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UBV photometry of the minor planets 86 Semele, 521 Brixia, 53 Kalypso and 113 Amalthea (*)

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Summary. — Asteroids 86 Semele, 521 Brixia and 53 Kalypso, 113 Amalthea were observed photometrically during the 1980 and 1981 oppositions, respectively. The *V* lightcurve of 86 Semele displays two asymmetric maxima and minima with a total amplitude $\Delta V = 0.18$ mag. The derived synodic rotation period for this minor planet is $P_s = 16^h38^m02^s \pm 16^s$ and the color indices are found to be $B\text{-}V = 0.690 \pm 0.011$ and $U\text{-}B = 0.320 \pm 0.015$ mag. For 521 Brixia, we can just state that this asteroid is a slow rotator ($P_s > 24^h$) showing light variations greater than $\Delta V \simeq 0.09$ mag and with color indices $B\text{-}V = 0.714 \pm 0.008$ and $U\text{-}B = 0.337 \pm 0.011$ mag. It is very likely that 53 Kalypso rotates with a period $P_s = 26^h33^m \pm 4^m$ with a total light amplitude $\Delta V > 0.10$ mag and color indices $B\text{-}V = 0.692 \pm 0.015$ and $U\text{-}B = 0.341 \pm 0.022$ mag. The lightcurve of 113 Amalthea shows large amplitude variations ($\Delta V > 0.26$ mag) with a noticeable broad minimum. However, only part of the rotation cycle was covered by our observations and we can just ascertain that the rotation period of 113 Amalthea is greater than 12^h with measured color indices equal to $B\text{-}V = 0.888 \pm 0.012$ and $U\text{-}B = 0.487 \pm 0.019$ mag. Let us finally mention that the *B-V* and *U-B* color indices of these four minor planets do not present any variation exceeding the mean scatter over the observed rotation cycles.

Key words : asteroids — minor planets — lightcurves — rotation period — 86 Semele, 521 Brixia, 53 Kalypso and 113 Amalthea.

1. **Introduction.** — The Ephemeris of Minor Planets for the years 1980 (I.T.A., 1980) and 1981 (I.T.A., 1981) predicted oppositions for 86 Semele, 521 Brixia, 53 Kalypso and 113 Amalthea on 13 October 1980, 4 November 1980, 2 April 1981 and 9 April 1981 with $B_{opp} = 12.5$, 11.4, 12.9 and 11.9 mag, respectively.

Photometric observations of asteroids 86 Semele, 521 Brixia and 53 Kalypso, 113 Amalthea in the standard *UBV* system were therefore carried out during two distinct observing runs 2-17 October 1980 and 4-5 April 1981 — a few nights being rejected because of bad weather conditions — with the ESO 50 cm telescope at the observatory of La Silla (ESO, Chile).

Table I summarizes the dates of our observations, the right ascension and declination, the ecliptic longitude and latitude, the geocentric distance Δ, the heliocentric distance r, the phase angle α, the light time, the comparison star used for each of the four minor planets and the number of the figure corresponding to the given date and object. The aspect data were computed by using the MP-programme complex designed and kindly put at our disposal by R. M. West.

Table II namely includes the identification, colors and magnitude of the comparison stars observed with each asteroid (cf. Table I).

Until today, the only photometric data available for these four minor planets are very fragmentary : 86 Semele is known to show light variations with a total amplitude $\Delta V < 0.4$ mag and 113 Amalthea with $\Delta V > 0.2$ mag and a rotation period $P_s > 10^h$ (see Tedesco, 1979 and references therein). Debehogne *et al.* (1982) report a possible synodic rotation period of about 27^h, with an amplitude $\Delta V \geqslant 0.09$ mag for 53 Kalypso.

Furthermore, Bowell *et al.* (1979) provide the taxonomic types, diameters (in km) and *B-V, U-B* color indices for 86 Semele (C, 113, 0.68, 0.32), 521 Brixia (C, 136, 0.71, 0.36), 53 Kalypso (C, 110, 0.71, 0.32) and 113 Amalthea (U, 48.6, 0.93, 0.51). For the latter, Morrison and Zellner (1979) also report accurate values for the radiometric diameter $d = 47$ km and visual albedo $A_V = 0.244$.

2. **Observations.** — A single-channel photometer equipped with an EMI 6256 photomultiplier, Schott standard filters for the *UBV* magnitudes and a Pelletier cooling system was used in the pulse counting mode for the photoelectric measurements. A similar value of 22 arcsec for the diaphragm was used during the two observing runs and a basic integration time of 40 s (resp. 30 s) was chosen for each single measurement of 86

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Semele and 521 Brixia (resp. 53 Kalypso and 113 Amalthea).

The general observing routine included frequent measurements of the asteroid, sky, comparison star and some E-region standard stars (Cousins and Stoy, 1962). The data were reduced to the standard *UBV* system in the usual way, taking into account the first and second order extinction as well as a linear color transformation.

3. **Lightcurves and rotation period for 86 Semele.** — Figures 1-5 illustrate the V photoelectric magnitudes of 86 Semele *versus* U.T., recorded on 3, 4, 5, 6, 11 October 1980. For these and all subsequent lightcurves, no correction has been applied for the distance, phase and light time effects.

Figure 6 represents the mean composite lightcurve of 86 Semele constructed from the five single ones when taking into account the distance (see Table I) and phase — a mean phase coefficient $\beta = 0.051$ mag/deg leading to the best-fitting-effects. The horizontal line in figure 6 refers to a mean magnitude level, the areas enclosed by the composite lightcurve above and below that line being equal. One sees that a full cycle of light variations consists of two asymmetric maxima M_1, M_2 and minima m_1, m_2. The total amplitude of the V lightcurve is easily derived to be $\Delta V = 0.18$ mag. As usually, these gross characteristics of 86 Semele's lightcurve are the best interpreted as being due to the changing shape of the asteroid during its rotation. Let us notice that the small hump located near the rotational phase 0.8 in figure 6 is very probably due to spottedness over the minor planet's surface. Van Houten (1965) has first proposed that such a feature could result from near-specular reflection from a rather small flat area.

Table III gives the epochs and time lapses between similar extrema appearing in the V lightcurve of 86 Semele. Assigning weights proportional to the number of cycles elapsed between two similar extrema, we derive the following synodic rotation period

$$P_s = 16^h38^m02^s \pm 16^s \text{ or } 0^d.69307 \pm 0^d.00018 .$$

By fitting the V lightcurve of 86 Semele recorded on 4 October 1980 (see Fig. 2) with the composite lightcurve in figure 6, we are able to calculate a mean magnitude $\overline{V}(r, \alpha)$, and subsequently the mean magnitudes $\overline{V}(1, \alpha)$ and $\overline{V}(1,0)$ at unit distances (i.e. for $r\Delta = 1$) and zero phase angle (see Table II, assuming that $\beta = 0.051$ mag/deg). We have also reported in table II the magnitudes $V_0(r, \alpha)$, $V_0(1, \alpha)$ and $V_0(1, 0)$ for the primary maximum M_1. Finally, out of 298 single measurements, the B-V and U-B color indices derived for 86 Semele are found to be in good agreement with previously published values (cf. Sect. 1 and table II). These indices do not show any variation during a full rotation cycle which exceeds the mean scatter of the observations.

4. **Lightcurves and results for 521 Brixia.** — Figures 7-13 display the photometric measurements of 521 Brixia in the V filter obtained on the seven nights 7, 8 and 11-15 October 1980. Considering a fictive feature at the magnitude level $V = 11.05$ mag on 7 October 1980 and after correction for the distance (cf. Table I) and phase effects ($\beta = 0.036$ mag/deg has been assumed for C-type asteroids ; see Bowell and Lumme, 1979), the different horizontal dashed lines in figures 8-13 indicate for the other nights the location at which this same feature would appear in the lightcurve of 521 Brixia.

After many plausible combinations and trials, it has not been possible to find any satisfactory fitting between the individual lightcurves which would have led to the determination of a rotation period for 521 Brixia. We can only conclude that 521 Brixia is a slow rotator with $P_s > 24^h$ and that the total light amplitude is greater than $\Delta V = 0.09$ mag. The measured B-V and U-B color indices of 521 Brixia are reported in table II and these are found to be in good agreement with values compiled by Bowell *et al.* (1979).

5. **Lightcurves and rotation period for 53 Kalypso.** — The V photoelectric magnitudes recorded for 53 Kalypso on 4 and 5 April 1981 are illustrated in figures 14 and 15, respectively. As suggested by Dr. Zappalà, the maximum observed on 5 April looks very much the same as the one recorded by Debehogne *et al.* (1982) on 16 March 1981 ([1]). After correction for the distance (cf. Table I) and phase effects ($\beta = 0.045$ mag/deg) a good superposition between the four lightcurves observed on 16, 17 March (Debehogne *et al.*, 1982) and 4, 5 April 1981 could be obtained (see Fig. 16) when adopting $P_s = (478 \pm 1^h)/18$, i.e.

$$P_s = 26^h33^m20^s \pm 4^m$$

for the synodic rotation period of 53 Kalypso. This result refines the approximate value of 27^h first suggested by Debehogne *et al.* (1982).

Identifying the primary maximum of 53 Kalypso's lightcurve with M_1 in figure 16, we have reported in table II the magnitudes $V_0(r, \alpha)$, $V_0(1, \alpha)$ and $V_0(1, 0)$ altogether with the observed color indices. The latter agree quite well with previous published values (cf. Sect. 1).

6. **Lightcurves and results for 113 Amalthea.** — For 113 Amalthea, the photometric observations carried out on 4 and 5 April 1981 and illustrated in figures 17 and 18 consist of two distinct parts of the V lightcurve. From these data alone, we can only state that the rotation period of this asteroid is greater than 12^h and that the total light amplitude is $\Delta V > 0.26$ mag. We shall notice the broad and deep minimum recorded on 5 April 1981 and after a careful check of the photometric accuracy on 4 April 1981, we can ascertain with great confidence that the jump-like behaviour of the V lightcurve in figure 17 is real.

The measured color indices of 113 Amalthea (see Table II) are quite typical for a U-type asteroid, in good agreement with the taxonomic type assigned by Bowell *et al.* (1979).

Acknowledgements. — We are indebted to S. Vidal and R. Arancibia, ESO, Chile, for their help in carrying preliminary reductions of the photometric data.

([1]) There is an error in figure 1 of the paper by Debehogne *et al.* (1982). The date referring to the upper lightcurve should be « 17 March » and that to the lower « 16 March » (Zappalà, 1982).

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TABLE I. — *Aspect data, light times, comparison stars and figure numbers for the minor planets 86 Semele, 521 Brixia, 53 Kalypso and 113 Amalthea.*

Date of observation (0^h U.T.)	R.A. (1950.0)	Decl. (1950.0)	λ (1950.0)	β (1950.0)	Δ (A.U.)	r (A.U.)	α	Light time	Comp. star	Figure
86 Semele										
Oct. 3,1980	$1^h18^m57^s$	+0°01'26"	18°.229	-7°.700	1.4539	2.4422	4°.7	$0^d.00840$	C1	1
4,	1 18 13	+0 02 49	18.067	-7.609	1.4519	2.4417	4.4	0.00839	C1	2
5,	1 17 29	+0 07 01	17.922	-7.475	1.4502	2.4411	4.1	0.00838	C1	3
6,	1 16 44	+0 11 10	17.773	-7.340	1.4487	2.4406	3.8	0.00837	C1	4
11,	1 12 55	+0 31 00	17.011	-6.672	1.4451	2.4380	3.1	0.00835	C1	5
521 Brixia										
Oct. 7,1980	$2^h56^m55^s$	-1°31'25"	41°.293	-17°568	1.0693	1.9859	15°.7	$0^d.00618$	C2	7
8,	2 56 32	-1 34 11	41.183	-17.583	1.0641	1.9850	15.3	0.00615	C2	8
11,	2 55 12	-1 41 58	40.808	-17.606	1.0494	1.9825	14.1	0.00606	C2	9
12,	2 54 42	-1 44 22	40.671	-17.607	1.0449	1.9817	13.7	0.00603	C2	10
13,	2 54 09	-1 46 39	40.521	-17.602	1.0406	1.9809	13.3	0.00601	C2	11
14,	2 53 36	-1 48 50	40.372	-17.595	1.0365	1.9802	12.9	0.00599	C2	12
15,	2 53 00	-1 50 52	40.212	-17.581	1.0326	1.9794	12.5	0.00596	C2	13
53 Kalypso										
Apr. 4,1981	$12^h43^m46^s$	+2°04'05"	189°.243	+6°.233	1.5658	2.5605	3°.0	$0^d.00904$	C3	14
5,	12 42 55	+2 10 34	189.004	+6.249	1.5688	2.5627	3.3	0.00906	C3	15
113 Amalthea										
Apr. 4,1981	$13^h15^m01^s$	+1°39'02"	196°.667	+8°.876	1.1783	2.1713	4°.3	$0^d.00681$	C4	17
5,	13 14 09	+1 45 49	196.421	+8.898	1.1775	2.1712	4.2	0.00680	C4	18

TABLE II. — *Magnitudes and colors of the asteroids 86 Semele, 521 Brixia, 53 Kalypso, 113 Amalthea and of their associated comparison stars. $\bar{V}$ (resp. $\bar{B}$) refers to the mean V (resp. B) magnitude of the composite lightcurve, whereas V_0 (resp. B_0) indicates the V (resp. B) magnitude of the primary — or only recorded — maximum M_1.*

Object	B-V	U-B	$\bar{V}(r,\alpha)$ or V	$V_o(r,\alpha)$	$\bar{V}(1,\alpha)$	$V_o(1,\alpha)$	$\bar{V}(1,0)$	$V_o(1,0)$	$\bar{B}(1,0)$	$B_o(1,0)$
86 Semele	0.690±0.011	0.320±0.015								
(mean from 298 meas.)	ref. to Oct.4, 1980 :		11.64	11.57	8.89	8.82	8.67	8.60	9.36	9.29
C1	0.496±0.009	0.090±0.009	11.100±0.012							
(not catalogued) R.A.=$1^h17^m.9$ Decl.=+0°08'.1 (1950.0)										
521 Brixia	0.714±0.008	0.337±0.011								
(mean from 223 meas.)										
C2	0.617±0.006	0.191±0.007	10.337±0.006							
(not catalogued) R.A.=$2^h55^m.7$ Decl.=-1°37'.1 (1950.0)										
53 Kalypso	0.692±0.015	0.341±0.022								
(mean from 103 meas.)	ref. to Apr.5, 1981 :		____	12.02	____	9.00	____	8.88	____	9.57
C3	0.583±0.009	0.123±0.018	11.031±0.016							
(not catalogued) R.A.=$12^h43^m.6$ Decl.=+2°01'.4 (1950.0)										
113 Amalthea	0.888±0.012	0.487±0.019								
(mean from 72 meas.)										
C4	0.353±0.005	-0.004±0.012	10.366±0.009							
(not catalogued) R.A.=$13^h15^m.4$ Decl.=+1°32'.7 (1950.0)										

TABLE III. — *Epochs and time lapses for the different extrema appearing in the V lightcurve of 86 Semele.*

Epoch (U.T.,1980)	Extremum	Time lapse (n° of cycles)
3 oct., $5^h.000 \pm 0^h.030$	m_2	$49^h.923$
5 oct., 6.923		(3)
4 oct., $5^h.000$	M_1	$49^h.882$
6 oct., 6.882		(3)
4 oct., $8^h.000$	m_1	$166^h.335$
11 oct., 6.335		(10)

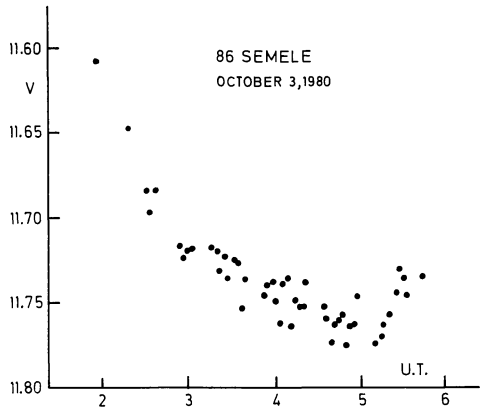

FIGURE 1. — *V* lightcurve of 86 Semele on 3 October 1980.

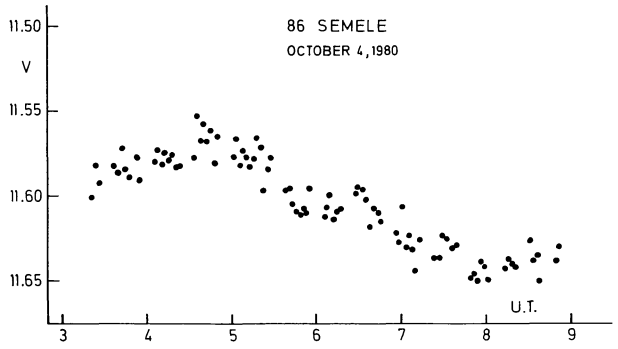

FIGURE 2. — *V* lightcurve of 86 Semele on 4 October 1980.

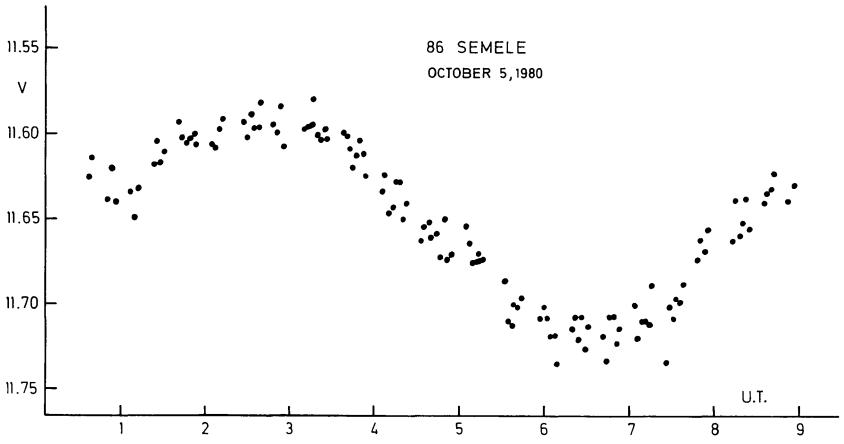

FIGURE 3. — *V* lightcurve of 86 Semele on 5 October 1980.

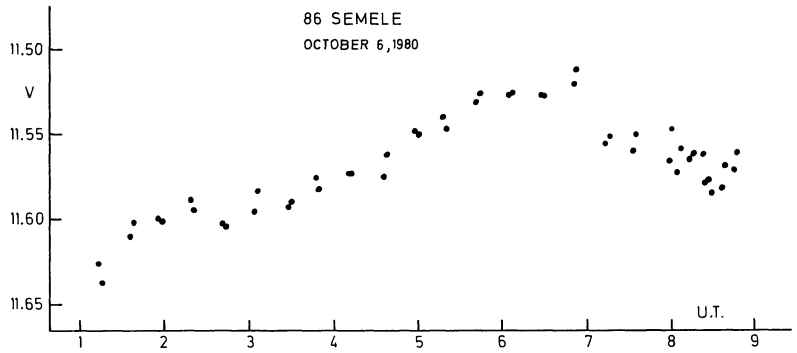

FIGURE 4. — *V* lightcurve of 86 Semele on 6 October 1980.

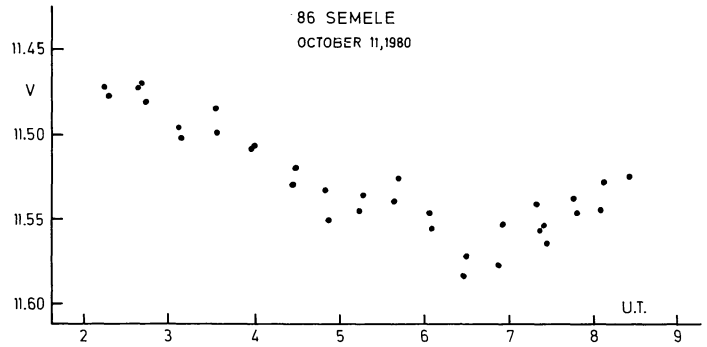

FIGURE 5. — *V* lightcurve of 86 Semele on 11 October 1980.

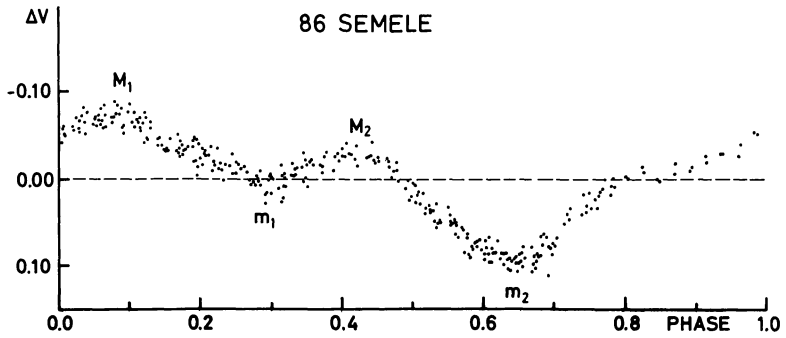

FIGURE 6. — Composite lightcurve of 86 Semele. The ordinates are referred to the mean magnitude line (see Text).

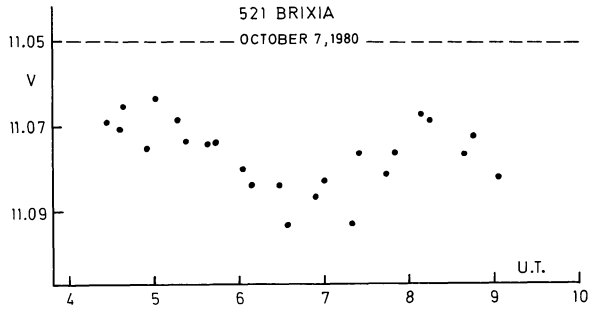

FIGURE 7. — *V* lightcurve of 521 Brixia on 7 October 1980. In this and figures 8-13, the horizontal dashed line indicates the fictive location of a same feature when allowance is made for the distance and phase effects (see Text).

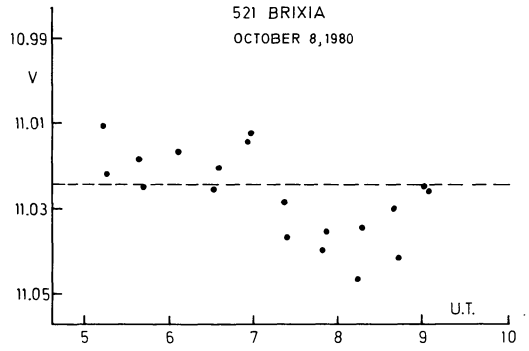

FIGURE 8. — *V* lightcurve of 521 Brixia on 8 October 1980.

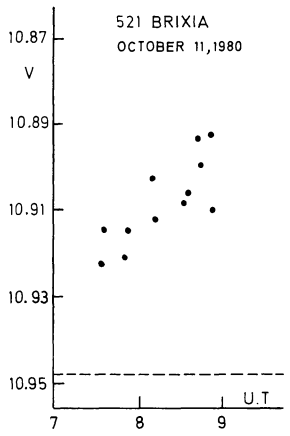

FIGURE 9. — *V* lightcurve of 521 Brixia on 11 October 1980.

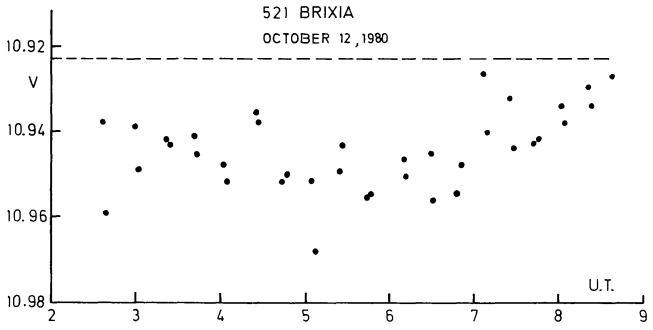

FIGURE 10. — *V* lightcurve of 521 Brixia on 12 October 1980.

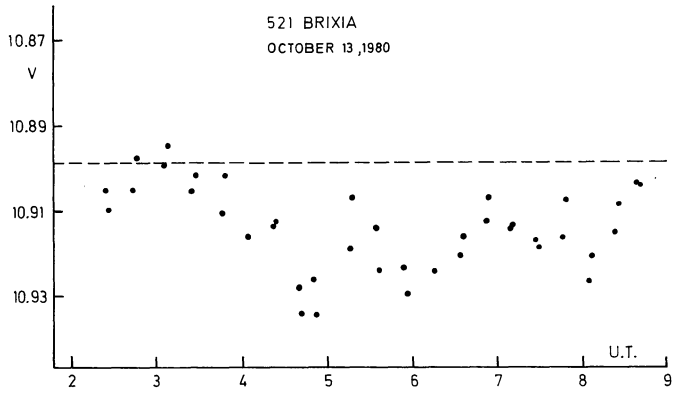

FIGURE 11. — *V* lightcurve of 521 Brixia on 13 October 1980.

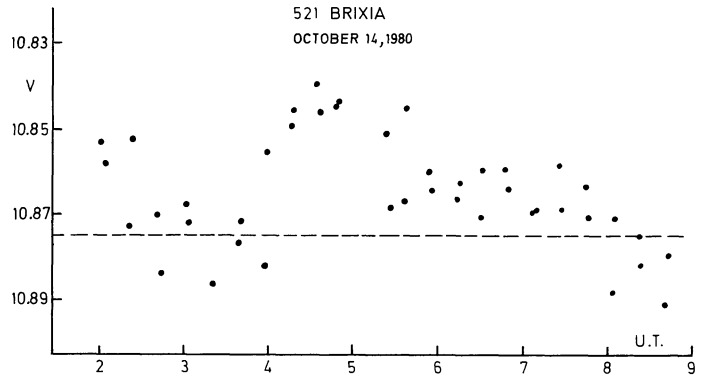

FIGURE 12. — *V* lightcurve of 521 Brixia on 14 October 1980.

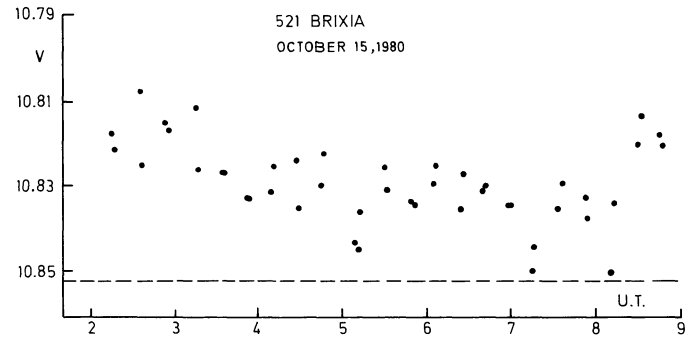

FIGURE 13. — *V* lightcurve of 521 Brixia on 15 October 1980.

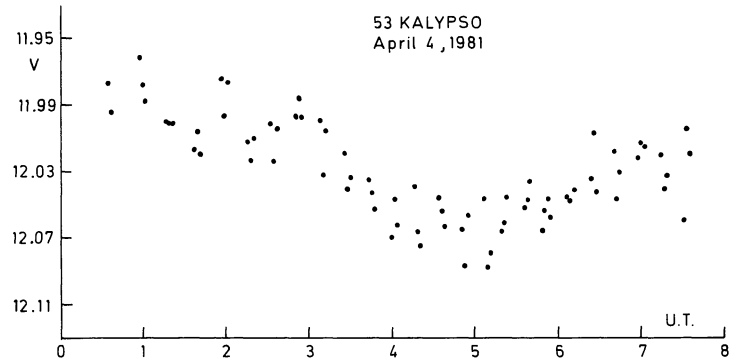

FIGURE 14. — *V* lightcurve of 53 Kalypso on 4 April 1981.

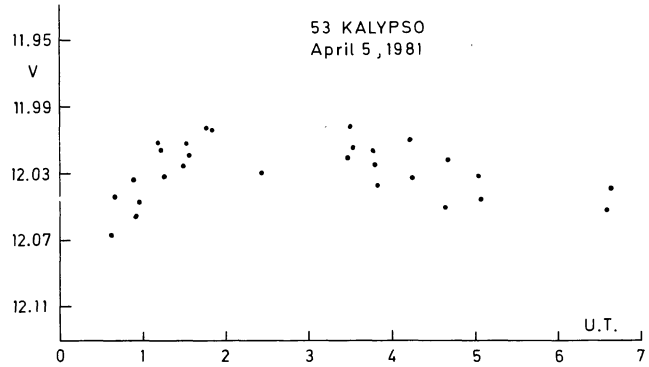

FIGURE 15. — *V* lightcurve of 53 Kalypso on 5 April 1981.

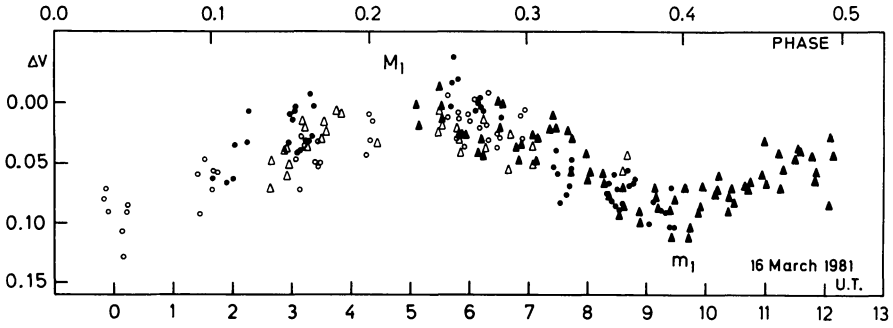

FIGURE 16. — Composite lightcurve of 53 Kalypso, adopting a period of 26^h.56 and a phase coefficient β_V = 0.045 mag/deg. The different symbols (●, ○, ▲, △) refer to observations made on 16, 17 March (Debehogne *et al.*, 1982) and 4, 5 April 1981. The times are reduced to 16 March 1981 and the ordinates are referred to the maximum M_1 (see Text).

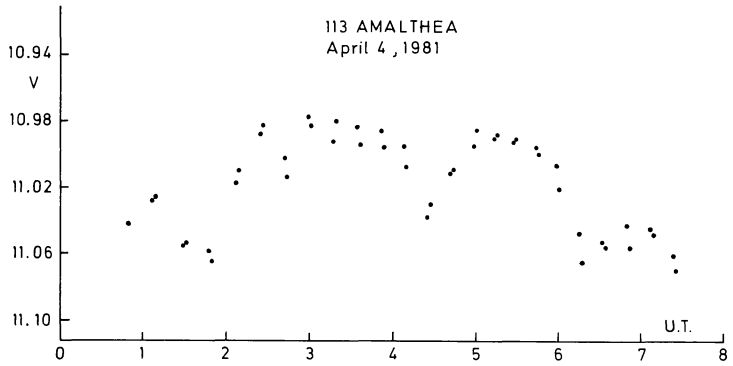

FIGURE 17. — *V* lightcurve of 113 Amalthea on 4 April 1981.

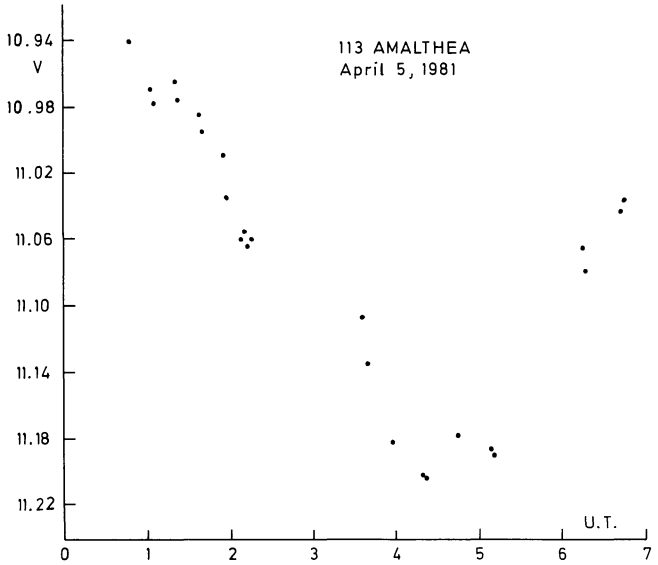

FIGURE 18. — *V* lightcurve of 113 Amalthea on 5 April 1981.