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PHOTOELECTRIC PHOTOMETRY OF SEVEN ASTEROIDS

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Photoelectric light curves of the asteroids 19 Fortuna, 23 Thalia, 24 Themis, 28 Bellona, 29 Amphitrite, 43 Ariadne, and 54 Alexandra are presented as observed by I. and C.J. van Houten at the Leiden Southern Station in South Africa from February to July 1965.
For each asteroid a value of the rotation period as well as the values of the magnitudes of the primary maxima and the $B-V$ colours are determined and summarized in table 2.
Where observations of other authors are available, a comparison with the rotational properties as found here is made.

Key words: asteroids – light curve – photometry – rotational period

OBSERVATIONS

This paper presents observations of seven minor planets made by I. and C.J. van Houten at the Leiden Southern Station near Hartebeespoortdam in South Africa from February to July 1965. The asteroids presented were, for the most part, not observed before 1965. Subsequent results by other observers will be discussed here. For information on the instrumental facilities and methods of observations and reduction we refer to Zappalà *et al.* (1978).

Table 1 gives the aspect data for the asteroids taken from the daily ephemerides kindly sent to us by Herget (private communication). Table 2 reports information on magnitudes, colours, amplitudes and periods of the minor planets, the names of comparison stars and remarks; V_0 and $V_0(1, \alpha)$ are, respectively, the observed magnitude of the primary maximum, and the magnitude of the primary maximum reduced to the unit distances. Some of the periods differ from those listed by Taylor (1971), because I. and C.J. van Houten put to his disposal preliminary results only. Table 3 gives the epochs of the extrema which we use for period determinations. They are listed in Julian Days corrected for light time.

19 Fortuna

This object was observed by Yang *et al.* (1965) on two consecutive nights in 1963 and a period $P_{syn}=7.43$ hours was reported.

The light curves of 1965 Mar 21–22 and Mar 22–23 are given in figures 1 and 2. The extrema are identified in the usual way by m_1, m_2, M_1 and M_2. From the epochs of M_2 and m_2, we obtain a mean synodic period $P_{syn}=7^h.50 \pm 0^h.02$. This value agrees well with the result of Yang *et al.*, taking into account that the number of cycles was very small in both oppositions. The maximum observed amplitude in our observations is $0^m.255$, very close to the value of $0^m.25$ obtained by Yang *et al.* (1965).

Zellner *et al.* (1975) adopted $B-V=0.76$ mag and $U-B=0.39$ mag, while Chapman *et al.* (1975) derived a very low geometrical albedo: $p_v=0.032$. Moreover Zellner and Bowell (1977) classified 19 Fortuna as a C type object with a diameter D = 215 km.

23 Thalia

Figures 3 and 4 show the observed light curves of 23 Thalia. They suggest the presence of a shallow secondary minimum so we conclude that the period is about 6 hours. This result is in contrast with the data of Yang *et al.* (1965) who found a period of 12.308 hours. We should note that Yang *et al.* (1965) used, for their composite light curve, runs at very different phase angles, and did not consider the dependence of the form of the light curve upon the phase angle. Accordingly their conclusion that the lower maximum of December 21 was not the same as that for the runs from January 31 to February 3 may be incorrect. We can easily make the hypothesis that they always observed the same maximum. In such a way a period of 6.154 hours satisfies their observations very well, taking into account that the run of December 21 was made at $6^{\circ}.0$ phase, while the remaining three were observed at about $19^{\circ}.7$. From the epochs of m_1 and M_1 in 1965 we determined the period $P_{\mathrm{syn}} = 6^{\mathrm{h}}.150 \pm 0^{\mathrm{h}}.011$, very close to the new value adopted from the observations of Yang *et al.* (1965).

Figure 5 shows the mean light curve of December 21, 1963 and the mean one obtained averaging the observations of January 31, February 2 and 3, 1964. In the upper part the composite light curve of 1965 June 6–7 and 8–9 is plotted. A very good agreement in the shape is present and a small secondary minimum appears in both the oppositions.

Of course we cannot be completely sure to have solved the ambiguity between $6^{\mathrm{h}}.150$ and its double value; we think that observations longer than 10 hours or consecutive observations from observatories at different longitudes should be decisive for the solution of this problem.

Zellner *et al.* (1975) reported $B-V=0.87$ mag for 23 Thalia. Chapman *et al.* (1975) adopted a $p_v=0.172$ and more recently Zellner and Bowell (1977) classified Thalia as an S type object with a diameter of 111 km.

24 Themis

The present light curves are the only ones available. They are shown in figure 6 to 8 in the usual way. The runs suggest a very irregular shape for this object with several maxima and minima of very small amplitude. Only the highest maximum, indicated by M_1 in the figures, is easily recognized in the light curves of May 23–24 and 26–27. From these epochs a period $P_{\mathrm{syn}} = 8^{\mathrm{h}}.363 \pm 0^{\mathrm{h}}.013$ is calculated and this value also gives a very good fit to the May 27–28 observation. Figure 9 shows the mean light curve as obtained by superposition of the three runs. The B observations confirm the trend of the V ones, so the several humps are correlated probably with an irregular shape and not with a variation of the albedo on the surface of the asteroid.

Further observations at different aspects would be very useful to confirm the period and to see the changes in shape. For 24 Themis Zellner *et al.* (1975) published $B-V=0^{\mathrm{m}}.70$ and $U-B=0^{\mathrm{m}}.35$. Zellner and Bowell (1977) classified this asteroid as a C type object with an approximate diameter of 211 km.

28 Bellona

The observations of 1965 are the only ones available to date and they are shown in figures 10 to 12. They were made on two consecutive nights (February 27–28 and February 28–March 1) and one subsequent night, March 12–13. From the first two light curves we deduce that only periods ranging from 15 to 19 hours are possible. From this starting point a superposition of the light curves of February 27–28 and March 12–13, in which the same minimum is present, gives the following periods:

$$P_1 = 14^{\mathrm{h}}.950 \qquad P_2 = 15^{\mathrm{h}}.697 \qquad P_3 = 16^{\mathrm{h}}.523 \qquad P_4 = 17^{\mathrm{h}}.441 \qquad P_5 = 18^{\mathrm{h}}.467$$

Taking into account that the full cycle light curve seems to be quite regular, we calculated the deviations of the epochs of the extrema, for each possible period, assuming a theoretical light curve in which the maxima and minima are equally spaced at rotational phases $\phi = k\ x\ 0.25$ ($k=0, 1, 2, 3, 4$). The period P_3 gives the smallest standard deviation with minima separated by a rotational phase exactly equal to 0.5; therefore we adopt: $P_{\mathrm{syn}} = 16^{\mathrm{h}}.523 \pm 0^{\mathrm{h}}.009$. Of course, we cannot be sure that this asteroid has a regular shape, so further observations are strongly recommended to confirm our period. Zellner and Bowell (1977) classified 28 Bellona as an S type asteroid with a diameter of approximately 123 km.

29 Amphitrite

Amphitrite was observed photoelectrically for the first time by Chang and Chang (1963) in October and November 1962. They found a period of 5.389 hours with an unusual light curve showing three maxima and minima. This feature was confirmed by Debehogne *et al.* (1978) who gave a period of 5.390 hours. Also our observations, plotted in the usual way in figures 13, 14 and 15, show three maxima and minima. From all epochs of 1965 we derive a mean synodic period $P_{syn} = 5^{h}.390 \pm 0^{h}.005$ in very good agreement with the other values.

The plot of the mean light curves from the oppositions of 1962, 1965 and 1977 in figure 16 illustrates changes of shape with the aspect angle. The extrema show quite strong relative shifts. The light curves of 1965 and 1977 have similar minima which fall fairly close to 1/3 and 2/3 of the period. The 1962 curve shows one of these minima close to 1/2 of the period. The similarity of the 1965 and 1977 light curves may be attributed to the almost equal aspects, the differences in longitudes and latitudes being only 20° and 1°, respectively. The 1962 longitude differs by about 200° from that of 1977, so a different hemisphere of the asteroid was probably seen. These results could be explained by a "pyramidal" shape for Amphitrite, but it is not possible to construct a model from the light curves alone. An irregular shape such as this was seen in the asteroid 471 Papagena, which also showed three maxima and minima. It was observed in the 1976 opposition by several authors (Surdej and Surdej, 1977; Lustig, 1977; Scaltriti and Zappalà, 1978). For Amphitrite Zellner *et al.* (1975) adopted $B-V=0^{m}.83$ and $U-B=0^{m}.45$ and Chapman *et al.* (1975) gave a geometrical albedo of 0.135. 29 Amphitrite is classified as an S type asteroid with a diameter of 195 km by Zellner and Bowell (1977).

43 Ariadne

No observations of 43 Ariadne were made before 1965. In 1972 Burchi and Milano (1974) obtained nine single-night light curves and adopted a period $P_{syn} = 5.751$ hours. The 1965 light curves are presented in figures 17 and 18. The asteroid shows two maxima and minima per cycle with a maximum amplitude of 0.13 mag. Using the epochs of the extrema M_1 and m_1 we obtain $P_{syn} = 5^{h}.753 \pm 0^{h}.012$, in very good agreement with the value of Burchi and Milano (1974). These authors observed 43 Ariadne at ecliptic longitudes ranging from 345° to 331° and latitudes near 6°. Our observations fall at about $\lambda = 221°$ and $\beta = -5°$. The great difference in these coordinates and therefore in the aspect angles explains the very large change in amplitude ($0^{m}.66$ against $0^{m}.13$), suggesting a high inclination of the rotational axis and a quite elongated shape for the asteroid. Chapman adopted a $p_v = 0.123$ and Zellner and Bowell (1977) classified 43 Ariadne as an S type asteroid with a probable diameter of 82 km.

54 Alexandra

Also for this object no other information on rotational period is reported to date. We present observations (figures 19 and 20) on two consecutive nights, July 7–8 and 8–9. Two maxima and minima at different level are present in each light curve and we use the extrema m_2 and M_1 for the determination of the period. The result in $P_{syn} = 7^{h}.04 \pm 0^{h}.03$. Zellner *et al.* (1975) reported $B-V=0.76$ and $U-B=0.42$ and Zellner and Bowell (1977) classified 54 Alexandra as a C type asteroid with $D=180$ km.

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Table 1 Aspect data

Asteroid No	Date 1965 0^hUT	R.A. 1950	Decl. 1950	λ 1950	β 1950	r AU	Δ AU	α	Light time
19	Mar 22	$11^h45.4$	$+00°07'$	176°60	−01°34	2.736	1.741	1°6	$0^d.0101$
19	23	11 44.5	+00 13	176.36	−01.34	2.737	1.743	2.1	0.0101
23	Jun 7	16 39.0	−23 50	251.53	−01.68	2.884	1.871	1.6	0.0108
23	9	16 36.9	−23 52	251.06	−01.78	2.888	1.878	2.4	0.0108
24	May 24	16 34.1	−22 35	250.24	−00.60	3.145	2.139	2.5	0.0123
24	27	16 31.6	−22 30	249.66	−00.60	3.149	2.137	1.4	0.0123
24	28	16 30.7	−22 28	249.45	−00.60	3.150	2.137	1.0	0.0123
28	Feb 28	10 51.8	+11 47	159.79	+04.19	2.418	1.429	1.7	0.0082
28	Mar 1	10 51.0	+11 56	159.55	+04.26	2.419	1.430	1.7	0.0082
28	13	10 42.1	+13 41	156.87	+05.06	2.430	1.459	6.4	0.0084
29	Jun 24	18 08.1	−33 08	271.72	−09.70	2.707	1.700	3.6	0.0098
29	27	18 04.8	−33 07	271.02	−09.68	2.706	1.700	3.9	0.0098
29	Jul 4	17 57.3	−33 02	269.43	−09.59	2.703	1.710	5.7	0.0099
43	May 2	14 28.2	−19 49	221.10	−04.90	1.968	0.961	2.5	0.0055
43	4	14 26.2	−19 36	220.58	−04.85	1.964	0.958	2.8	0.0055
54	Jul 8	20 46.6	−24 10	307.57	−05.99	2.170	1.197	10.5	0.0069
54	9	20 45.8	−24 07	307.40	−05.89	2.170	1.193	10.0	0.0069

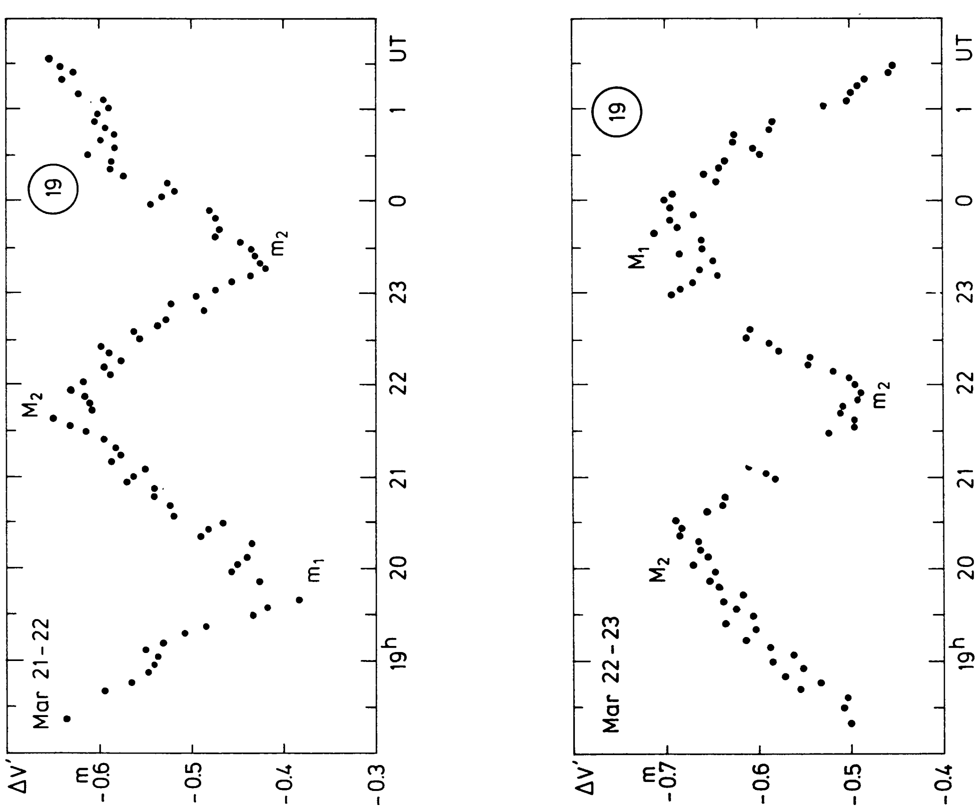
Table 2 Magnitudes, colours, amplitudes, periods and comparison stars

Asteroid No	Date 1965	V_o	$V_o(1,\alpha)$	B−V	$(B-V)_z$	Ampl. (m_1-M_1)	Period	Comparison Stars No	V	Remarks
19	Mar 21-22	$10^m.60$	$7^m.21$	$0^m.73$	$0^m.76$	$0^m.25$	$7^h.50$	BD + 0° 2842	$11^m.25$	
19	22-23	10.65	7.26	0.74		0.24		A	11.37	disturbed by clouds
23	Jun 6- 7	10.85	7.19	0.84	0.87	0.18	6.150	CoD−23°12887	8.80	seeing poor
23	8- 9	10.93	7.26	0.84		0.18		CoD−23°12887	8.80	
24	May 23-24	-	-	-	0.70	0.14		B	-	
24	26-27	11.33	7.19	0.66		0.14	8.363	BD −22° 4174	9.08	seeing poor
24	27-28	11.32*	7.18*	0.66		0.13*		BD −22° 4174	9.08	disturbed by clouds
28	Feb 27-28	10.00+	7.31+	0.84		0.17		BD +12° 2271	9.25	
28	Feb 28- 1	9.96+	7.26+	0.84		0.22	16.523	BD +12° 2271	9.25	
28	Mar 12-13	10.31	7.57	0.83		0.20		BD +14° 2290	11.17	
29	Jun 23	9.48	6.16	0.84	0.83	0.10		CoD−33°12924	7.60	excellent night
29	26	9.48	6.17	0.81		0.10	5.390	CoD−33°12851	10.13	
29	Jul 3- 4	9.57	6.24	0.84		0.13		CoD−33°12719	10.48	$21^h.9-22^h.9$ star close to ast.
43	May 1- 2	9.45	8.07	0.85		0.13	5.753	BD −19° 3899	8.15	
43	3- 4	9.46	8.08	0.84		0.13		BD −19° 3892	11.03	
54	Jul 7- 8	10.32	8.25	0.74	0.76	0.12	7.04	CoD−24°16289	9.60	
54	8- 9	10.29	8.22	0.74		0.12		CoD−24°16289	9.60	seeing poor

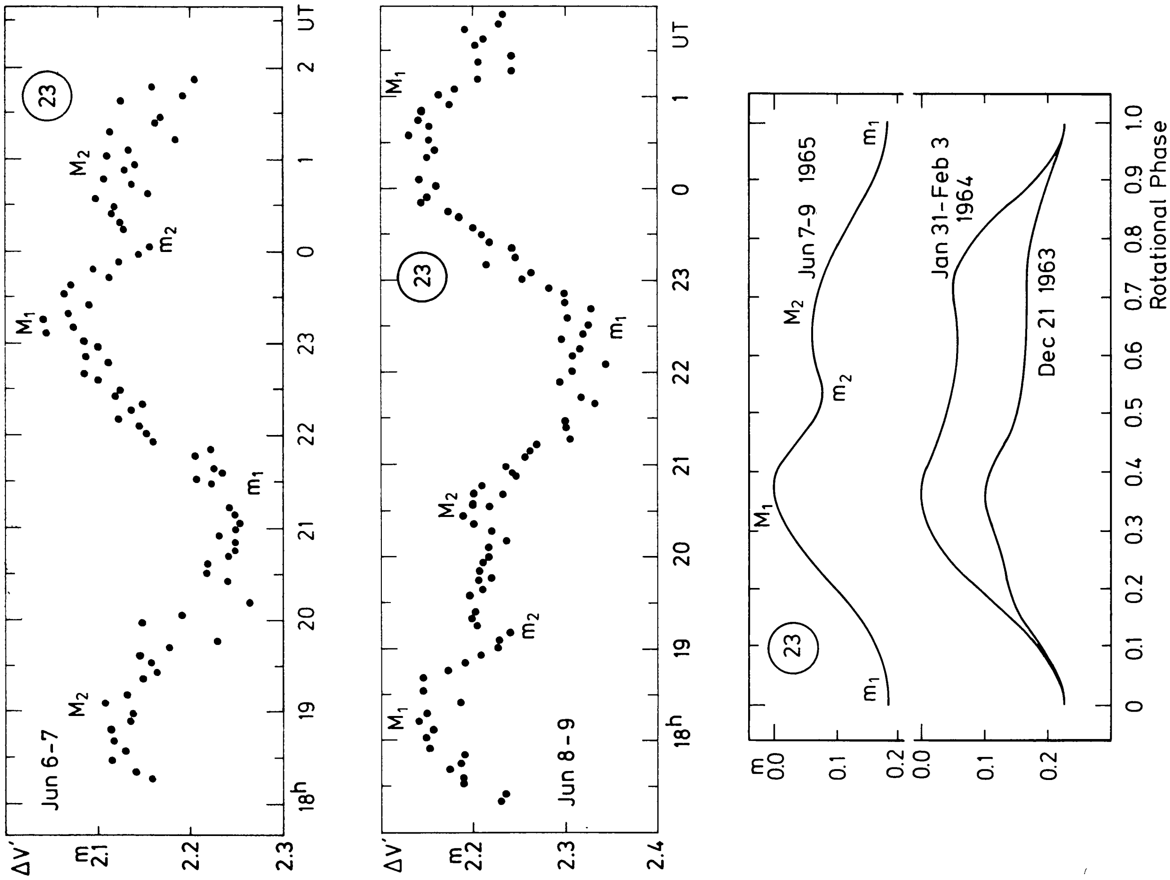
$(B-V)_z$: Zellner et al. 1975
A : R.A. 1950 = $11^h44^m.7$, Decl. 1950 = + 0°14'. B: R.A. 1950 = $16^h34^m.3$, Decl. 1950 = −22°32'.
* : Extrapolated value.
+ : The brightest level of the single-night light curve is considered.

Table 3 Epochs of the extrema

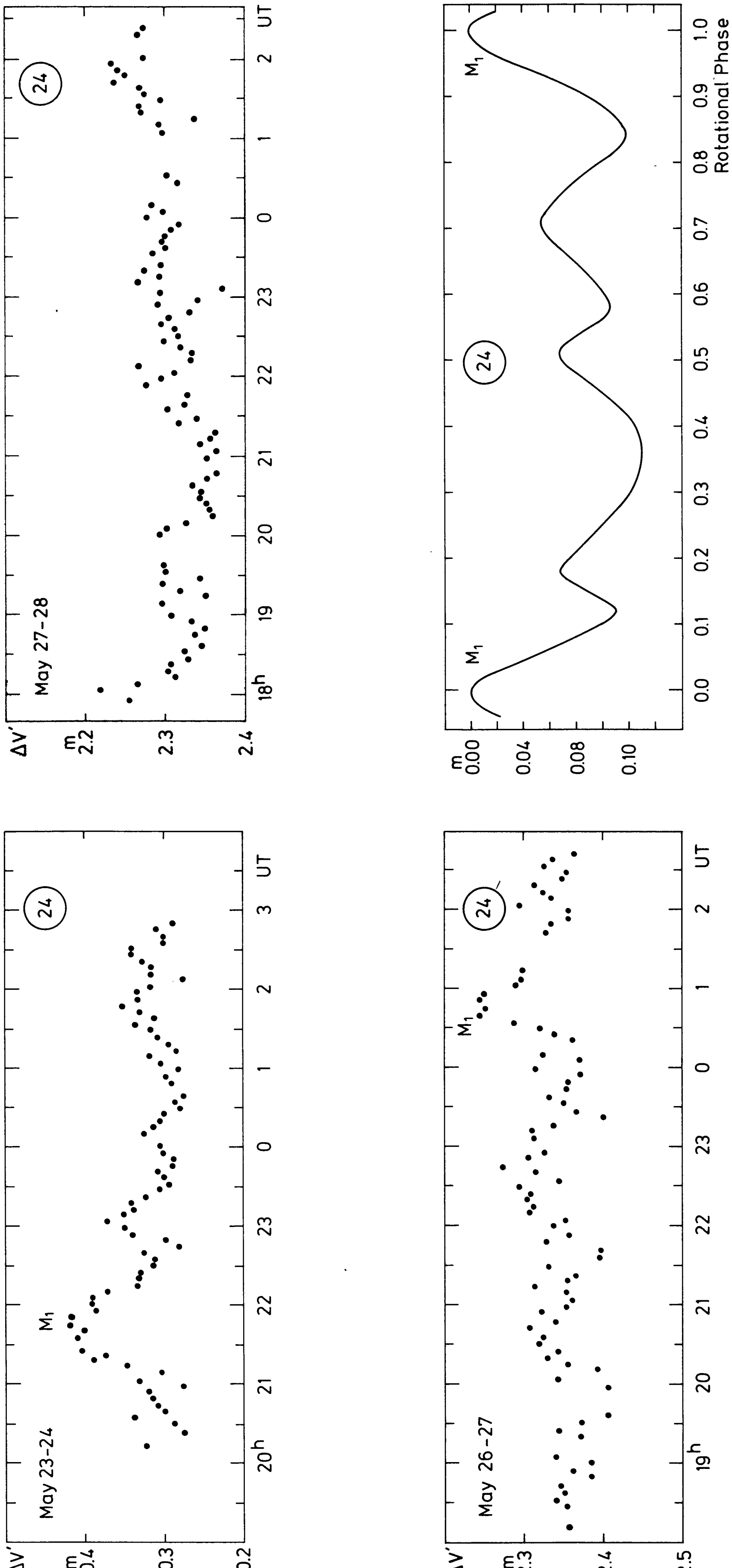
Asteroid No	Date 1965	JD(c) 2438000+ m_1	m_2	m_3	M_1	M_2	M_3
19	Mar 21-22	-	841.462	-	-	841.397	-
19	22-23	-	842.400	-	-	842.335	-
23	Jun 6-7	918.361	-	-	918.457	-	-
23	8-9	920.411	-	-	{920.251 920.507}	-	-
24	May 23-24	-	-	-	904.391	-	-
24	26-27	-	-	-	907.527	-	-
28	Feb 27-28	-	819.390	-	-	-	-
28	Mar 12-13	-	832.471	-	-	-	-
29	Jun 23	-	-	935.306	935.342	935.280	-
29	26	938.317	938.376	938.225	938.262	-	938.341
29	Jul 3-4	{945.273 945.500}	945.341	-	945.458	945.381	945.302
43	May 1-2	882.440	-	-	882.376	-	-
43	3-4	884.356	-	-	884.295	-	-
54	Jul 7-8	949.413	949.579	-	949.518	-	-
54	8-9	950.588	950.458	-	950.396	-	-



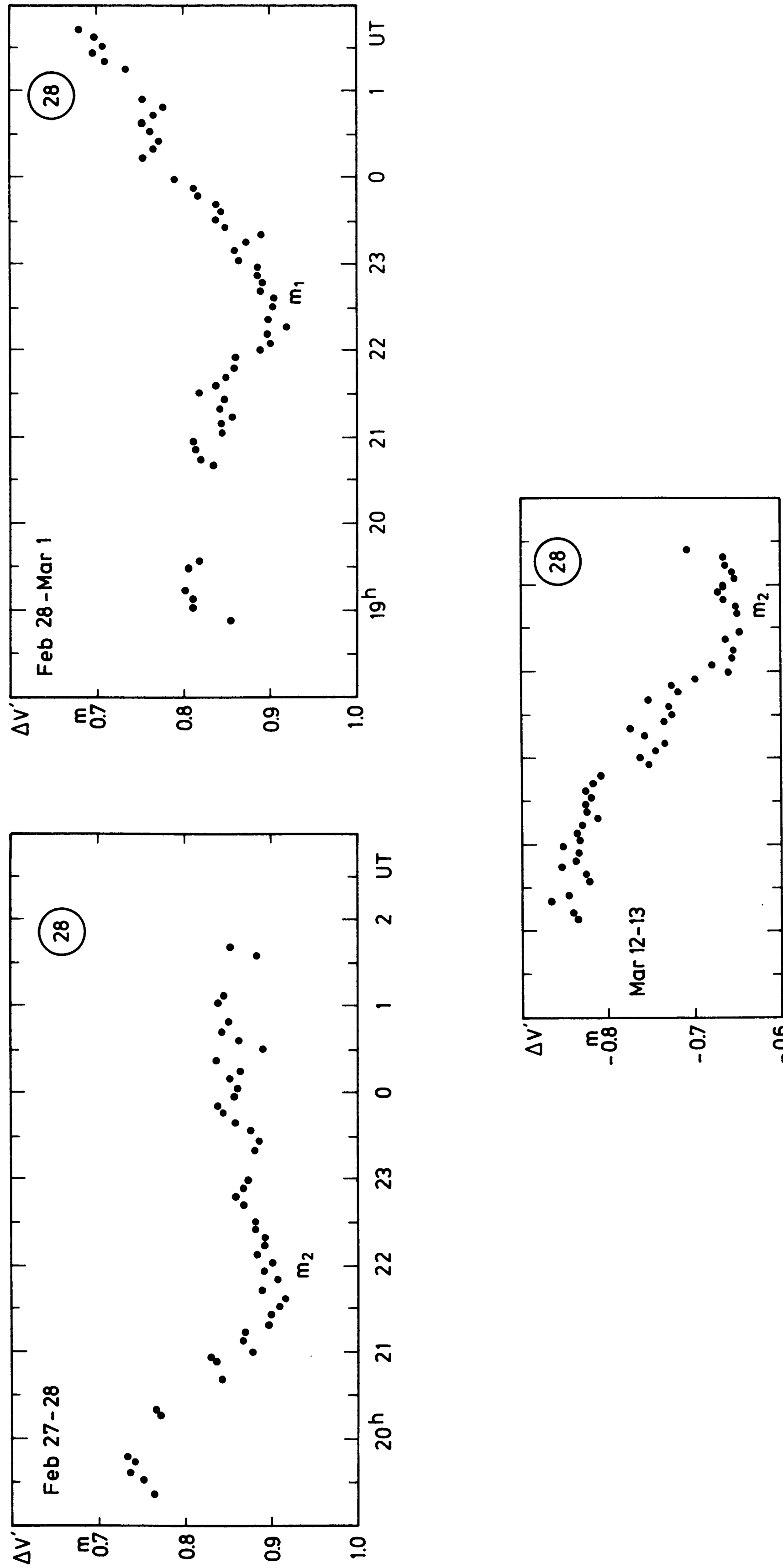
Figures 1 and 2 Light curves of 19 Fortuna for 1965 March 21–22, March 22–23.



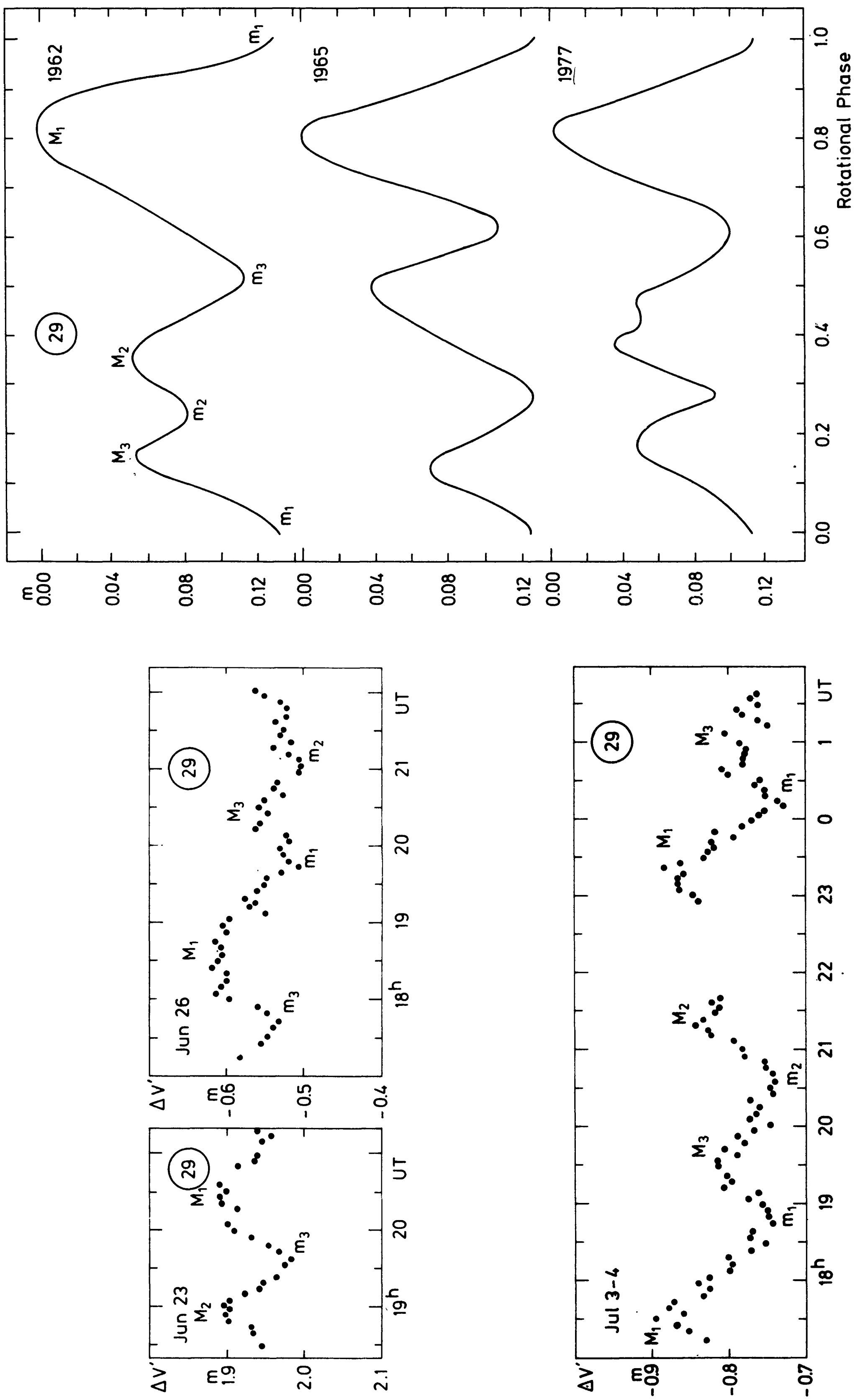
Figures 3–5 Light curves of 23 Thalia for 1965 June 6–7, June 8–9. Mean light curve of Thalia in 1963–1964 and 1965. The lower line is at phase angle 6°0, the middle one at 19°7 in the same 1963–1964 apparition; the upper line is at 2° phase angle in the 1965 apparition.



Figures 6-9 Light curves of 24 Themis for 1965 May 23–24, May 26–27, May 27–28. Mean composite light curve from 1965 observations.

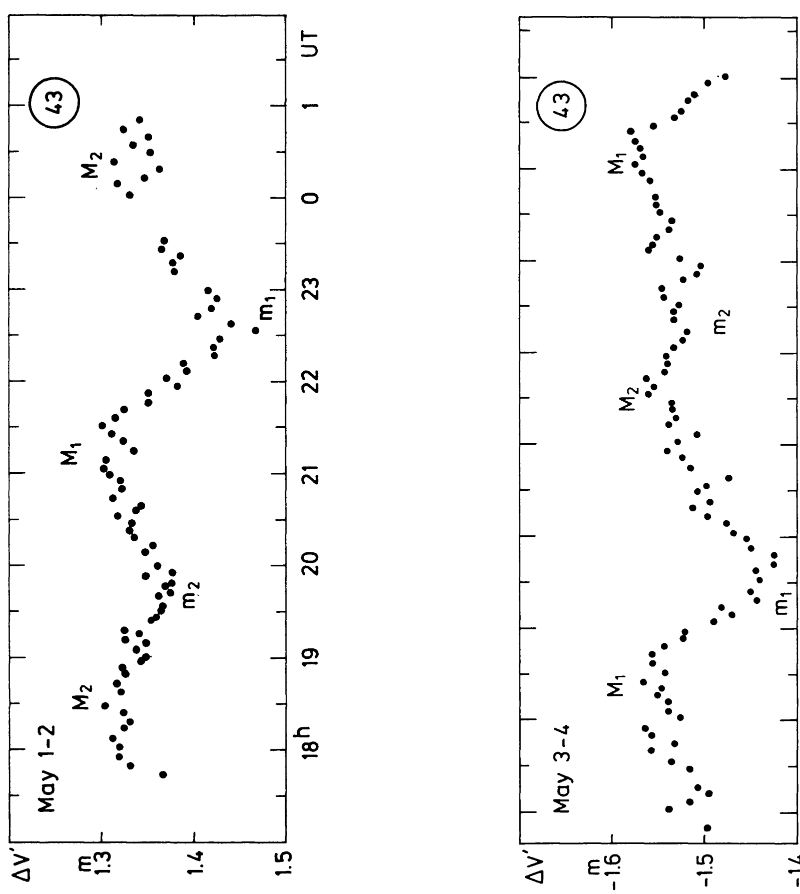


Figures 10-12 Light curves of 28 Bellona for 1965 Feb 27–28, Feb 28–Mar 1, Mar 12–13.

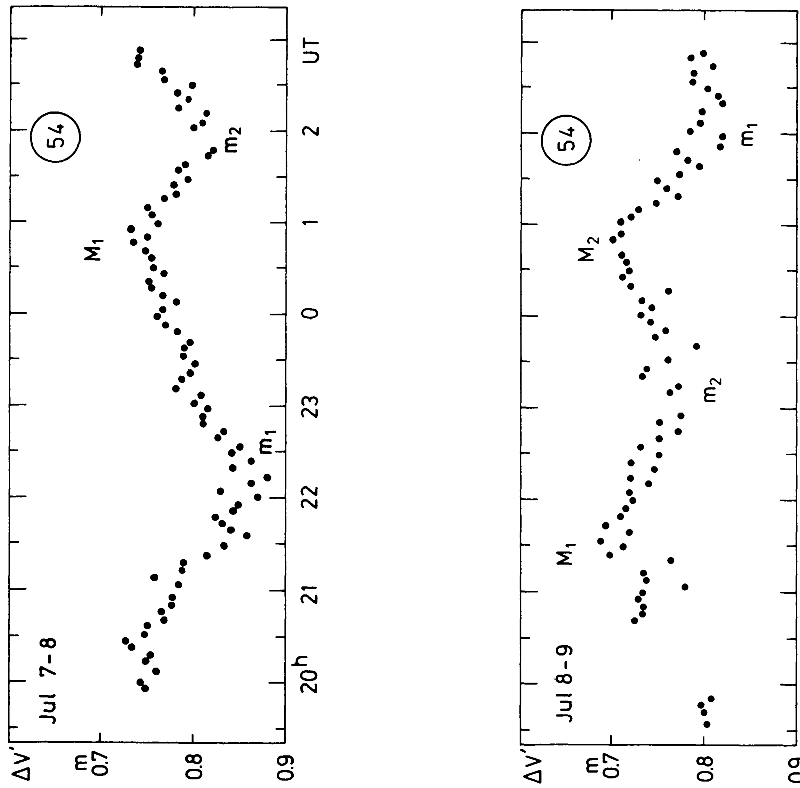


Figures 13-16 Light curves of 29 Amphitrite for 1965 June 23, June 26, July 3–4. Mean light curves of Amphitrite in 1962, 1965 and 1977 apparitions. The ecliptic coordinates and phase angles are:

$\lambda = 44°$	$\beta = +7°$	$\alpha = 6°$	for 1962
$\lambda = 271°$	$\beta = -10°$	$\alpha = 4°$	for 1965
$\lambda = 247°$	$\beta = -9°$	$\alpha = 3°$	for 1977



Figures 17 and 18 Light curves of 43 Ariadne for 1965 May 1–2, May 3–4.



Figures 19 and 20 Light curves of 54 Alexandra for 1965 July 7–8, July 8–9.