OCCULTATION OF THE MARS BY THE MOON ON 3 JANUARY 1967

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Abstract

Reappearance of an occultation of the Mars by the moon on 3rd January 1967 was observed at the Sirahama and Kurasiki Hydrographic Observatories by equipments for routine observation of ordinary occultations.

Photoelectric device at Sirahama is calibrated against the UBV-system by observation of some field stars and Hyades members. The record of the Mars' occultation is then converted into the luminosity ratio on B-magnitude.

For prediction of occultation, the inclination of the moon's limb to its mean level and the phase of the Mars are taken into account. Brightness of the Mars is assumed to be uniform all over its illuminated part of the disk. Several light curves of the Mars are thus drawn and are compared with the observation record.

(O-C) in time of the reappearance of the centre of the Mars' disk is $+0^{s}.6 \pm 0^{s}.3$ for Sirahama, if the Astronomical Ephemeris is used without any amendment.

1. Introduction

At its three branch observatories in Sirahama, Simosato and Kurasiki, the Hydrographic Office carries out the observations of occultations of stars by the moon as routine in order to determine the values of $\Delta T = \mathrm{ET} - \mathrm{UT}$. The results are reported on the Data Report of the Hydrographic Observations, Series of Astronomy and Geodesy, annually.

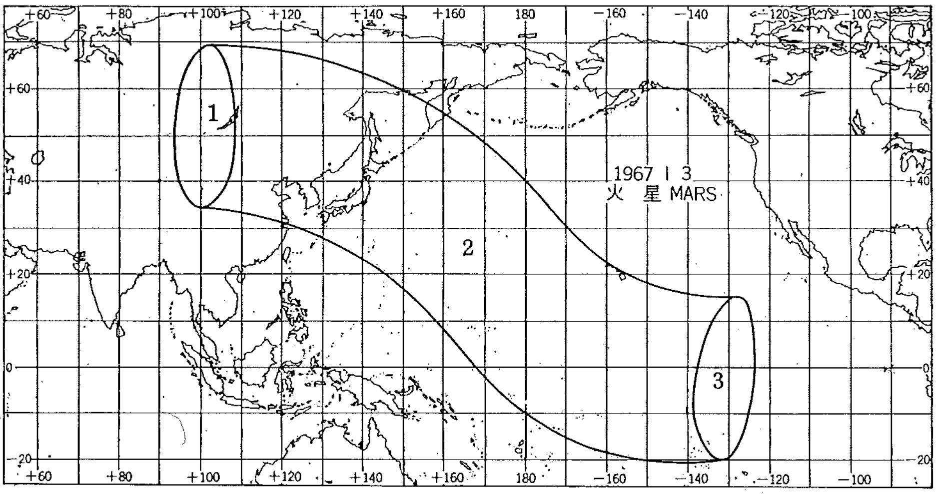

Fig. 1. Occultation of the Mars on 3rd Jan. 1967.

On 3rd January, 1967 the reappearance of an occultation of the Mars by the moon (Fig. 1) was observed at Sirahama and Kurasiki. In these observations the photoelectric devices for routine observations of occultation were directly employed without any photometric attachment.

Present report treats mainly the data obtained at the Sirahama Observatory.

2. Prediction

(1) Primary prediction

Ephemerides of the moon and the Mars are taken from the Astronomical Ephemeris for 1967 both for their positions and physical observations. A correction of $-0''.6$ is applied to the tabular latitude of the moon in order to allow the difference in position between the centres of figure and mass. Effect of the light time to the tabular distance of the Mars is taken into account. Geocentric conjunction in right ascension occurs at January $3^d\ 18^h\ 58^m\ 01^s.1$ ET0, the Mars being situated $26'.7$ south of the moon's centre.

Adams and Scott (1968) give the result of meridian observations of the Mars at the U.S. Naval Observatory for February to June, 1967. Its (O-C)'s in right ascension show some regularity, while those in declination are quite at random around $0''.00$. Extrapolation suggests that the (O-C) in right ascension takes a value between $+0^s.10$ and $+0^s.15$ for the date of the Mars' occultation. Then, a prediction with correction of $+0^s.1$ in right ascension of the Mars is also made tentatively.

From the results of the photoelectric observations of occultations of the *NZC*-stars made at the Hydrographic Office the following values of ΔT have been obtained (unpublished),

(p.e.)

$$\Delta T1 = +35^s.68 \pm 0^s.12 \quad \text{for } 1966.5 \text{ from 45 events,}$$

$$\Delta T1 = +36.52 \pm 0.12 \quad \text{for } 1967.5 \text{ from 61 events.}$$

Then, we obtain $\Delta T1$ at the date of the Mars' occultation to be $+36^s.10$, which corresponds to $+35^s.43$ in $\Delta T0$. Here, it should be noted that the values of ΔT for 1956 to 1965 obtained by the Hydrographic Office from photoelectric observations of stars agree well with those obtained by the U.S. Naval Observatory from the meridian observations of the moon (Suzuki and Harada, 1967).

The coordinates of the observation stations refer to the geodetic datum of Japan on the International ellipsoid with provisional datum corrections of $+10''$ in latitude and $+20''$ in longitude (e.g. Hirose, 1956).

Mr. Y. Tano of the Astronomical Section of the office has calculated the corrections to the moon's ephemeris for reduction to the system of ET2, and the equatorial geocentric ephemeris of the Mars from the rectangular heliocentric coordinates by Duncombe and Clemence (1960). These ephemerides are then employed together with the value of k and the geodetic coordinates of the observation stations in the new system of the astrnonmical constants remaining the datum correction unchanged.

Prediction of the Mars' occultation is given in Table 1. The apparent paths of the Mars with respect to the moon's disk as seen from Sirahama and Kurasiki are shown in Fig. 2.

TABLE 1. PREDICTION OF THE OCCULTATION

Prediction No.	1	2	3	4
Station	Sirahama		Kurasiki	Sirahama
Longitude	$-9^h15^m56.^s134$		$-8^h55^m03.^s893$	$-9^h15^m56.^s127$
Latitude	$+34°42'56.''16$		$+34°35'32.''92$	$+34°42'56.''09$
Altitude	170m		4.9m	170m
with datum correction				
Time	ET0			ET2
3rd contact	$18^h33^m59.^s8$	$18^h34^m03.^s8$	$18^h24^m40.^s4$	$18^h34^m03.^s6$
4th contact	34 17.3	34 21.4	24 59.2	34 21.2
Reappearance of centre of the Mars' disk	34 08.6	34 12.7	24 49.8	34 12.4
3rd contact of illuminated part of the Mars' disk	34 01.6		24 42.2	
Ephemeris of the moon	AE			AE with correction for ET2
Ephemeris of the Mars	AE	AE with $+0.^s1$ in R.A.	AE	Duncombe and Clemence (1960)
k	Innes (1924)			New system of Astronomical Constants
Earth spheroid	International			

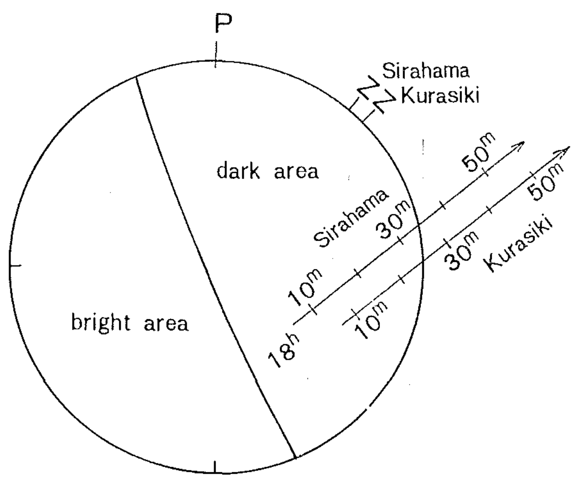

Fig. 2. Apparent Paths of the Mars on the Moon's Disk as seen from Sirahama and Kurasiki.

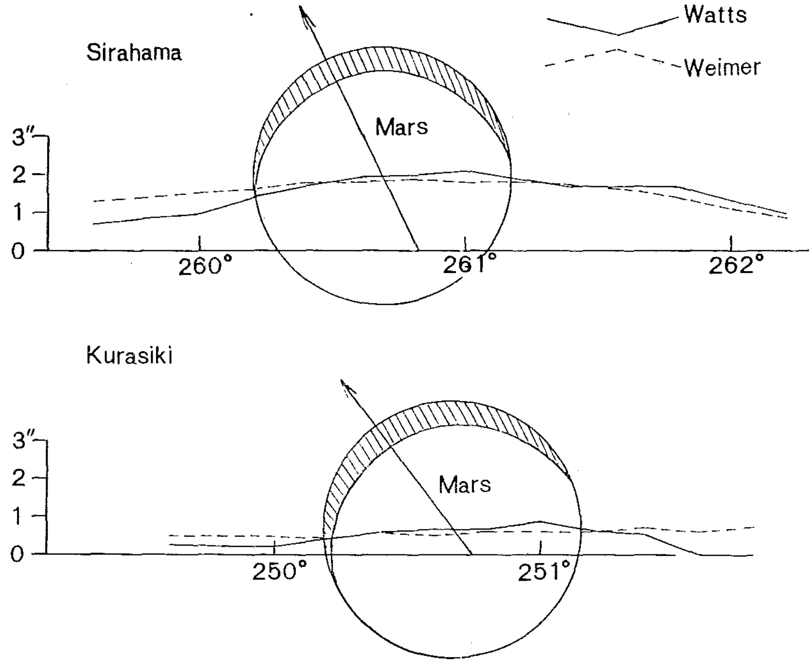

Fig. 3. Profiles of the Moon's Limb at the Occultation Points

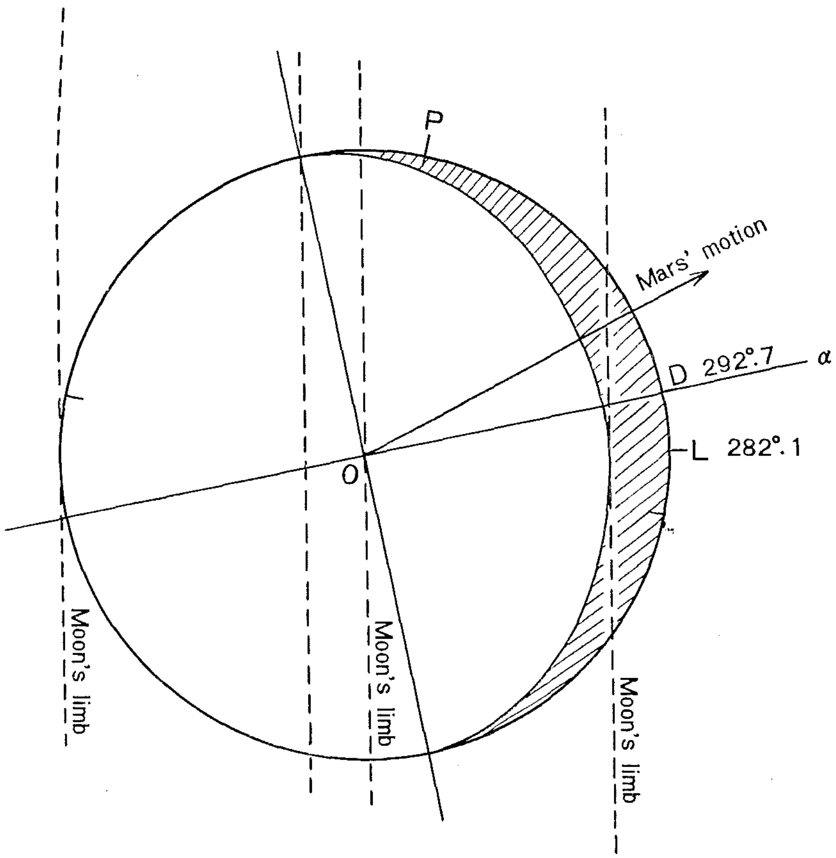

Fig. 4. Disk of the Mars as seen from Sirahama.

(2) Variation of the light intensity of the Mars

From the atlases by Weimer (1952) and by Watts (1963) the profiles of the moon's limb at the occultation points are read and are shown in Fig. 3. Comparing with the apparent size of the Mars' disk the inclinations of the moon's limb to its mean level at the occultation points seem to be around 10° for Sirahama and 5° for Kurasiki.

Fig. 4. shows the situation of the moon's mean limb with respect to the Mars' disk as seen from Sirahama.

We assume that the Mars shines with uniform intensity in its illuminated part of disk. Then, variation of the area of the illuminated part is calculated for several cases of inclination of the moon's limb, i. e. $I=-30°$, $-25°$, $-20°, \ldots,$ $+25°$, $+30°$. Some examples for Sirahama are shown in Fig. 5, in which abscissa α denotes the distance to the moon's limb from the Mars' centre measured along the line OD in Fig. 4 toward the point of maximum defect and ordinate S denotes the area of the reappeared part of the illuminated disk. α and S are both expressed in the unit of the Mars' radius. Then, total area, S_{max}, of the illuminated part of the disk after the 4th contact equals to $(1+\cos i)\frac{\pi}{2}=2.840$, where i is the areocentric angle between the sun and the earth.

Since $\alpha=0$ corresponds to the time of reappearance of the centre of the Mars' disk, we can convert the scale α into the ordinary time scale by comparing the value of α at S_{max} with time difference between the reappearance of the disk centre and the 4th contact, assuming that the value of the Mars' radius in ephemeris is correct. We can then compare the calculated light curves in Fig. 5 with observation record.

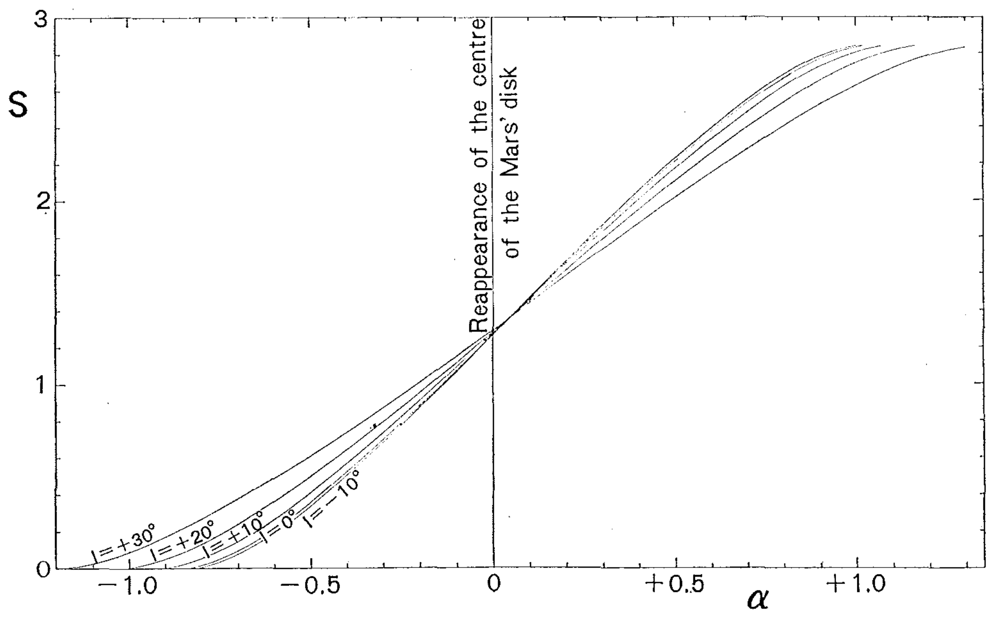

Fig. 5. Light Curves for Reappearance.

3. Equipments

(1) Sirahama Hydrographic Observatory

Telescope: Equatorial Cassegrain reflector with
$\phi = 30$ cm and $f = 500$ cm,

Photomultiplier: EMI 6094 B with 6 diaphragms of 2.0
to 0.2 mm in diameter,

Amplifier: DC-amplifier with attenuators 20, 24, 28,
32, 36 and 40 dB,

Recorder: Inkoscillograph,

Clock: Crystal clock regulated by JJY.

(2) Kurasiki Hydrographic Observatory

Telescope: Equatorial Cassegrain reflector with
$\phi = 30$ cm and $f = 1000$ cm,

Photomultiplier: 1P21 with iris diaphragm,

Amplifier: AC-amplifier,

Recorder: Inkoscillograph,

Clock: Crystal clock regulated by JJY.

4. Photometric calibration

(1) Observation of stars

Until the occultation of the Mars on 3rd January, 1967, the photoelectric devices had never calibrated on photometric scale, because for the use of ordinary occultation observation, in principle, it is sufficient to record the time of dis- or reappearance. In practice, the time of dis- or reappearnce is read from the record of decreasing or increasing curve of star light by adopting the point at which the intensity of the star light reaches one third of the total intensity recorded immediately before or after the phenomenon, taking the effect of diffraction at the moon's limb into account.

Since it is complicated to calibrated the device of Kurasiki photometrically, the calibration for Sirahama alone is made in the present report.

For calibration two groups of stars were adopted. The first group of 31 stars, whose V magnitudes were between 3.4 and 6.5 and spectral types were bewteen FO and KO mainly with luminosity classes of III, IV and V, were selected from the Arizona-Tonantzintla Catalogue (Iriarte et al., 1965). The second group consists of 28 stars of Hyades cluster, whose colour-magnitude array after Johnson et al. (1962) is shown in Fig. 6. We shall call the stars of first group as "field stars" and those of second group as "Hyades members", hereafter.

The observation of the field stars was made from Jan. $3^d22^h30^m$ to Jan. 4^d05^h JST ($=$UT$+9^h$) immediately before and after the occultation of the Mars. Altitude of stars ranges 32° to 66° and azimuth ranges 70° to 199°. Seeing might have hence changed considerably both for direction and for time during the observation. The observation of the Hyades members was made from Jan. 9^d

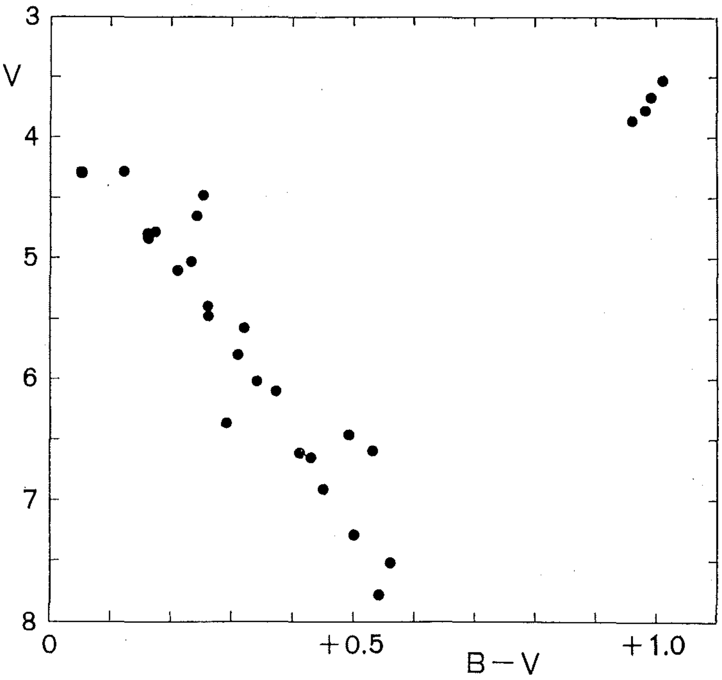

Fig. 6. Hyades Members after Johnson et al. (1962)

18^h30^m to 19^h30^m JST. Seeing was fairly good at that observation.

(2) Magnitude and colour sensitivities

For reduction of the atmospheric extinction $\Delta m = aF(z)$, we assume $a = 0.23$ for V and $a = 0.40$ for B magnitude. Apparent B magnitudes, B_{app}, shown in Fig. 7a for the field stars and in Fig. 7b for the Hyades members are thus obtained, where R is the reading of oscillograph record measured from an arbi-

TABLE 2. CALIBRATION COEFFICIENTS OF THE MULTIPLIER

	attn.	n	σ_V	a_V	p. e.	b_V	p. e.	c_V	p. e.	σ_B	a_B	p. e.	b_B	p. e.	c_B	p. e.
Hyades members	dB 20	15	±0.020	4.96	±0.10	−0.504	±0.022	−0.21	±0.15	±0.020	5.01	±0.10	−0.511	±0.022	+0.34	±0.17
	20	12(1)	0.002	4.56	0.05	0.435	0.010	0.29	0.06	0.002	4.69	0.06	0.444	0.011	0.19	0.07
	28	12	0.005	3.83	0.09	0.357	0.023	0.63	0.16	0.005	3.88	0.10	0.352	0.024	0.30	0.19
	36	13	0.009	3.37	0.10	0.357	0.020	0.23	0.03	0.010	3.42	0.12	0.352	0.022	0.13	0.02
	36	9(2)	0.009	3.38	0.17	0.358	0.037	0.25	0.02	0.010	3.44	0.19	0.357	0.040	0.12	0.21
Field stars	20	5	±0.001	4.47	±0.09	−0.414	±0.013	−0.27	±0.04	±0.000	4.89	±0.07	−0.441	±0.009	+0.00	±0.02
	20	4(3)	0.000	3.71	0.17	0.293	0.027	0.17	0.03	0.000	5.07	0.69	0.467	0.100	0.00	0.04
	28	16	0.005	3.96	0.04	0.395	0.007	0.22	0.01	0.006	4.06	0.05	0.391	0.008	0.14	0.01
	28	15(3)	0.005	4.87	0,06	0.379	0.011	0.21	0.01	0.005	3.93	0.07	0.368	0.011	0.13	0.01
	36	26	0.024	3.47	0.05	0.375	0.008	0.21	0.01	0.023	3.54	0.05	0.366	0.008	0.14	0.01
	40	28	0.026	3.40	0.04	0.401	0.008	0.22	0.01	0.031	3.45	0.04	0.389	0.009	0.16	0.02

Note : (1) 3 faintest stars are omitted.
(2) 4 giant stars are omitted.
(3) 1 faintest star is omitted.
(See Fig. 7a and 7b.)

trary level. Similar figure for V_{app} against log R can also be drawn.

Putting

$$\log R = a_V + b_V V_{app} + c_V (B-V)_0, \qquad (1)$$

$$\log R = a_B + b_B B_{app} + c_B (B-V)_0, \qquad (2)$$

where $(B-V)_0$ denotes the catalogue value of $B-V$, these figures yield the values of the coefficients of (1) and (2) as shown in Table 2, in which σ denotes the standard deviation of the residuals of log R.

So far we have assumed the values of the extinction coefficient a to be 0.23 for V and 0.40 for B. The ranges of the values of sec z are 0.8 for the field stars and 0.17 for the Hyades members. If actual values of a differ for 0.1 from the respective assumed values, the relative displacements of V_{app} and B_{app} among respective groups are 0.08 for the field stars and 0.02 for the Hyades members. Hence, we may ignore the effect of misadoption of a to evaluate the coefficents of (1) and (2) for the case of Hyades members.

Since among U, B and V magnitudes the pass-band of B (Johnson, 1955) has the nearest range to the sensitivity curve of the EMI 6094 B tube, we may employ B scale.

If we assume that the Mars has uniform colour all over its illuminated part of the disk, the term $c(B-V)$ in (1) or (2) needs not to be taken into account, and B magnitude scale can be employed, though the pass-band of V may be nearer to the Mars' spectrum than that of B. Hence, we shall adopt the values of b_B for the Hyades members in the reduction of the occultation.

We rewrite (2) in the form

$$\log (R/R_0) = bB, \qquad (3)$$

where R_0 is an arbitrary level of record. Comparing (3) with the Pogson's formula

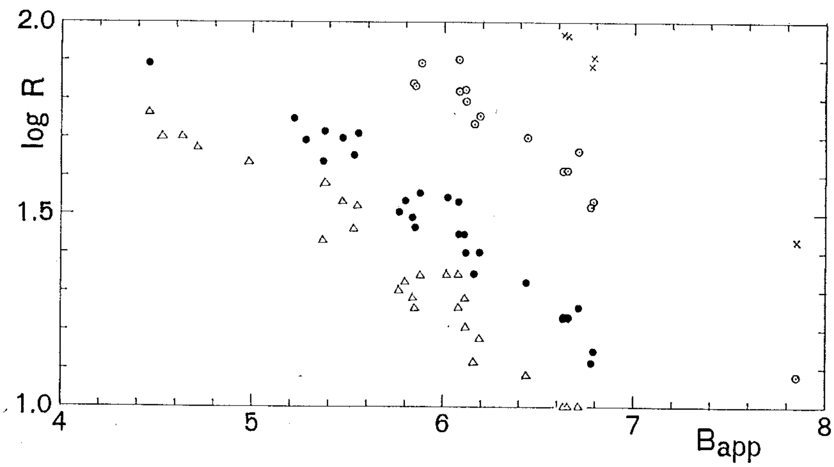

Fig. 7a. Relation between Record Reading and Apparent B-magnitude for the Field Stars.

Cross : Attenuator 20, Circle dot : Attenuator 28,
Dot : Attenuator 36, Triangle : Attenuator 40.

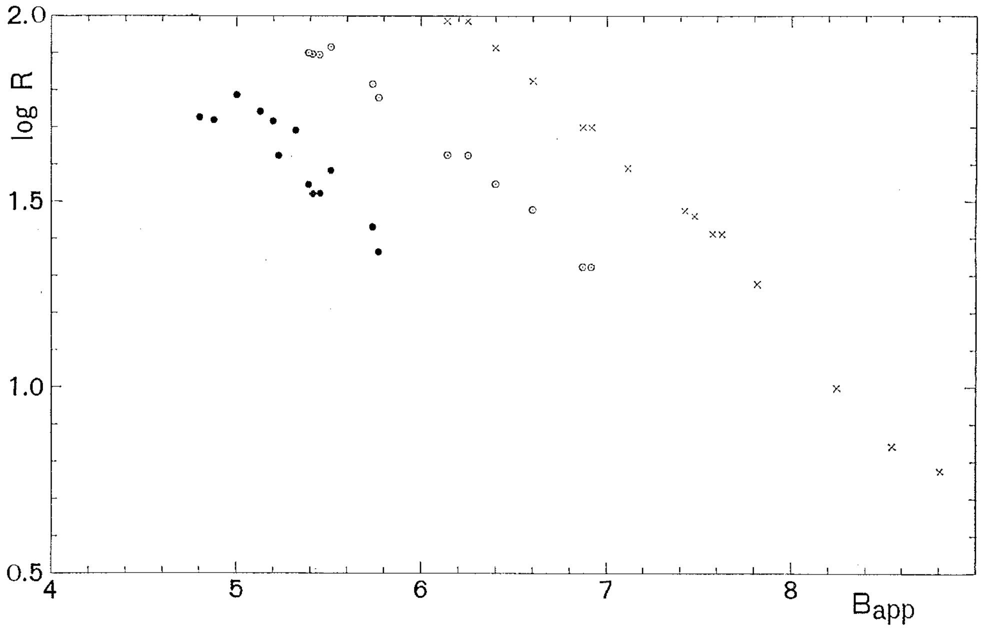

Fig. 7b. Relation between Record Reading and Apparent *B*-magnitude for the Hyades Members. Symbols are same as Fig. 7a.

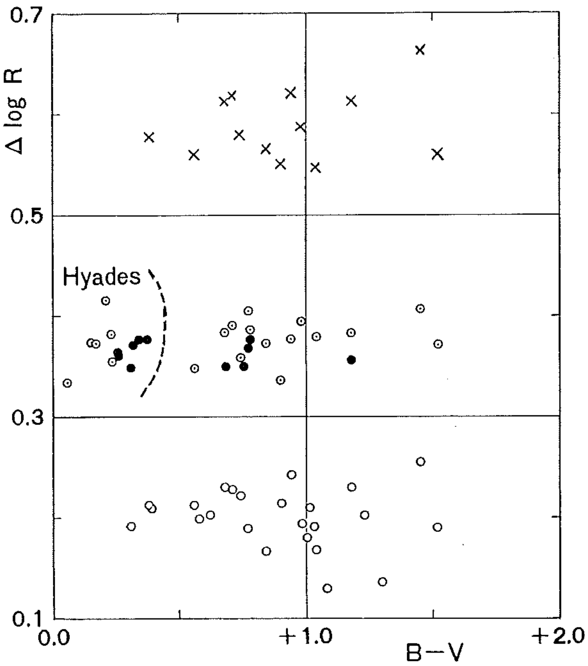

Fig. 8. Record Difference for Different Attenuators.

Left of dashed curve : Hyades members,

Others : Field stars.

Cross : $\log R_{28}$—$\log R_{40}$, Circle dot : $\log R_{28}$—$\log R_{36}$,

Dot : $\log R_{20}$—$\log R_{28}$, Circle : $\log R_{36}$—$\log R_{40}$.

$$\log\ (L_B/L_{B0}) = -0.4(B-B_0),$$

we obtain

$$L_B/L_{B0} = (R/R_0)^{-0.4/b}, \qquad (4)$$

by adjusting the value of R_0. We shall apply this relation for the reduction of the occultation record.

(3) Attenuator difference

In Fig. 8 the differences in log R_i for same stars measured with different attenuators i dB's are plotted against $B-V$. It is found that there is no significant dependency of log R-difference against colour. Then, we make arithmetical means of log R-difference as follows:

(i) Field stars

	p. e.	
$\log R_{20} - \log R_{28} = 0.361 \pm 0.008$		for 5 stars,
$\log R_{28} - \log R_{36} = 0.378 \pm 0.014$		for 14 stars,
$\log R_{28} - \log R_{40} = 0.589 \pm 0.007$		for 13 stars.

(ii) Hyades members

$\log R_{20} - \log R_{28} = 0.366 \pm 0.007$	for 6 stars,
$\log R_{28} - \log R_{36} = 0.372 \pm 0.019$	for 6 stars.

There exists no significant difference between two groups with each other for the respective mean values of $\log R_i - \log R_{28}$ within their probable errors. Hence, two groups can be combined together. The mean values are

$$\begin{aligned} &\log R_{20} - \log R_{28} = 0.364 \quad \text{for 11 stars,} \\ &\log R_{28} - \log R_{36} = 0.376 \quad \text{for 20 stars.} \end{aligned} \qquad (5)$$

We shall adopt these values of record difference between different attenuators in the later reduction of the occultation.

5. Reduction of the occultation observation

Seeing during the occultation of the Mars at Sirahama was fairly good. A fan-shaped iris was attatched to the head of the telescope so as to make the

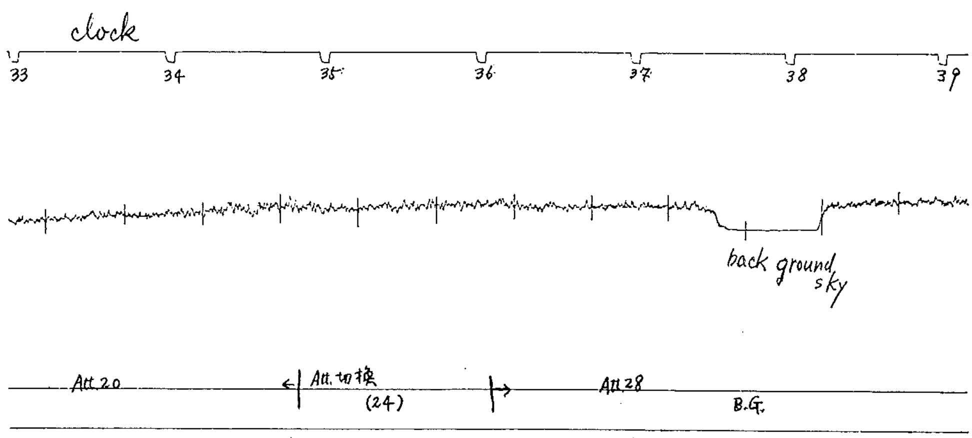

Fig. 9. Record of Occultation at Sirahama.

TABLE 3. OBSERVATION DATA

clock	attn.	R	log R_{28}	L_B/L_{B0}
s	dB	mm		
25.00	20	−4.9		
.25		−5.0		
.50		−5.1		
.75		−5.0		
26.00		−4.8		2.8
.25		−4.9		1.5
.50		−5.0		
.75		−4.9		1.5
27.00		−4.8		2.8
.25		−4.9		1.5
.50		−4.8		2.8
.75		−4.8		2.8
28.00		−4.7	+0.113	3.9
.25		−4.8	−0.042	2.8
.50		−5.0		
.75		−4.9	−0.364	1.5
29.00		−4.8	−0.042	2.8
.25		−4.8	−0.042	2.8
.50		−4.8	−0.042	2.8
.75		−4.7	+0.113	3.9
30.00		−4.5	+0.335	6.2
.25		−4.3	+0.481	8.4
.50		−4.0	+0.636	11.5
.75		−3.9	+0.677	12.5
31.00		−3.6	+0.782	15.6
.25		−3.5	+0.812	16.6
.50		−3.2	+0.891	19.6
.75		−2.8	+0.978	23.4
32.00		−2.7	+0.998	24.4
.25		−2.1	+1.098	30.0
.50		−1.9	+1.127	31.9
.75		−1.3	+1.204	37.4
33.00		−0.7	+1.270	42.9
.25		−0.4	+1.299	45.5
.50		+0.5	+1.376	53.4
.75		+0.9	+1.407	56.9
34.00		+1.3	+1.435	60.4
.25		+1.9	+1.475	65.6
.50		+2.6	+1.517	71.5
.75		+3.3	+1.555	77.5
35.00	24	+2.8		
.25		+2.9		
.50		+3.4		
.75		+4.6		

clock	attn.	R	log R_{28}	L_B/L_{B0}
s	dB	mm		
36.00	28			
.25				
.50		+3.5	+1.775	122.3
.75		+3.5	+1.775	122.3
37.00		+3.7	+1.789	126.6
.25		+3.8	+1.796	128.9
.50				
.75		−2.4*		
38.00		−2.5*		
.25				
.50		+4.6	+1.848	146.6
.75		+5.1	+1.878	158.2
39.00		+5.2	+1.884	160.4
.25		+5.7	+1.911	171.9
.50		+5.7	+1.911	171.9
.75		+5.9	+1.922	176.7
40.00		+6.0	+1.927	178.8
.25		+6.2	+1.937	183.4
40.50	32	+4.6		
.75		+4.9		
41.00		+4.9		
.25				
41.50	36	+3.6	+2.024	228.2
.75		+3.8	+2.044	240.0
42.00		+3.8	+2.044	240.0
.25		+3.8	+2.044	240.0
.50				
.75		−0.9*		
43.00				
.25		−0.8*		
.50		+4.1	+2.068	255.4
.75		+4.3	+2.088	268.7
44.00		+4.5	+2.104	279.4
.25		+4.5	+2.104	279.4
.50		+4.6	+2.112	284.0
.75		+4.8	+2.128	297.4
45.00		+4.5	+2.104	297.4
.25		+4.7	+2.120	291.5
.50		+4.7	+2.120	291.5
.75		+4.7	+2.120	291.5
46.00		+4.8	+2.128	297.4
.25		+4.7	+2.120	291.5
.50		+4.7	+2.120	291.5
.75		+4.6	+2.112	284.0

light intensity of the Mars to be approximately equal to that of a star HR 5429 (V=3.59, K3III). Image of the Mars seemed to be brought accurately to the centre of the diaphragm of 0.2 mm in diameter situated just in front of the photomultiplier. Intensity of the background sky was recorded by shifting the telescope for about 1'.2 northward from the Mars during the occultation.

Fig. 9 shows a part of the occultation record taken at Sirahama, and in the 3rd column of Table 3 the readings of the record measured from an arbitrary level are shown. Reading with asterisk shows the record for background sky.

At first, readings for background are subtracted from those for the Mars for respective attenuators employed. We ignore here the contribution of the light from the dark part of the moon. The correction (5) are then applied and the reduced log R_{2S} are shown in the 4th column of Table 3. Then, these values are converted into the intensities of the received lights by (4) with value of b_B for Hyades members.

Further, two steps of adjustment are made for intensity scale. First adjustment is made in such a way that the intensities of a (fictious) same reading calculated with two kinds of b_B according as the attenuators 20 dB and 28 dB become equal to each other. Difference of b_B between 28 dB and 36 dB may be neglected. Intensity scale thus obtained is then adjusted so that the maximum intensity of the Mars after occultation is equal to $\frac{\pi}{2}(1+\cos i)$ which has been derived in Section 2.

Values of L_B/L_{B0} thus obtained are shown in the 5th column of Table 3 and by dots in Fig. 10. Among the light curves illustrated in Fig. 5, the one

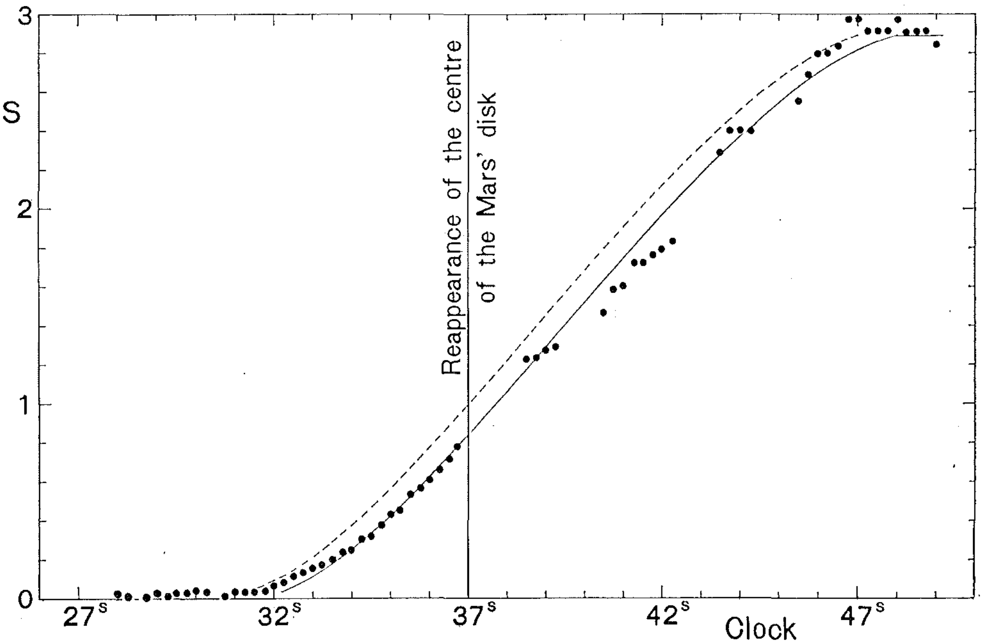

Fig. 10. Curve-Fitting of the Observation.

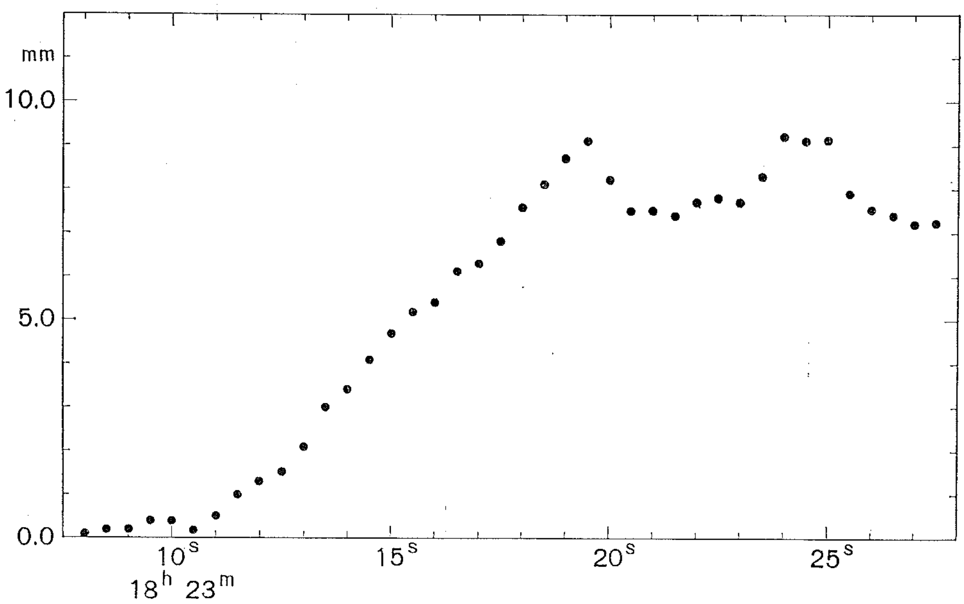

Fig. 11. Readings of Record at Kurasiki.

for $-10°$ in inclination of the moon's limb, which agrees with Watts' profile in Fig. 3, seems to be most appropriate for fitting the dot series of Fig. 10, and is shown in the figure by solid curve.

The time of reappearance of the centre of the Mars' disk is then

$$\text{Jan. } 3^d 18^h 33^m 37^s\!.0 \pm 0^s\!.3,$$

on clock face, where the error $\pm 0^s\!.3$ is estimated from the dispersion of the dots from the calculated curve and agrees with the feeling at the curve fitting. These scatter of dots in Fig. 10 may be composed of (i) observational error, (ii) inadequateness of the photometric calibration and (iii) irregular distributions of brightness and colour on the Mars' disk.

If we fit the curve at the beginning and end of the light increase, other dots are situated far below the curve which is shown by dashed line in the figure.

It is difficult to find out the accurate times of 3rd contact of the illuminated disk and 4th contact from Fig. 10. The 3rd contact seems to have occured at $33^m 30^s\!.5$ and the 4th contact at $33^m 46^s\!.5$. The time interval between them is $16^s\!.0$, which coincides nearly with that of prediction in Table 1. It is probable that the Mars' radius adopted in the ephemeris is incorrect. If so, the adjustment of time scale for α in Section 2 become unadaptable. However, the curves of Fig. 5 pass a same point at a time near the reappearance of the centre of the Mars' disk. Then, comparison of the dots with curve at this reappearance may be almost free from the error of misuse of the calculated curve.

The readings of the record obtained at Kurasiki are directly shown in Fig. 11 without photometric calibration. The record suffers disturbances in its latter part, enabling the fitting with the calculated curves difficult. It seems that the time of the 3rd contact of the illuminated disk is about $3^d18^h23^m09^s$ and the 4th contact is about $18^h23^m24^s.5$. The time interval between them is $1^s.4$ smaller than the prediction. A small protuberance is found at the beginning of the reappearance. Same phenomenon is seen slightly in the record of Sirahama. They may be attributed to the effects of the instruments and/or the atmosphere of the Mars.

(O - C)'s in time are shown in Table 4.

TABLE 4. O - C OF THE OCCULTATION

Station	Sirahama		Kurasiki		Sirahama
Phenomena	Reappearance of disk centre		3rd contact of illuminated disk	4th contact	Reappearance of disk centre
Prediction No. in Table 1	1	2	3		4
Record	1967 Jan. 3^d $18^h33^m37^s.0\pm0^s.3$		$18^h23^m0^s.9$	$18^h23^m24^s.5$	$18^h33^m37^s.0\pm0^s.3$
Clock corr.	+ 2.6		0.0		+ 2.6
Limb corr. from Watts	− 5.9		− 2.3		− 5.9
ΔT	+35.4		+35.4		+36.1
O	18 34 09.2		18 23 42.1	18 23 57.6	18 34 09.9
C	18 34 08.6	18 34 12.7	18 24 42.2	18 24 59.2	18 34 12.4
O − C	+0.6±0.3	−3.5±0.3	0	+2	− 2.5±0.3

The observation at Sirahama and measurement of the record for the calibration stars were made by one of the author, T. Mori, the then director of the observatory. The observation at Kurasiki was made by Mr. K. Kenmotsu, the director of the observatory. The remaining work was done by the other author, A. M. Sinzi.

(Astronomical Section)

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