# PHOTOMETRIC STUDIES OF ASTEROIDS. II*

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## ABSTRACT

This paper gives twelve light-curves of asteroids, determined during eighteen nights, and a number of color determinations. The principal derived quantities are found in Table 1 and the figures. The arrangement of the material follows that of Paper I.

## I. PLAN OF INVESTIGATION

The present investigation is in all respects a continuation and extension of Paper I in this series (Groeneveld and Kuiper 1954). It is based on photoelectric observation with the 82-inch telescope made mostly during January, 1954. Two earlier series are included, for Pallas and Laetitia, which were observed in collaboration with Messrs. Harris and Shatzel. The record of the observations and the principal results are contained in Table 1. As the table shows, Mr. Harris collaborated also during four nights of the recent series; for this aid we are deeply indebted to him. The magnitude and color system used is again that of Johnson and Morgan. We wish to acknowledge the valuable aid which Mr. Hiltner gave us during reductions.

## THE LIGHT-CURVES

The presentation of the data follows in its essentials the arrangement of Paper I. The times given in the legends of the light-curves are U.T. as observed, uncorrected for light-time. The magnitudes are all visual ($V$) values, relative to the maximum of the curve; the $V$-value of the zero so defined is inserted in each figure (except for Laetitia, for which no standard had been observed). Uncertain values are plotted as open circles.

Table 1 resembles closely Table 1 of Paper I, but $m_0$ has been omitted, since its computation is readily made from $g$. Furthermore, the phase angle and the light-time have been added. The values of $r$, $\rho$, and $\phi$ have been taken from the Russian ephemeris, except for asteroids 2, 9, 14, and 44, for which the data were kindly computed by Dr. Rabe. For asteroids 9 and 44 the ephemeris position showed large O − C values, so that a new computation was desirable.

*2 Pallas*.—A single night's run of 4.2 hours was obtained in 1951. The results are shown in Figure 1. The phase angle was 13°1. With Müller's average phase coefficient of 0.037 mag/degree and the known distances, the $g$-value of Table 1 was derived. The amplitude of the observed part is 0.13 mag. A half-period (or whole period, if only *one* maximum occurs per cycle) of 5–6 hours is suspected, which would confirm the provisional value of 5.7 hours derived by O. Günther (1951, 1953), obtained from photographic estimates.

*3 Juno*.—Observations of Juno were made on January 10, 11, 17, 27, and 28, 1954, but only the runs of January 10 and 17 are several hours long. On the other nights clouds cut off observations, while a few clouds interfered even on January 10. The two long runs define a period of about 7 hours and a light-curve having two unequal maxima and minima each. Examination showed that only one period is compatible with all our data; that period is $7^h12^m.6$. On this basis the light-curves of Figures 2, 3, and 4 were constructed. Figure 4 combines the results of January 27 and 28, reduced to January 28. The

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TABLE 1

SUMMARY OF PHOTOMETRIC RESULTS

| No. | Obs. | Date | Obs. | V of Zero | $B-V$ | $U-B$ | Amp. | Period | Mean $V$* | $g$ | Phase Coeff.† | $\phi$ | Light-Time | R.A. | Dec. | Fig. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1..... | 16 | Jan. 54 | G, K | $8^{\rm m}17$ | $+0^{\rm m}73$ | $+0^{\rm m}45$ | ..... | ............... | ....... | $3^{\rm m}40$ | 0.049H | 21°9 | $-17^{\rm m}8$ | $13^{\rm h}01^{\rm m}$ | + 7°3 | ..... |
| 2..... | 30 | June 51 | H, K | 9.66 | + .67 | ...... | $0^{\rm m}13$ | $5$–$6^{\rm h}$ or $10$–$12^{\rm h}$ | $9^{\rm m}71a$ | 4.38 | .037M | 13.1 | −22.1 | 20 12 | +19.5 | 1 |
| 3..... | 10 | Jan. 54 | G | 8.61 | + .86 | + .44 | .15 | $7^{\rm h}12^{\rm m}6\pm0^{\rm m}1$ | 8.861$b$ | 5.634 | .025 | 15.5 | −12.2 | 9 34 | + 0.4 | 2 |
| | 11 | Jan. 54 | G | 8.63 | + .85 | + .43 | .... | | ....... | ..... | ....... | 15.0 | −12.2 | 9 34 | + 0.5 | ..... |
| | 17 | Jan. 54 | G, K | 8.51 | + .83 | + .43 | .14 | | 8.580$b$ | 5.634 | ....... | 12.5 | −12.0 | 9 30 | + 1.0 | 3 |
| | 27 | Jan. 54 | K | ..... | ...... | ...... | .... | | ....... | ..... | ....... | 8.3 | −11.8 | 9 23 | + 2.2 | 4 |
| | 28 | Jan. 54 | K | 8.39 | ...... | ...... | .... | | 8.462$b$ | 5.636 | ....... | 7.9 | −11.8 | 9 23 | + 2.3 | |
| 9..... | 3 | Jan. 54 | G | 8.54 | + .84 | + .50 | .26 | 5 04.6±0.02 | 8.67$b$ | 6.61 | .049 | 2.9 | − 9.5 | 6 39 | +28.7 | 5 |
| | 5 | Jan. 54 | G | 8.61 | + .85 | + .51 | .26 | | ....... | ..... | ....... | 3.6 | − 9.5 | 6 36 | +28.7 | 6 |
| | 8 | Jan. 54 | G | 8.70 | + .85 | + .49 | .... | | ....... | ..... | ....... | 5.3 | − 9.6 | 6 33 | +28.9 | |
| | 16 | Jan. 54 | G, K | 8.95 | + .85 | + .48 | .25 | | 9.08$b$ | 6.62 | ....... | 9.4 | − 9.8 | 6 25 | +29.2 | 7 |
| 10..... | 31 | Dec. 53 | G, H | 10.27 | + .69 | + .36 | .09 | 18? | 10.32$c$ | 5.656 | (.030) | 5.3 | −19.8 | 7 56 | +20.1 | 8 |
| | 1 | Jan. 54 | G, H | 10.24 | + .68 | + .37 | .10 | | 10.29$c$ | 5.641 | ....... | 5.0 | −19.8 | 7 55 | +20.1 | 9 |
| 14..... | 30 | Dec. 53 | G, H | 10.10 | + .81 | + .40 | .035 | 11? | 10.12$d$ | 6.59 | .034M | 9.9 | −13.9 | 4 39 | +20.8 | 10 |
| | 4 | Jan. 54 | G | 10.23 | + .82 | + .39 | ..... | | 10.23$d$ | 6.60 | ........ | 12.1 | −14.2 | 4 34 | +21.0 | |
| 39..... | 9 | May 49 | K, S | ..... | ...... | ...... | .43 | ............... | ....... | ..... | .022M | 6.1 | −16.5 | 15 34 | −03.8 | 11 |
| 40..... | 10 | Jan. 54 | G | 10.68 | + .88 | + .43 | .04 | ............... | ....... | ..... | .018M | 22.4 | −13.0 | 3 07 | +15.2 | ..... |
| 44..... | 6 | Jan. 54 | G | 9.85 | + .70 | + .24 | .40 | 6 25.2±0.1 | 10.04$b$ | 7.12 | .025M | 21.9 | −11.6 | 3 22 | +13.5 | 12 |
| | 7 | Jan. 54 | G | 9.87 | + .70 | + .24 | .35 | | ....... | ..... | ....... | 22.2 | −11.7 | 3 22 | +13.6 | 13 |
| | 11 | Jan. 54 | G | 9.91 | + .69 | + .24 | .41 | | 10.11$b$ | 7.10 | ....... | 23.3 | −12.0 | 3 22 | +13.8 | 14 |
| 354..... | 2 | Jan. 54 | G, H | ..... | + .94 | + .58 | .... | 4 16 ±1 | ....... | ..... | (.030) | 17.5 | −14.4 | 10 06 | + 8.0 | ..... |
| | 5 | Jan. 54 | G | 10.09 | + .95 | + .53 | .15 | | 10.15$b$ | 6.53 | ....... | 16.6 | −14.1 | 10 04 | + 8.3 | 15 |
| | 6 | Jan. 54 | G | 10.10 | + .95 | + .58 | .12 | | ....... | ..... | ....... | 16.3 | −14.0 | 10 04 | + 8.4 | 16 |
| 433..... | 2 | Jan. 54 | G, H | 12.13 | + .96 | + .56 | ..... | ............... | ....... | 10.9: | .024B | 57.2 | ....... | 13 12 | −13.5 | ..... |
| 532..... | 2 | Jan. 54 | G, H | 9.42 | +0.83 | +0.44 | 0.08 | $16$–$17^{\rm h}$? | 9.46$c$ | 7.07 | (0.030) | 4.5 | −14.1 | 6 07 | +17.5 | 17 |

* The letters have the following meanings: $a$ = mean over half or quarter-period (see text); $b$ = mean over full period; $c$ = mean over quarter period; $d$ = mean over night's run.

† B = M. Beyer (1938); H = Haupt (1953); M = Müller (1897); values in ( ) are adopted; the two remaining values are derived here.

figures define the following epochs of primary minimum:

| 1954 | U.T. |
|---|---|
| January 10........ | $8^h35^m \pm 3^m$ |
| January 17........ | 6 30 ±4 |
| January 28........ | 9 11 ±6 |

The first and last epoch, separated by 60 periods, give $P = 7^h12^m.6 \pm 0^m.1$. This value predicts the January 17 epoch as $6^h25^m \pm 4^m$, compatible with the observed value. The two principal light-curves show evidence of changes within the week elapsed. For this reason the unobserved parts in Figure 4 are somewhat hypothetical.

The mean magnitudes over one period were derived from all three curves and are given in Table 1. To give consistent $g$-values, they require a phase coefficient of 0.025

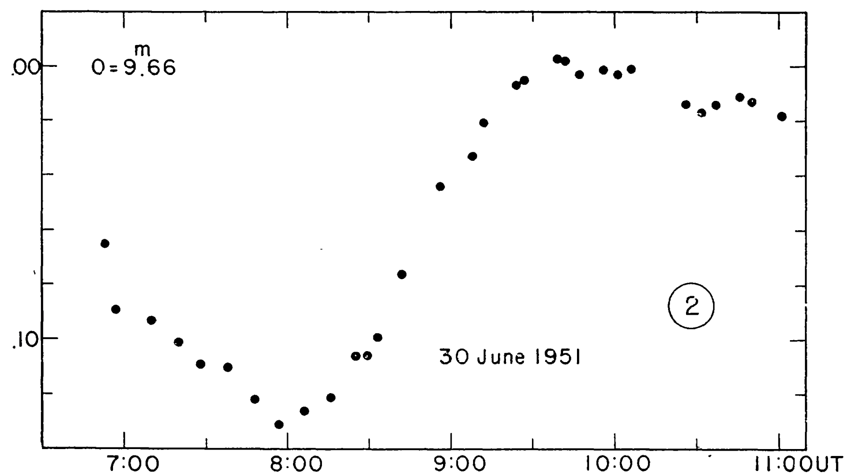



FIG. 1.—Observations of 2 Pallas

mag/degree. This figure appears well determined and is slightly less than the values of Müller (1897), 0.030; Günther (1951), who found 0.039 for phase angles smaller than 11° but a smaller value for larger angles; and Haupt (1953), 0.036. However, comparison with Haupt's plot shows no real contradiction between our value and his observations.

*9 Metis*.—In Paper I it was found that the 1949 observations gave a period of $5^h03^m \pm 2^m$. The 1954 observations were made on January 3, 5, 8, and 16, and covered 6, 2, $1\frac{1}{2}$, and $7\frac{1}{2}$ hours, respectively. The first 2 hours of the last night were disturbed by a small discontinuity in the apparent sensitivity and are not plotted here. The other data are shown in Figures 5, 6, and 7. Because of the complexity of the variation, all available evidence was combined in drawing the light-curves in Figures 5–7. The shapes differ in detail between the three figures. We find later that the epochs are also slightly variable if compared to a linear formula.

Müller's phase coefficient for Metis is 0.041 mag/degree, but a slightly larger value, of 0.049 mag/degree, fits our observations better. The phase angle on January 5 was 2°.9 and on January 16, 9°.4, so that our coefficient should be well determined. The remaining quantities are found in Table 1. It is noted that the amplitude of 0.26 mag. is considerably greater than that of the 1949 observations, which was 0.12 mag. The light-curves define the epochs given in the table on p. 532. These epochs give the intervals

$$I(m) \underset{1^h14^m}{-} I(M) \underset{1^h43^m}{-} II(m) \underset{0^h56^m}{-} II(M) \underset{1^h11^m}{-} I(m)\,,$$

| 1954 | | U.T. | 1954 | | U.T. |
|---|---|---|---|---|---|
| Jan. 3 | IIMin. | $5^h01^m$ | Jan. 8 | IIMin. | $6^h51^m$ |
| | IIMax. | 5 53 | | | |
| | IMin. | 7 04 | Jan. 16 | IIMax. | 3 38: |
| | IMax. | 8 19 | | IMin. | 4 49 |
| | IIMin. | 9 57 | | IMax. | 6 03 |
| | | | | IIMin. | 7 50 |
| Jan. 5 | IMin. | 4 45 | | IIMax. | 8 49 |
| | IMax. | 5 59 | | | |

making the total period $5^h04^m$. With the aid of these data four epochs of primary maximum are derived, as shown in the accompanying table.

| 1954 | U.T. | Light-time |
|---|---|---|
| Jan. 3 | $8^h18^m4 \pm 0^m5$ | $-9^m5$ |
| 5 | 5 59 $\pm 0.5$ | $-9.5$ |
| 8 | 5 08 $\pm 3$ | $-9.6$ |
| 16 | 6 04 $\pm 1$ | $-9.8$ |

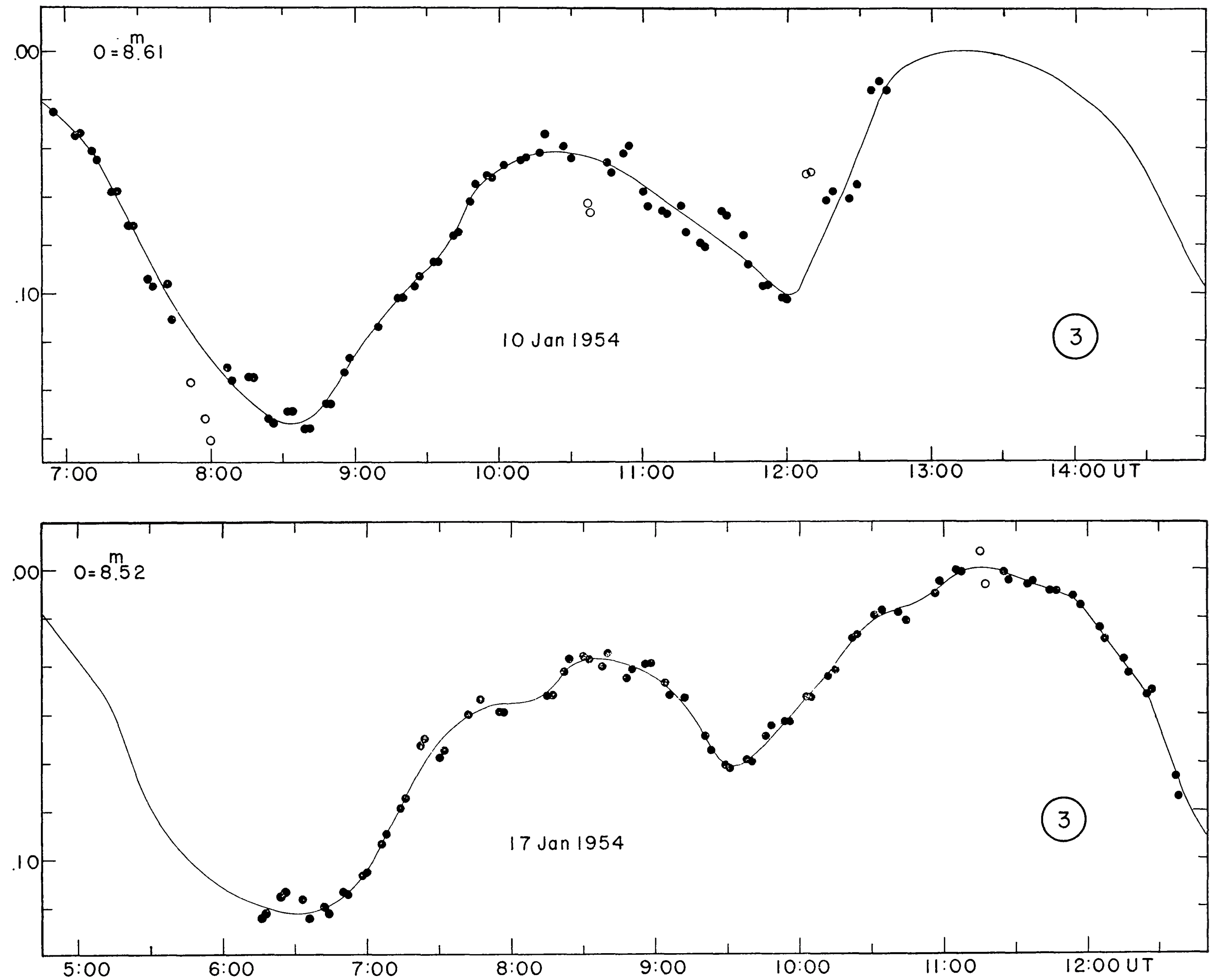
The interval January 3–5, which is 2740.6 ± 0.7 minutes, is about nine times the 1949 period of 303 ± 2 minutes. The improved period is then 304.5 ± 0.1 min. This shows that the interval January 3–16 is 61 cycles; it leads to the mean synodic period of 304.68 ± 0.02 minutes or 0.2115833 ± 0.000014 day. The interval 1949–1954 is 1523 days, or about 7200 periods. The uncertainty of the period carried back over this interval is nearly half a cycle, so that our observations do not suffice to bridge the gap with certainty. This situation is not changed by inclusion of the photoelectric observations published by Giclas (1950), since they happen to be nearly simultaneous with our 1949 epoch. For future reference all 1949 data are collected in Table 2.

TABLE 2

EPOCHS OF THE MAXIMA AND MINIMA OF 9 METIS

| 1949 | | U.T. | |
|---|---|---|---|
| Nov. 2 | IIMax. | $5^h41^m \pm 2^m$ | |
| | IIMin. | 6 32 $\pm 2$ | |
| | IMax. | 7 47 $\pm 1$ | |
| | IMin. | 9 21 $\pm 3$ | |
| Nov. 16 | IIMax. phase | $0.07 \pm 0.01 =$ | Nov. 16.198 $\pm$ 0.002 day U.T. |
| | IIMin. | $.26 \pm .02 =$ | $.238 \pm .004$ |
| | IMax. | $.51 \pm .01 =$ | $.291 \pm .002$ |
| | IMin. | $.84 \pm .03 =$ | $.360 \pm .006$ |
| Dec. 21 | IIMax. | $.13 \pm .03 =$ | Dec. 21.122 $\pm$ .006 |
| | IIMin. | $.34 \pm .03 =$ | $.167 \pm .006$ |
| | IMax. | $.57 \pm .03 =$ | $.215 \pm .006$ |
| | IMin. | $0.90 \pm 0.03 =$ | $.285 \pm 0.006$ |

Giclas listed 74 measures each in blue and yellow, running from October 27, 1949, to January 10, 1950. He deduced a provisonal period of 0.213 days and a phase coefficient of 0.040 mag/degree for the yellow and 0.043 mag/degree for the blue. We have replotted the yellow measures against our accurate period, with the material divided into three groups, October 27–November 1 (18 measures); November 13–19 (32 measures); and November 29–January 10 (24 measures). The magnitudes used were those listed in the last column of Giclas' Table II, which are corrected to the distances of mean opposition and with the phase coefficient of 0.045 mag/degree. These plots did not give consistent mean magnitudes, and new plots were made with the corrected phase coefficient, 0.037 mag/degree, found from the first plots. Of the three groups, the first has much scatter, but the second and third show the light-variation well; they are reproduced in our Figure 8. The November 16 group defines a light-curve quite similar to that of our November 2 run (Fig. 5 of Paper I). In both cases the primary minimum is broad and flat, with the




FIGS. 2 (*above*) and 3 (*below*).—Light-curves of 3 Juno

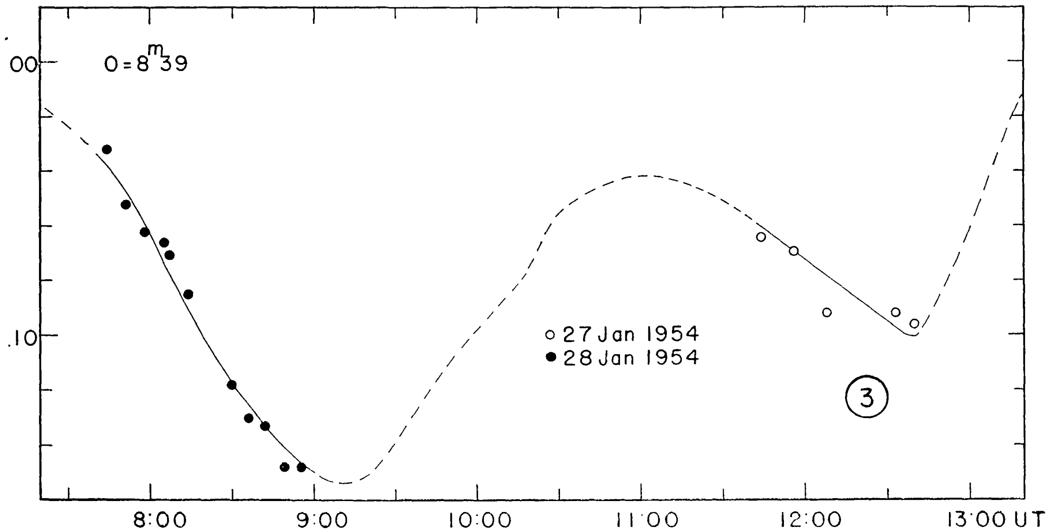



FIG. 4.—Observations of 3 Juno

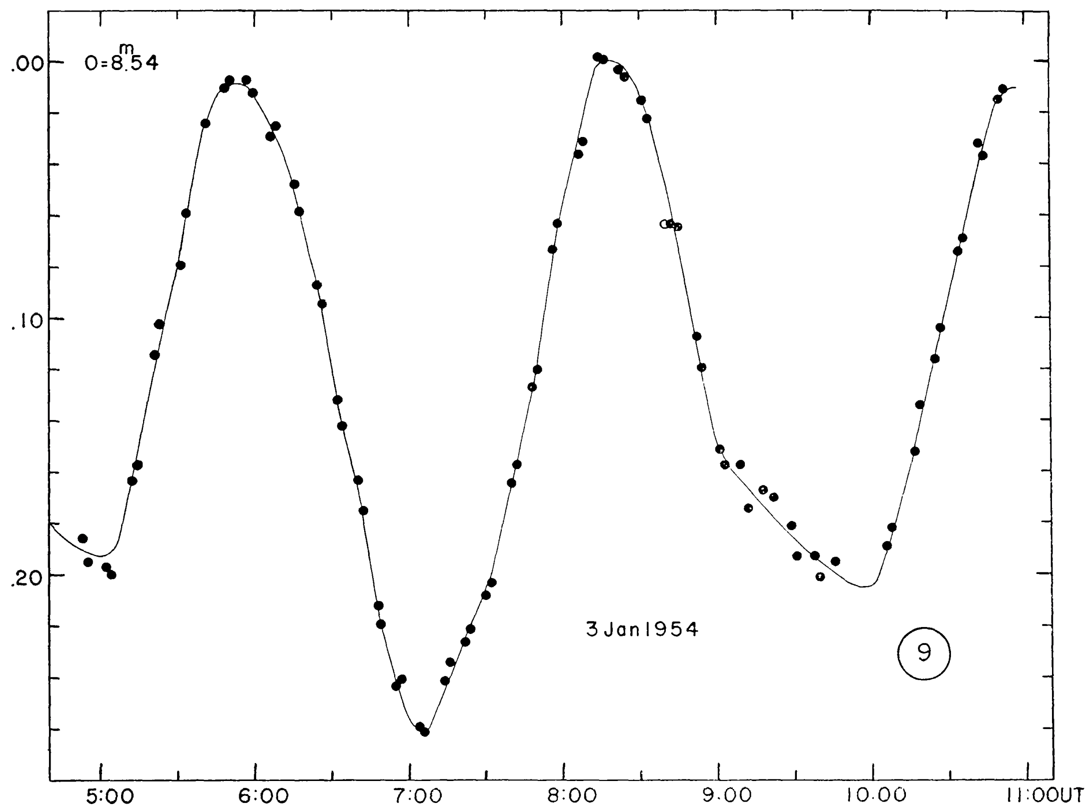



FIG. 5.—Light-curve of 9 Metis

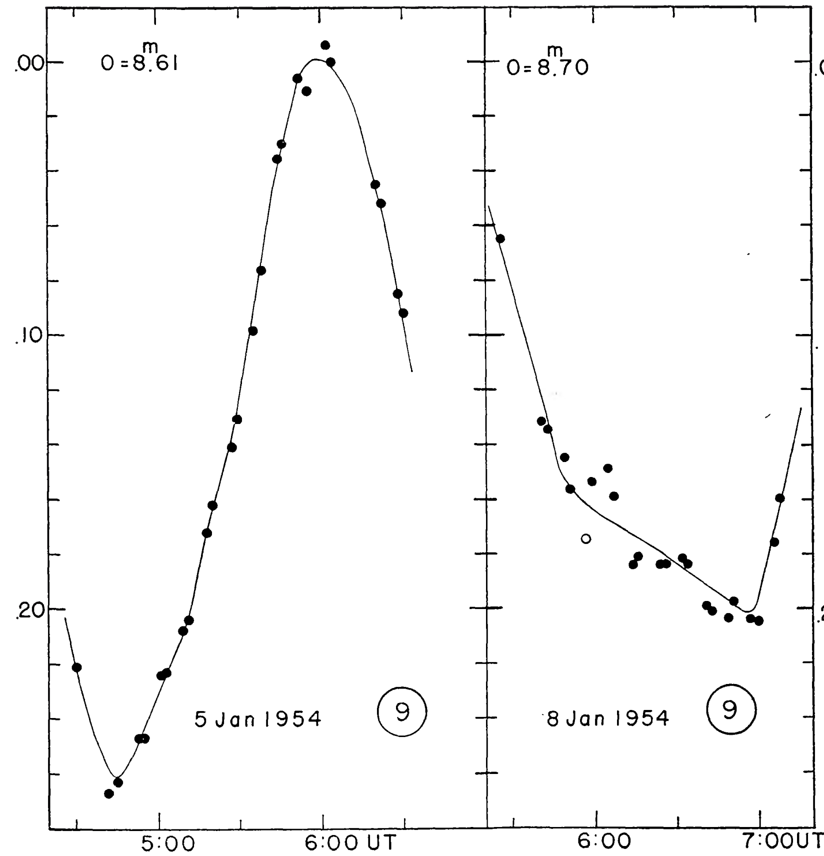



FIG. 6.—Observations of 9 Metis

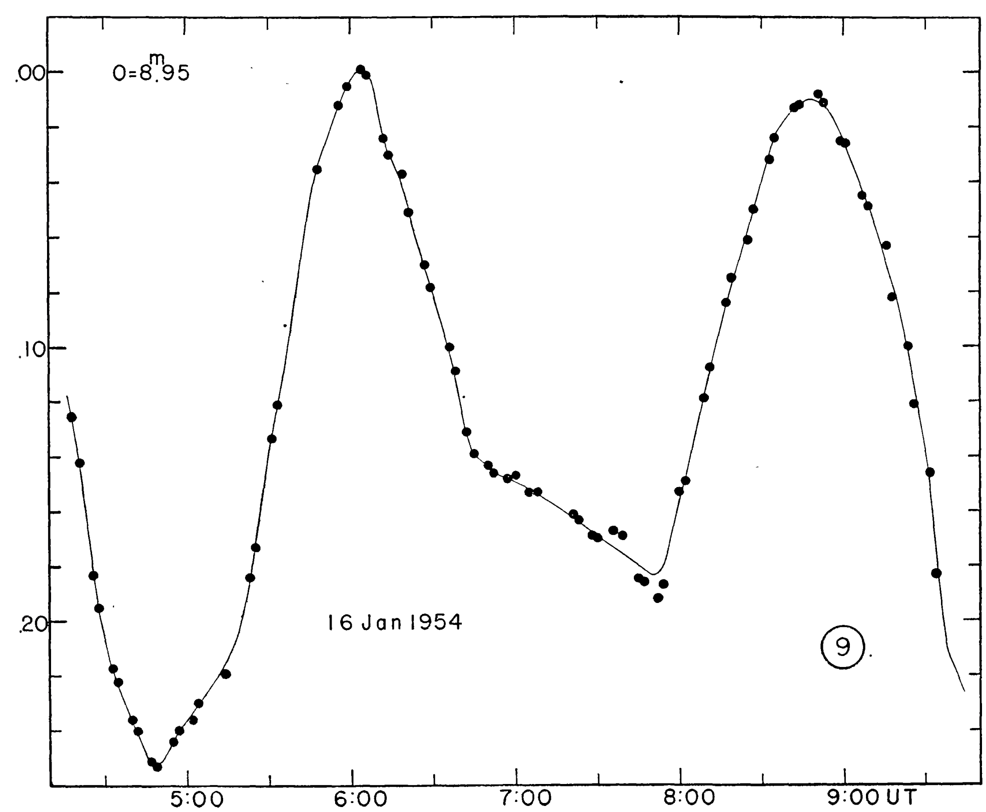



FIG. 7.—Light-curve of 9 Metis

primary maximum 0.11 mag. above it. The curve drawn in Figure 8 is based on this similarity and leads to good epochs of maximum and minimum. The December group is more uncertain, and the primary minimum seems to be skew, somewhat like the secondary minimum in January, 1954 (with which it is probably identical; see next paragraph). The amplitude appears to have increased to about 0.18 mag.

The three 1949 light-curves define the epochs, uncorrected for light-time, as given in Table 2. Comparison of the intervals fixed by these epochs with those previously listed for 1954 makes it probable that the primary maxima of the two sets of data refer to the

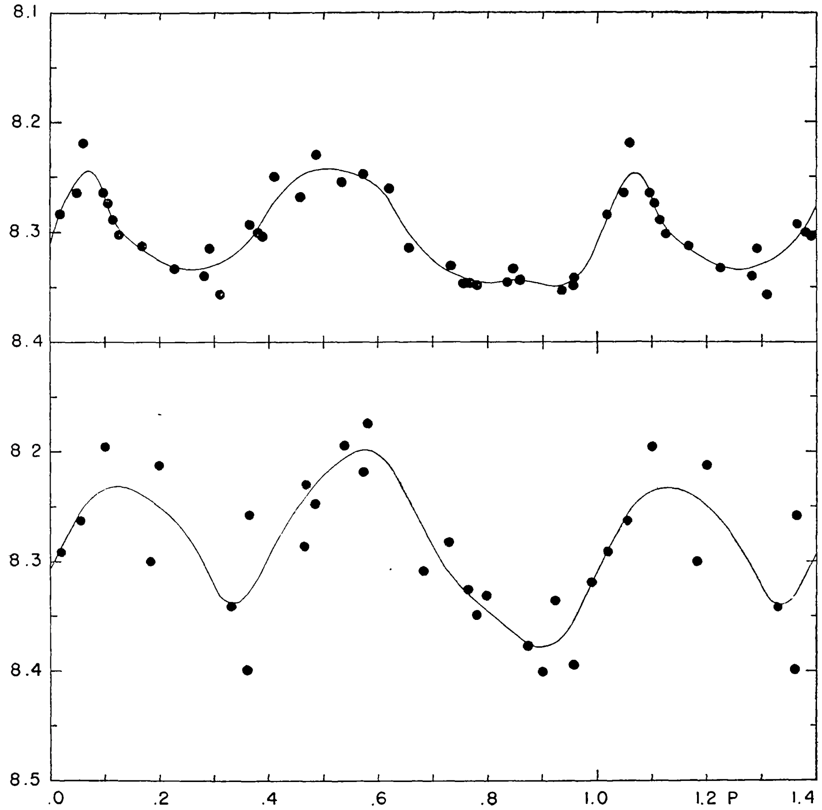



FIG. 8.—Light-curves of 9 Metis based on measures by Giclas (1950). *Abscissae:* phases (with zero on October 0.0000, 1949); *ordinates:* visual magnitudes reduced to mean opposition and phase zero with the coefficient 0.037 mag/degree. When comparing with Figs. 5–7, note that 0.20$P$ is nearly 1 hour.

same event but that the primary and secondary minima have interchanged. A third epoch will clarify this relation and also determine the sense of rotation.

Examination of the individual 1954 curves shows that the period of $5^{h}04^{m}.7$ does not always fit precisely between corresponding features in successive cycles. A lack of strict periodicity is thus indicated but requires confirmation. It is further noted that the somewhat divergent values found for the phase coefficient are not necessarily due to errors of measurement; the results may have been distorted by an admixture of an independent effect, namely, a simultaneous change of aspect (or mean projected area).

*10 Hygeia.*—Two runs on consecutive nights, of 7.1 and 7.6 hours, respectively, failed to cover the entire period (see Fig. 9). The first run suggests a minimum between 6 and 7 hours, U.T., if the peculiar feature during the first 20 minutes is ignored. A maximum appears to occur about $11^{h}10^{m}$ or $20^{m}$ U.T. If this interval is considered to be one-quarter period, the total period would be 18–20 hours. This is compatible with the next

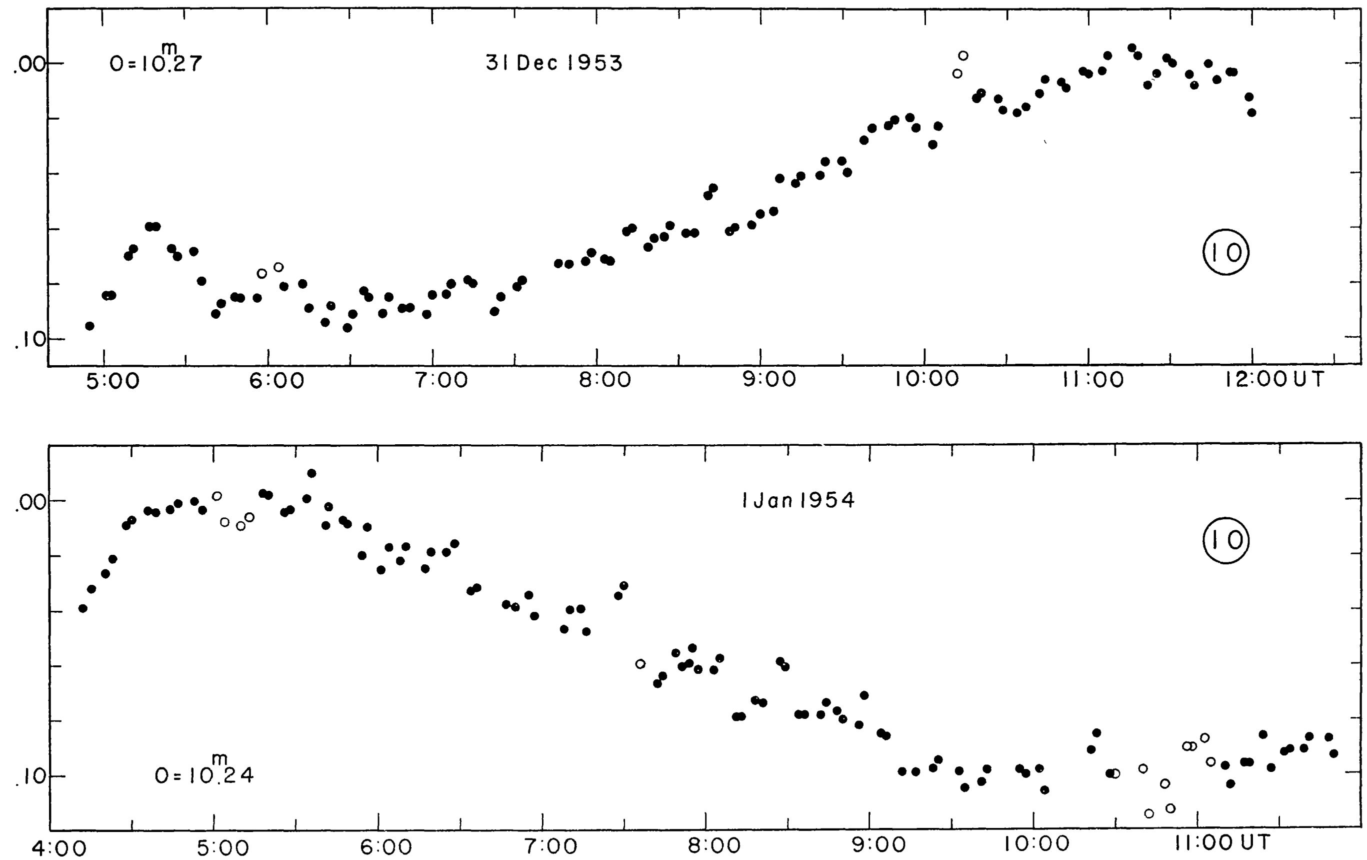



FIG. 9.—Observations of 10 Hygeia

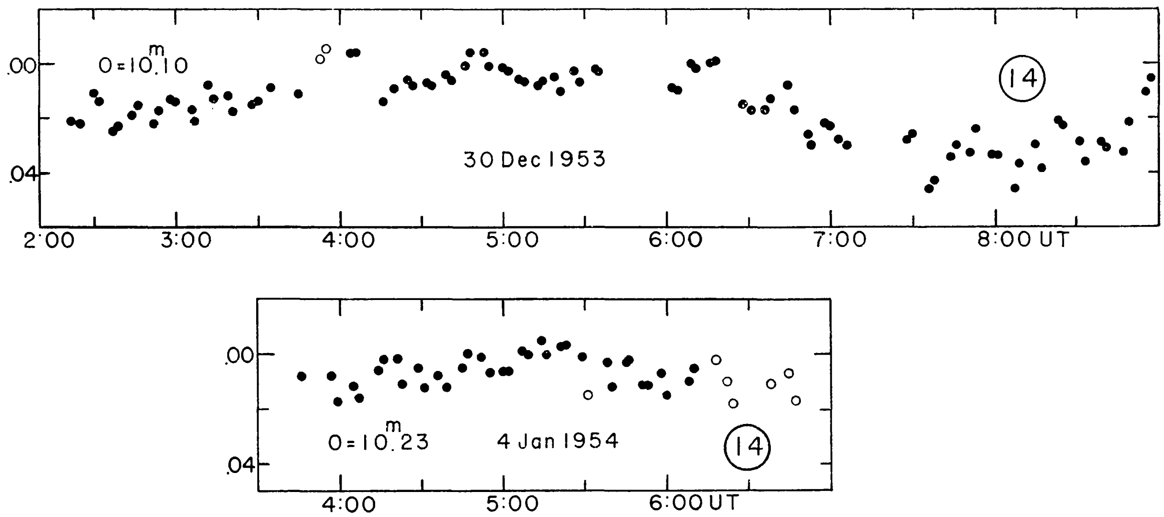



FIG. 10.—Observations of 14 Irene

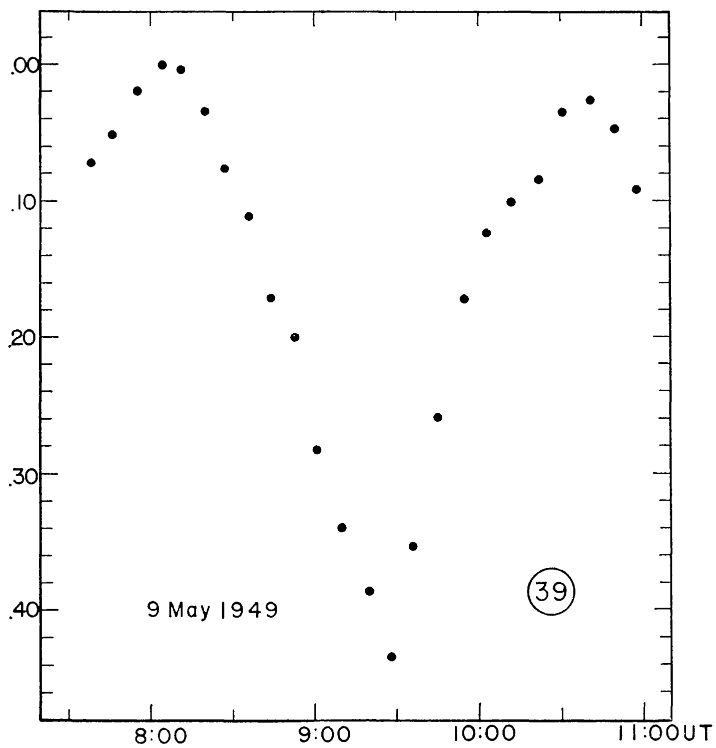



FIG. 11.—Observations of 39 Laetitia

night's maximum, which occurs 18 hours later than the first. A period of 18 hours may, therefore, be provisionally adopted. On this basis the two nights represent slightly more than half the total light-curve, with both minima but only one maximum shown. The minima are 0.09 and 0.10 mag. deep. The mean magnitude, each for a quarter-period, derived from the two nights, if corrected for changes in phase and distance, agree within 0.015 mag., if the phase coefficient 0.03 mag/degree is used.

*14 Irene.*—This object was observed on December 30, 1953, and January 4, 1954, U.T. The results are plotted in Figure 10. The December 30 run was nearly 7 hours and suggests two minima and one maximum. However, the total amplitude is only 0.035 mag., and the suggested half-period of perhaps $5\frac{1}{2}$ hours must be taken with great reserve. On this interpretation, the secondary minimum is only 0.02 mag. deep. Some irregularities are indicated which likewise need confirmation.

The mean magnitudes, corrected for changes in distance and phase, bring the two nights into good accord, as is seen from Table 1; the phase coefficient used is Müller's value, 0.034 mag/degree.

*39 Laetitia.*—The 1949 observations, plotted in Figure 11, supplement the 1952 and 1953 observations of Paper I. The amplitude in 1949 was twice that of the later observations, 0.43 mag. We shall see below that the 1949 minimum is the secondary one; it is so listed in Table 3, which gives all epochs now at hand.

TABLE 3

EPOCHS OF MAXIMA AND MINIMA OF 39 LAETITIA

| | | U.T. |
|---|---|---|
| 1949 May 9 | IMax. | $8^h08^m \pm 2^m$ |
| | IIMin. | 9 29 ±1 |
| | IIMax. | 10 40 ±2 |
| 1952 Jan. 29 | IMax. | 3 40 ±2 |
| | IIMin. | 4 56 ±2 |
| | IIMax. | 6 00 ±2 |
| | IMin. | 7 07 ±2 |
| | IMax. | 8 52 ±2 |
| 1953 Apr. 4 | IIMax. | 7 00 ±5 |
| 1953 Apr. 10 | IMax. | 4 28 ±2 |
| | IIMin. | 5 37 ±2 |
| | IIMax. | 6 54 ±3 |
| | IMin. | 7 53 ±4 |
| | IMax. | 9 37 ±4 |

The 1952 and 1953 observations give the following intervals between the cardinal points of the light-curve:

$$I(M)\underset{1^h17^m\!.5}{-}II(m)\underset{1^h05^m\!.5}{-}II(M)\underset{1^h03^m}{-}I(m)\underset{1^h44^m\!.5}{-}I(M)\ ,$$

adding up to a period of $5^h10^m\!.5$. According to the 1949 observations, the first two intervals are $1^h21^m$ and $1^h11^m$. There are apparently small differences in these intervals, probably connected with the great changes in the shape of the light-curve; but the data are incompatible with a shift of half a period. The assignment in Table 3 is therefore correct.

Table 3 may be condensed into four epochs of the secondary minimum; this minimum has the most regular shape and was directly observed in 1949 (see accompanying table).

| | U.T. | | U.T. |
|---|---|---|---|
| 1949.......May 9 | $9^h29^m \pm 1^m$ | 1953.......Apr. 4 | $5^h53^m \pm 5^m$ |
| 1952.......Jan. 29 | 4 56 $\pm 1\frac{1}{2}$ | 1953.......Apr. 10 | 6 54 ±3 |

In Table 4 these times are expressed in terms of Julian days (−2430000). The third column gives values corrected for light-time. Epochs 3 and 4 lead to the period $5^h10^m.75 \pm 0^m.2 = 0.21580 \pm 0.00014$ day, already mentioned in Paper I. This period must now be combined with epochs 1, 2, and 4.

The varying amplitude of the light-curve shows that the pole of rotation is not at right angles to the ecliptic. There is no assurance, therefore, that the sense of rotation can be determined from the three principal epochs, which, moreover, are separated by long intervals of time. The interval 1–2 is $4609 \pm 3$ periods, while the interval 2–3 is $2025 \pm 1\frac{1}{2}$ periods. If the discussion is carried out along the lines used in Paper I on 15 Eunomia, one may consider the first interval to consist of any integral number of cycles between 4616 and 4600. Then, for *direct* rotation, the best representation of the second interval

TABLE 4

EPOCHS OF SECONDARY MINIMUM, 39 LAETITIA

| | JD | JD(*c*) | R.A. | Dec. | λ | β |
|---|---|---|---|---|---|---|
| 1......... | 3045.8951±0.0007 | 3045.8837 | $15^h34^m$ | − 3°.8 | 232° | +15° |
| 2......... | 4040.7056± .0011 | 4040.6945 | 06 26 | +11.6 | 96 | −12 |
| 3......... | 4471.7451± .0035 | 4471.7330 | 12 15 | + 6.2 | 181 | + 7 |
| 4......... | 4477.7875±0.0021 | 4477.7752 | 12 11 | + 6.8 | 180 | + 7 |

is obtained by assuming the first interval to be 4609 cycles. The second interval is then 2025.037 cycles, giving a residual of 0.008 days. For *retrograde* rotation, reasonable residuals for the second interval are obtained by assuming the first interval to be 4616, 4609, or 4600 cycles. The residuals for the second interval are then, respectively, 0.006, 0.011, and 0.0006 days. While the last residual is, of course, satisfactorily small (see Table 4), it would require the period found from epochs 3 and 4 to be in error by three times the estimated uncertainty. Clearly, an accurate additional epoch is needed to settle this question.

*40 Harmonia.*—A short run, of only 1.1 hours, was obtained when clouds interrupted further work. The observations define a maximum on January 10, 1954, $1^h45^m$ U.T.; the magnitude was 10.68. The total variation observed was 0.04 mag. No *g*-value is entered in Table 1 because the mean magnitude could not be determined; the *g*-value corresponding to the *maximum* is 7.57 mag. if Müller's phase coefficient of 0.018 mag/degree is used (the phase angle was 22°.4).

*44 Nysa.*—Reference is made to Shatzel's paper, No. III of this series (this issue) on the 1949 observations, in which he found a beautiful light-curve with a period of $6^h25^m$. Our observations were made on January 6, 7, and 11, 1954, and are shown in Figures 12, 13, and 14. Figure 12 also shows the observations of January 7 reduced to January 6, so as to complete the cycle. The reduction applied is 0.018 mag., 0.010 for change in the distances and 0.008 for phase (Müller's coefficient of 0.025 mag/degree was used). The light-curves define the epochs given in the accompanying table. These may be combined

| | | U.T. | | | U.T. |
|---|---|---|---|---|---|
| IMax.......... | January 6 | $2^h10^m$ | IMax......... | January 7 | $3^h46^m$ |
| IMin.......... | January 6 | 3 41 | IIMin......... | January 11 | 2 19 |
| IIMax.......... | January 6 | 5 20 | IMax......... | January 11 | 4 08 |
| IIMin.......... | January 6 | 6 46 | IMin. | January 11 | 5 42 |
| IIMin.......... | January 7 | 1 57 | IIMax......... | January 11 | 7 22 |

into epochs of primary maximum:

| 1954 | Wt. |
|---|---|
| Jan. $6^d2^h10^m$............... | 1 |
| 7 3 46 ............... | ½ |
| 11 4 09 ............... | 1 |

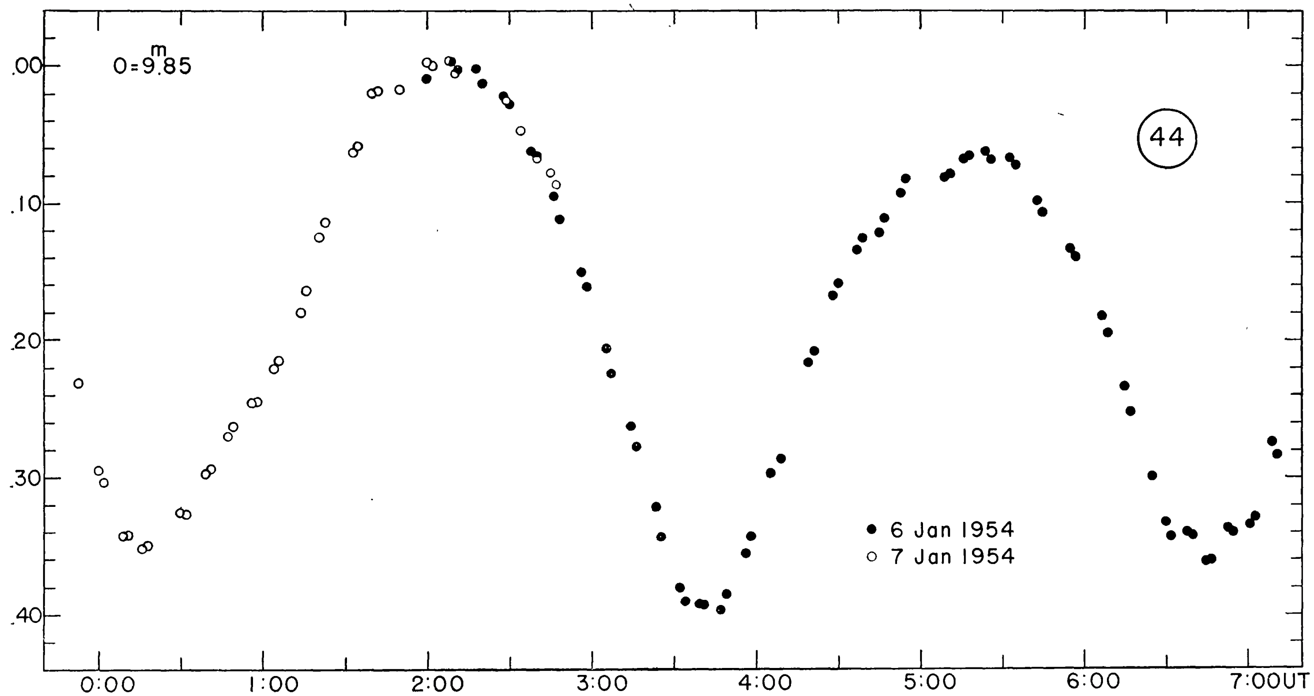



FIG. 12.—Light-curve of 44 Nysa

This will lead to a synodic period of $6^h25^m.2 \pm 0^m.1$. This period is identical with that derived by Shatzel. The interval between the two sets of data is 1522 days, or roughly 6000 periods. Clearly, a good epoch on a third opposition is needed to define the precise number of cycles and the sense of the rotation.

The shape of the light-curve in 1954 was similar, although different in detail from 1949; in particular, the minima were not flat, as in 1949. The 1954 amplitude was 0.40 mag., against 0.46 in 1949.

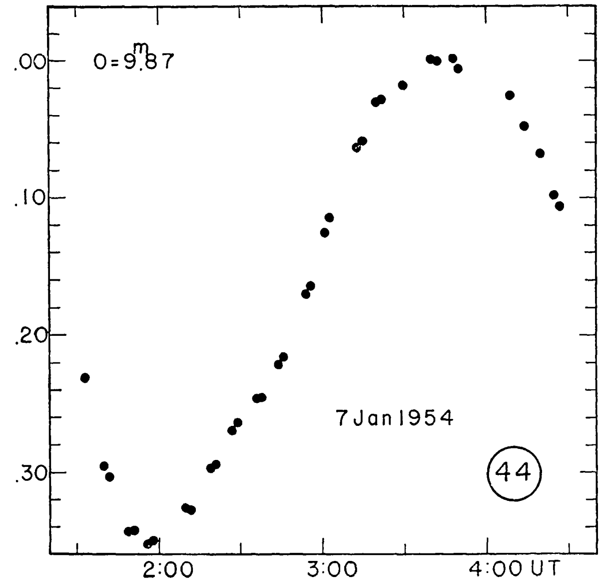



FIG. 13.—Observations of 44 Nysa

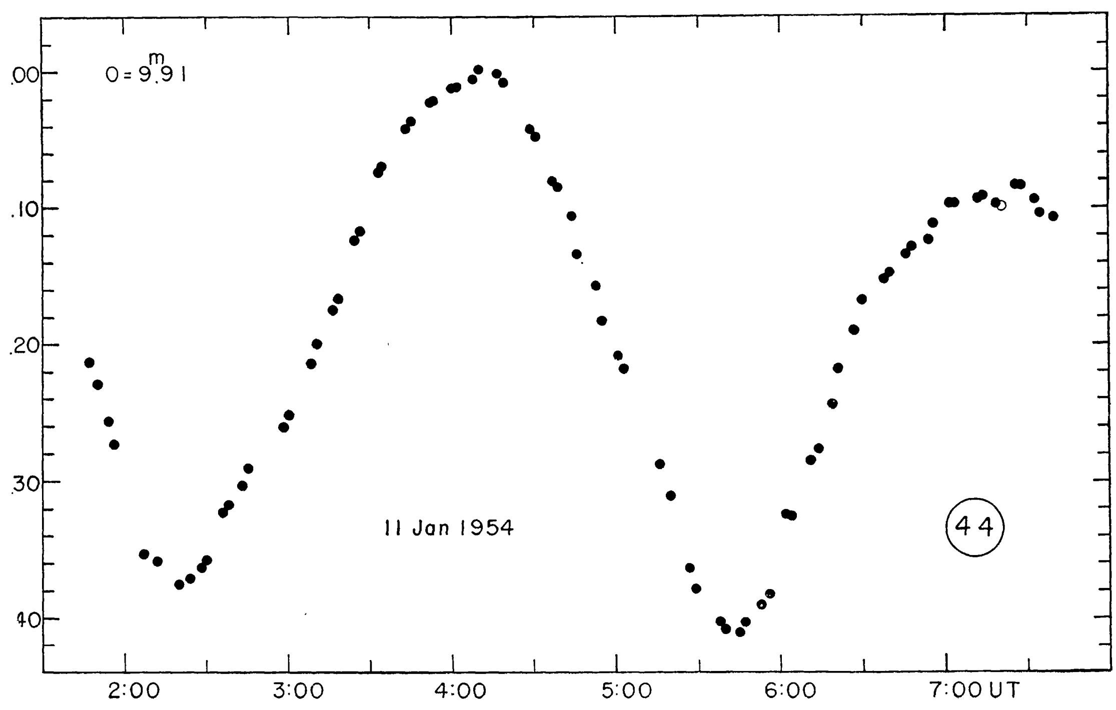



FIG. 14.—Light-curve of 44 Nysa

*354 Elenora.*—The observations on January 5, 1954, shown in Figure 15, define a light-curve of curious complexity. The first and last third of the run appear to cover the same phase of the cycle. They were combined to derive the shape of this part of the light-curve, which resulted in the full-drawn curves. The period so found is $4^h11^m$. As usual, two maxima and two minima are present in one complete cycle, and the total amplitude is 0.15 mag.

Observations on the next night were made during $2\frac{1}{2}$ hours (see Fig. 16). They are less accordant than those on January 5 but define the steep slope following the primary minimum and also the secondary maximum. The curve of January 5 is drawn in for comparison. The magnitude of the secondary maximum is then 10.10 on January 6 and 10.12 on January 5. The total reduction of January 6 to January 5 is +0.023 mag. if the phase coefficient 0.03 mag/degree is used. Therefore, the agreement between the two nights is complete.

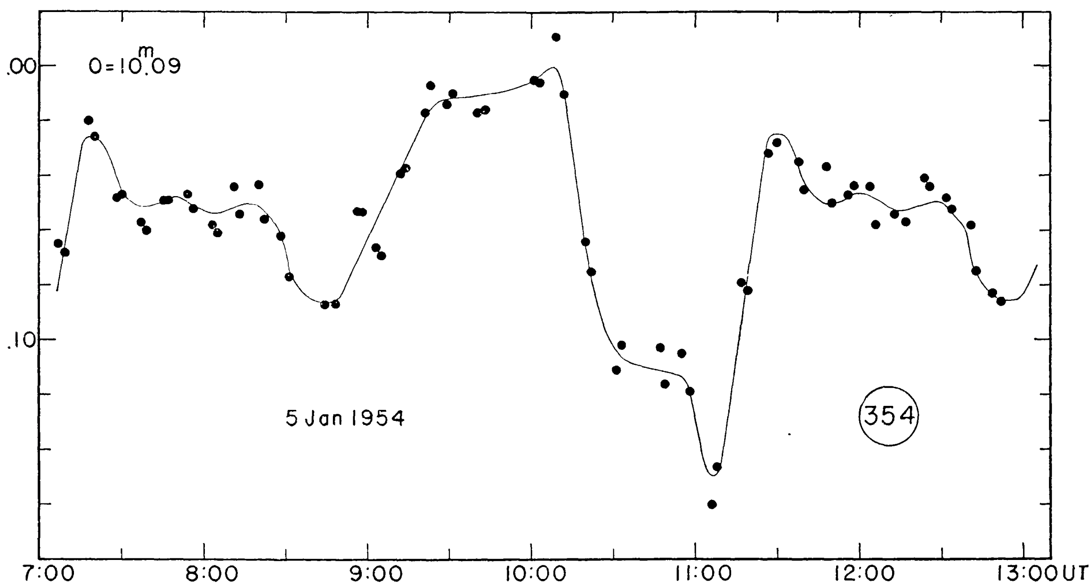



Fig. 15.—Light-curve of 354 Elenora

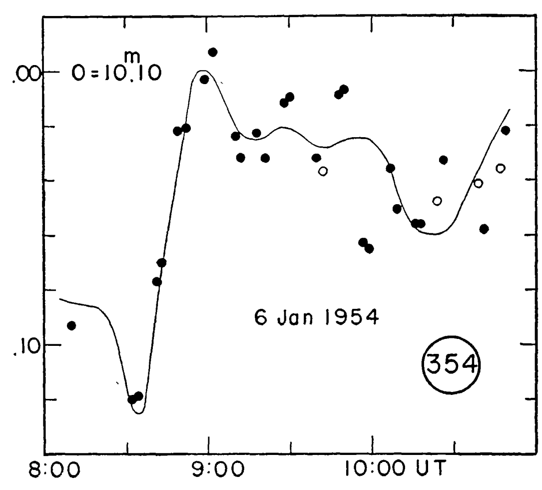



Fig. 16.—Observations of 354 Elenora

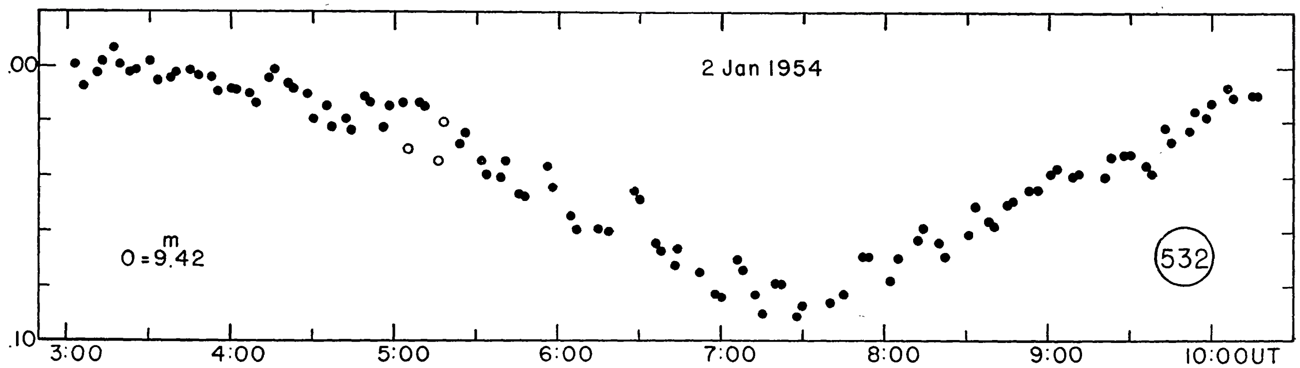



FIG. 17.—Observations of 532 Herculina

The steep slope on January 6, combined with the first slope on January 5, must be separated by six periods, making each period $4^h16^m$. This is 5 minutes more than the period found from January 5 alone, a discrepancy somewhat larger than expected. One suspects a lack of strict periodicity, but this requires confirmation. A color measurement was made on a third night, as is shown in Table 1.

*532 Herculina*.—A single night's run, of 7.3 hours, shown in Figure 17, gives a well-

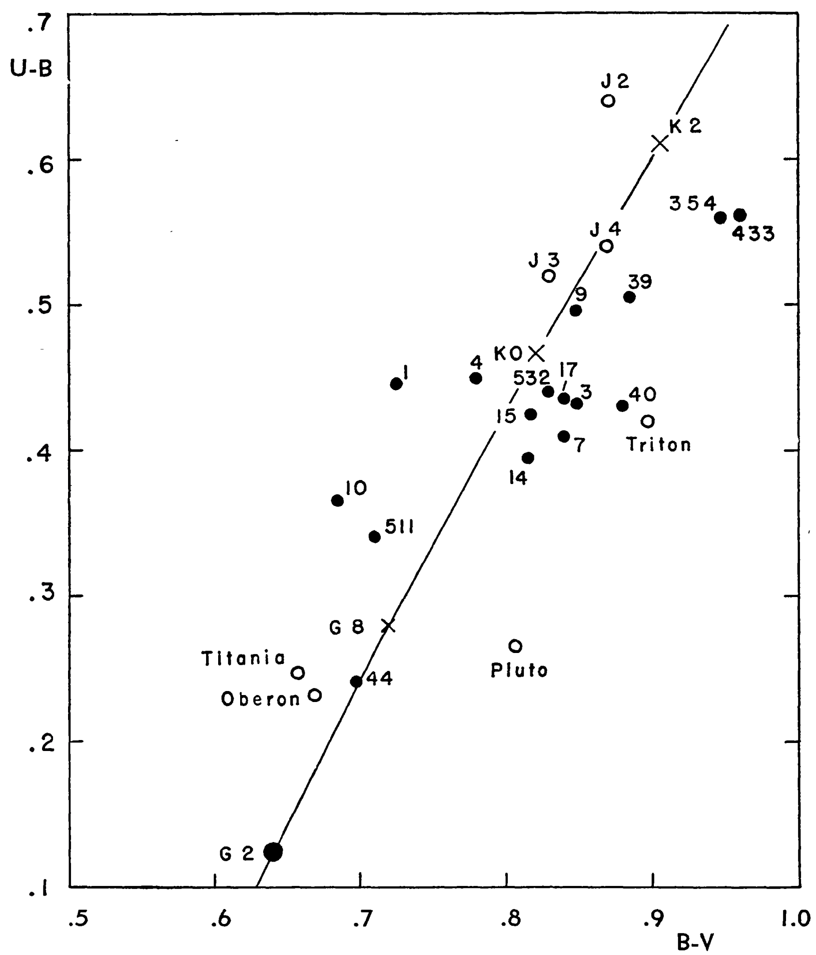



FIG. 18.—Colors, $B - V$ and $U - B$, of asteroids (*black dots*) compared to main-sequence stars (*line*) and selected satellites (*open circles*). Approximate position of sun is at *G2*.

defined variation, with an amplitude of 0.08 mag. and a suggested quarter-period of $4^h10^m \pm 10^m$. Accordingly, a period of some 16–17 hours is indicated.

## THE COLORS

The measures of color, both $B - V$ and $U - B$, are listed in Table 1. The combined color data of Paper I and this paper are shown graphically in Figure 18; the averages for each asteroid were used. The main sequence is indicated by the line and the symbols G2, G8, K0, and K2; the values are slightly smoothed means computed from the measures listed by Morgan, Harris, and Johnson (1953). Three of the Galilean satellites of Jupiter and two Uranus satellites are included for comparison. Jupiter I, at $B - V = 1.19$ and

$U - B = 1.11$ is well off the diagram; its colors correspond almost exactly to 61 Cygni A, dK5. The color of the moon is roughly $B - V = 0.98$. The Saturn satellite Dione is nearly as white as Oberon and Titania; Iapetus, Tethys, and Rhea follow, in order of increasing yellowness.

The precision of the dots in Figure 18 may be determined from the differences between nightly means for asteroids measured on more than one night. One thus finds that the p.e. per nightly result is $\pm 0.008$ mag. in $B - V$ and $\pm 0.012$ mag. in $U - B$. Since, on the average, 2 nights were combined in each dot, their average probable errors are about $\pm 0.006$ and $\pm 0.008$ mag. This proves that the asteroids shown in Figure 18 do not have identical colors. This conclusion cannot be reached from a list of photographically determined colors (Recht 1934), as is shown by a comparison of that list with the photoelectric data.

The asteroids are, on the average, slightly yellow, somewhat like a K0 main-sequence star, though they are slightly stronger in the ultraviolet than dK0. These results are of great interest in connection with studies of the presence of tenuous atmospheres for bodies like Pluto, Triton, etc., on the basis of their ultraviolet excess. This matter will be more fully discussed elsewhere; but it may be stated here that if the asteroids are used as a basis for comparison, Titan ($B - V = 1.28$, $U - B = 0.74$), Triton, and Pluto show such an excess, while the Jupiter satellites do not (cf. Fig. 18). On the contrary, the latter are slightly deficient in ultraviolet when compared to the asteroids; this fact adds to the interest of the three objects deviating from the asteroids in the opposite sense.

Figure 18 shows no evidence of a close relation between asteroid color and dimension. It is true that Eros is somewhat yellower than Ceres and Vesta, but objects of intermediate size exist both whiter and yellower than these large objects. One might perhaps expect some correlation between albedo and color, since a pulverized surface might be both brighter and whiter than the original one. Yet the proximity of Ceres and Vesta in Figure 18, in spite of their difference in albedo, indicates that such a correlation, if present, must be weak. This matter will be examined more fully upon completion of diameter measurements now in progress.

We are indebted to Dr. H. Kienle, Director of the Sternwarte Königstuhl, Heidelberg, for having made this collaboration possible by arranging the leave of absence of one of us (I. G.).

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