5211.8
Претходно саопштење

16. фебруара 1980. године чланови експедиције Астрономске опсерваторије у Београду снимили су ток фаза помрачења Сунца, боравећи у Индији недалеко од места Jawalagera, Карнатака.

У току двочасовног интервала посматрања реализовано је 66 снимака, од којих су 62 била обрађена.

Посматрања су реализова дурбином Askania 6.0/85 cm, коме је додато Barlow сочиво (увећање слике Сунца 1.62 пута). Коришћен је филтер О 2.8 и камера Zenit ES са филмом Фотокемика Микрофилм N ортохроматске емулзије.

Астрометријски параметри овог помрачења: ΔT, T_{max}, ΔR_s итд. изведени су са задовољавајућом тачности.