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ROTATION PERIOD AND PHASE CURVE OF THE ASTEROIDS 349 DEMBOWSKA AND 354 ELEONORA

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Photoelectric light curves of the Minor Planets 349 Dembowska and 354 Eleonora are presented as obtained by observations made at the Leiden Southern Station in South Africa.
For 349 a rotation period of $4^{h}.70117 \pm 0^{h}.00007$ is deduced with a maximum amplitude of 0.41 mag. and for 354 the period is $4^{h}.2772 \pm 0^{h}.0002$ with an amplitude of 0.26 mag.
The absolute magnitudes as well as the phase coefficients are derived from a linear magnitude-phase relation. An opposition effect is shown to be present in the phase functions. The amplitude of the light curves is also dependent on the phase angle. The $(B-V)$ colours are reported, showing a well defined reddening with phase for 349 only.

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

1. INTRODUCTION

From February till October 1965 photoelectric observations of Minor Planets were carried out by I. and C.J. van Houten at the Leiden Southern Station near the Hartebeespoortdam in South Africa, with the following purposes:

1) The determination of phase relations for objects with relatively short periods so that the full cycle can be covered in each observing night.
2) The observations of asteroids with known period in order to compare some rotational properties as amplitude, shape of the light curve and period, at aspects differing from earlier observations; in such a way informations on the pole orientation and sense of rotation can be deduced.
3) The determination of rotational properties of asteroids never before observed photoelectrically.

The definitive reduction and the discussion of the data were carried out in 1978 with the collaboration of V. Zappalà.

2. THE OBSERVATIONS

All observations were made with the 90-cm light-collector of the Leiden Southern Station by means of the Walraven photometer (Walraven and Walraven 1960; Lub and Pel 1977). The integration time was one minute. The passbands used are V and B only. Because the shapes of the light curves in V and B are the same within the observational errors, we publish those in the V band only.

The observations were made differentially with respect to one or two comparison stars, selected close to the asteroid and of about the same brightness and colour as the asteroid. During each night a set of standard stars were also measured; these were chosen from the list of primary standards published by Walraven *et al.* (1964), augmented by secondary standards calibrated by C.J. van Houten in the years 1968 and 1969. A list of the secondary standards will appear shortly (van Houten, in preparation).

The atmospheric extinction coefficients were derived partly from the observations of the standard stars and partly by plotting the instrumental magnitude of the comparison stars against the air mass.

All reductions of the observations are done in the V colour of the Walraven 5-colour system and are expressed in magnitudes. The ordinate $\Delta V'$ of the figures are magnitude differences in the Walraven system. In the tables we give the magnitudes transformed to Johnson's UBV system.

In 1970, 1977 and 1978 J.W. Pel and A.M. van Genderen were kind enough to remeasure most of the comparison stars to connect them with the Walraven System. We transformed them and the asteroids to the Johnson *UBV* system with formulae derived by Pel (1976) and Lub and Pel (1977). Comparison between the $B-V$ colours of asteroids determined with the Walraven photometer and published values determined by Zellner and co-workers in the *UBV* system indicates that the two systems differ in the range of the asteroid colours by a constant:

$$(B-V)_{\mathrm{J}}=(B-V)_{\mathrm{Walr.}}-0^{\mathrm{m}}.034$$

The same relation may be derived for solar type stars from table 7 of Walraven *et al.* (1964).

Tables 1 and 2 show the aspect data for 349 Dembowska and 354 Eleonora respectively as deduced by second order interpolation of the *Ephemerides of Minor Planets for the year 1965* edited by Chebotarev in Leningrad. The columns give: the date of observation, the equatorial and ecliptic coordinates for 1950.0, the geocentric and heliocentric distances, the phase angle and the light time correction.

Table 3 and 4 report informations about the magnitudes and colours of the asteroids and their comparison stars. The columns give: the observed magnitude of the primary maximum V_0 and the mean observed magnitude $\bar{V}$, the magnitude of the primary maximum reduced to unit distances, $V_0(1, \alpha)$, the $B-V$ colour, the amplitudes (m_1-M_1) and (m_2-M_1), the name of each main comparison star, its V magnitude and remarks.

The mean value of the magnitude of the asteroids was computed by planimetry, when the full cycle was covered in a single night, or by comparison with the nearest complete light curve (taking into account the variation in amplitude with phase) when the full cycle was not covered.

349 Dembowska

Previous informations on the rotational properties of this object were given only by Chang and Chang (1963), who found a period of $4^{\mathrm{h}}.700$ and a maximum observed amplitude of 0.31 mag by means of two runs on 1962 December 6 and 8.

More recently Morrison (1977) reports a value of the geometrical albedo of 349 Dembowska ($p_v=0.260$) which places this minor planet among objects with the highest albedo known to date.

Zellner *et al.* (1975) give informations on the colours; they report $B-V=0^{\mathrm{m}}.96$ and $U-B=0^{\mathrm{m}}.55$. Moreover Zellner and Bowell (1977) classified 349 as an O type object, with a diameter of 144 km.

Ten single-night light curves were obtained from 1965 March 11 to July 19 and they are shown in figures 1 to 10 in which the magnitude differences $\Delta V'$, in the sense asteroid minus comparison star, are plotted against the UT, not corrected for light time. As usual we identified the extrema with m_1, M_1, m_2, M_2; the points are single observations.

The light curves of Chang and Chang (1963) were obtained at 71° of longitude, so the difference in longitude with our observations made at the same phase angles, is about 160°. We could deduce that the aspects in these different oppositions are closely the same; comparisons of amplitudes and shape of the light curves confirm this, implying that the direction of the polar axis has had no significant variation during the time elapsed.

As already found for other asteroids (Gehrels 1956; Scaltriti and Zappalà 1976; Scaltriti *et al.* 1978) also 349 Dembowska shows a variation of amplitude with phase. This fact can be explained as a shadow effect on a macroscopically rough surface and we think that this amplitude-phase relation as well as the magnitude-phase relation, could be of great interest for the knowledge of the surface texture. Figure 11 gives the plot of the maximum observed amplitudes (m_1-M_1) and (m_2-M_1) versus the phase angle; it is interesting to note that the difference (m_1-m_2) decreases with decreasing phase angle. This fact, probably depending on different shapes of minima, was well observed also for 22 Kalliope (Scaltriti *et al.* 1978).

To obtain the mean synodic period of rotation all the extrema were considered. Table 5 gives the epochs in Julian Days corrected for light time.

Least-squares solutions of the equation $T=T_0+N\cdot P_{\mathrm{syn}}$ applied to the four extrema lead to the following results:

$$P_{syn,\,m_1} = 4^{h}\!.70106 \pm 0^{h}\!.00002$$
$$P_{syn,\,M_1} = 4^{h}\!.70104 \pm 0^{h}\!.00007$$
$$P_{syn,\,m_2} = 4^{h}\!.70129 \pm 0^{h}\!.00008$$
$$P_{syn,\,M_2} = 4^{h}\!.70129 \pm 0^{h}\!.00006$$

The discrepancy between periods relative to different extrema is larger than the intrinsic error of each determination. This fact is probably due to a relative shift of the maxima and minima due to the variation in phase and/or in aspect.

Finally we adopt as mean synodic period:

$$\bar{P}_{syn} = 4^{h}\!.70117 \pm 0^{h}\!.00007$$

This value is in good agreement with the previous one given by Chang and Chang (1963).

By an analysis of all published values of the magnitude-phase relation we can see that the opposition effect is nearly the same for all types of asteroids and that it can be fitted by a parabolic curve starting at about 8°.5. Accordingly the points near 7° of the present work should not be considered for the determination of the absolute magnitude $V_0(1, \alpha)$ of the primary maximum and the phase coefficient β. In fact, if we consider these points as well, the straight line so obtained gives an opposition effect for the points near 2° and 3° which is too small when compared with the parabolic line. If only the values from 12°.2 to 18°.1 of phase angle are used for the linear part, we obtain more realistic values for the points in the opposition effect interval, even if, because of the few points used and the very small range of phase, the resulting errors in the parameters $V_0(1, 0)$ and β_v are quite large. We obtain:

$$V_0(1, 0) = 6^{m}\!.13 \pm 0^{m}\!.04 \qquad \beta_v = (0.022 \pm 0.003) \text{ mag/degree.}$$

In figure 12 we see the magnitude of the primary maximum against the phase angle α. It also gives the plot of the $B-V$ colours versus the phase angle. A well defined effect of reddening with phase can easily be seen. That means the phase function depends on the wave-length. We found at zero phase $B-V = 0^{m}\!.916 \pm 0^{m}\!.011$ with $\beta_{B-V} = (0.0016 \pm 0.0010)$ mag/degree.

354 Eleonora

Eleonora was classified by Zellner and Bowell (1977) as an S type object with a diameter of 153 km. Zellner *et al.* (1975) adopted $B-V = 0^{m}\!.93$ and $U-B = 0^{m}\!.54$. The first photoelectric observations of 354 Eleonora were performed by Groeneveld and Kuiper (1954) in 1954 on two consecutive nights. They found a period of rotation $P_{syn} = 4^{h}\!.27$ with a maximum amplitude of $0^{m}\!.15$. Chang and Chang (1963) reobserved this object on three nights confirming the previous period, but with a maximum amplitude of about 0.30 mag. This large difference in amplitude between different oppositions shows that the rotational axis is highly inclined. Using also our 1965 observations the attempt to determine the pole coordinates from amplitudes or brightness relationships was not successful, chiefly because the longitudes in 1954 and 1965 differ by about 180°. Moreover the observations of 1954 show that the very irregular shape of the light curve could be hardly associated with a simple three-axis model. The 1965 light curves (from July 4 to September 26) are presented in figures 13 to 19 in the same way as for 349. Table 6 reports the epochs of the minima in Julian Days corrected for light time which were used for period determination. From a least-squares solution we found

$$P_{syn,\,m_1} = 4^{h}\!.27719 \pm 0^{h}\!.00023 \text{ and } P_{syn,\,m_2} = 4^{h}\!.27712 \pm 0^{h}\!.00016$$

so we adopt $P_{syn} = 4^{h}\!.2772 \pm 0^{h}\!.0002$, in very good agreement with the previous results.

A plot of the amplitude-phase relation is shown in figure 20, where both $(m_1 - M_1)$ and $(m_2 - M_1)$ are given. It is seen that the magnitude difference $(m_1 - m_2)$ does not change with phase, implying probably a difference in albedo between these extrema instead of a difference in shape.

Figure 21 shows the magnitude-phase relation for the primary maximum. We have only three points with phases larger than 8 degrees, therefore it is not possible to have a good value of the phase coefficient and of the absolute magnitude. The three points give

$$V_0(1, 0) = 6^{\mathrm{m}}.58 \text{ and } \beta_v = 0.020 \text{ mag/degree}$$

From the observations at angles smaller than 8°.5 we can see, as usual, the presence of the opposition effect.

ACKNOWLEDGEMENT

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Table 1 Aspect data for 349 Dembowska

No	Date 1965 0^{h}UT	R.A. 1950	Decl. 1950	λ 1950	β 1950	r AU	Δ AU	α	light time
1	Mar 12	$15^{h}48^{m}.5$	$-21°47'$	$239°.72$	$-01°.73$	3.148	2.649	$-17°.1$	$0^{d}.0153$
2	Apr 2	15 48.1	-22 38	239.81	-02.58	3.138	2.383	-13.7	0.0138
3	25	15 35.8	-23 00	237.13	-03.58	3.128	2.178	- 7.2	0.0126
4	May 7	15 25.8	-22 56	234.87	-04.07	3.122	2.122	- 3.1	0.0122
5	10	15 23.1	-22 54	234.26	-04.19	3.120	2.115	- 2.3	0.0122
6	22	15 12.2	-22 39	231.76	-04.60	3.113	2.111	+ 3.1	0.0122
7	Jun 3	15 02.2	-22 20	229.45	-04.93	3.107	2.147	+ 7.3	0.0124
8	4	15 01.5	-22 18	229.28	-04.94	3.106	2.152	+ 7.6	0.0124
9	19	14 52.8	-21 56	227.24	-05.17	3.097	2.250	+12.2	0.0130
10	Jul 20	14 50.8	-21 56	226.79	-05.30	3.077	2.579	+18.1	0.0149

Table 2 Aspect data for 354 Eleonora

No	Date 1965 0^{h}UT	R.A. 1950	Decl. 1950	λ 1950	β 1950	r AU	Δ AU	α	light time
1	Jul 5	$21^{h}06^{m}.7$	$-09°28'$	$316°.27$	$+06°.80$	3.098	2.209	$-10°.8$	$0^{d}.0128$
2	22	20 55.9	-11 19	313.18	+05.78	3.104	2.115	- 5.2	0.0122
3	Aug 5	20 44.9	-13 09	310.09	+04.74	3.109	2.097	+ 1.5	0.0121
4	16	20 36.4	-14 39	307.70	+03.82	3.112	2.123	+ 4.8	0.0122
5	23	20 31.5	-15 34	306.32	+03.23	3.114	2.157	+ 7.2	0.0124
6	Sep 3	20 25.3	-16 52	304.57	+02.33	3.117	2.236	+10.7	0.0129
7	27	20 21.0	-19 01	303.07	+00.47	3.121	2.495	+16.1	0.0144

Table 3 Magnitudes of 349 Dembowska and comparison stars

No	V_o	$\bar{V}$	$V_o(1,\alpha)$	B-V	Amplitudes (m_1-M_1)	(m_2-M_1)	Comparison Stars No	V	Remarks
1	$11^{m}.13$	$11^{m}.34$	$6^{m}.52$	$0^{m}.96$	$0^{m}.40$	$0^{m}.36$	BD $-21°4206$	$10^{m}.38$	
2	10.79	10.99	6.42	0.96	0.38	0.35	A	12.33	disturbed by clouds
3	10.40	10.62	6.24	0.91	0.37	0.36	CoD$-22°11123$	11.56	excellent night
4	10.25	10.43	6.14	0.92	0.33	0.32	CPD$-22°6021$	11.33	
5	10.14	10.34	6.04	0.91	0.34	0.33	B	11.61	stopped by clouds
6	10.22	10.40	6.13	0.91	0.33	0.32	CoD$-22°10925$	10.47	poor seeing
7	10.38	10.59	6.26	0.92	-	-	BD $-21°4025$	9.78	stopped by clouds
8	10.39	10.60	6.27	0.93	0.37	0.35	BD $-21°4025$	9.78	
9	10.61	10.83	6.40	0.97	0.38	0.34	BD $-21°3997$	10.89	
10	11.01	11.25	6.51	0.96	0.41	0.36	BD $-21°3992$	9.93	disturbed by clouds

A: R.A. 1950 = $15^{h}48^{m}.7$ Decl. 1950 = $-22°42'$

B: R.A. 1950 = 15 24.5 Decl. 1950 = -22 55

Table 4 Magnitudes of 354 Eleonora and comparison stars

No	V_o	$\bar{V}$	$V_o(1,\alpha)$	B-V	Amplitudes (m_1-M_1)	(m_2-M_1)	Comparison Stars No	V	Remarks
1	$11^{m}.00$	$11^{m}.10$	$6^{m}.82$	$0^{m}.95$	$0^{m}.24$	$0^{m}.20$	BD $-9°5678$	$9^{m}.87$	
2	10.72	10.82	6.64	0.92	0.20	0.16	A	11.17	seeing poor
3	10.48	10.58	6.41	0.91	-	0.15	BD $-13°5767$	9.23	$22^{h}.6-23^{h}.7$ star close to ast.
4	10.71	10.79	6.61	0.92	0.19	0.12	BD $-15°5761$	10.62	
5	10.79	10.89	6.66	0.96	0.20	0.18	BD $-15°5726$	9.88	bush fires
6	10.99	11.10	6.78	0.94	-	0.19	BD $-17°6008$	10.33	disturbed by clouds
7	11.35	11.48	6.90	0.92	0.25	0.21	BD $-19°5815$	9.12	excellent night

A: R.A. 1950 = $20^{h}58^{m}.8$ .decl. 1950 = $-11°13'$.

Table 5 Epochs of the extrema for 349 Dembowska

No	JD(c) 2438000+ m_1	M_1	m_2	M_2
1	831.470	831.517	831.568	-
2	852.429	852.479	852.529	852.575
3	875.542	875.592	875.450	875.492
4	887.491	887.539	887.398	887.443
5	-	890.477	890.531	-
6	902.378	902.427	902.282	902.328
7	-	-	914.233	914.278
8	-	-	915.409	915.454
9	930.388	930.436	-	930.340
10	961.337	-	-	961.293

Table 6 Epochs of minima for 354 Eleonora

No	JD(c) 2430000+ m_1	m_2
1	8946.443	8946.529
2	8963.550	8963.459
4	8988.495	8988.405
5	8995.450	8995.362
6	-	9006.408
7	9030.383	9030.288

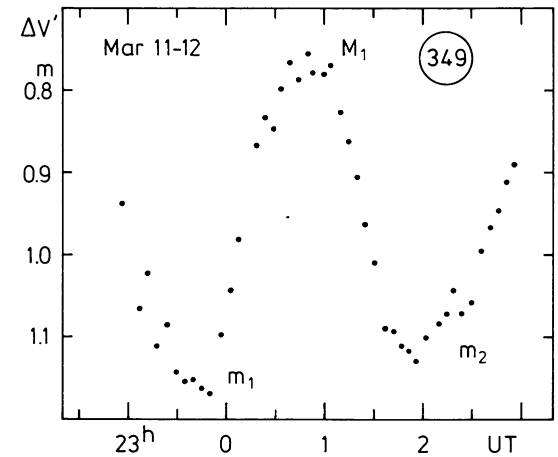


Figure 1

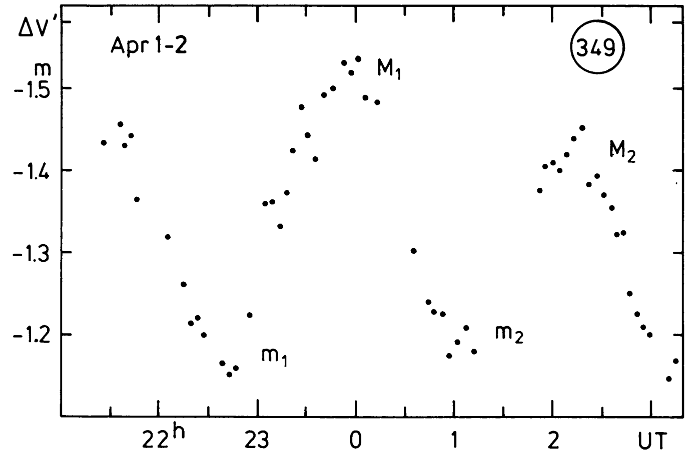
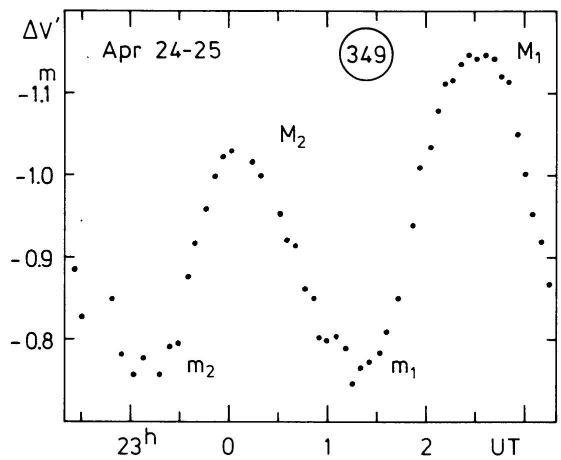


Figure 2



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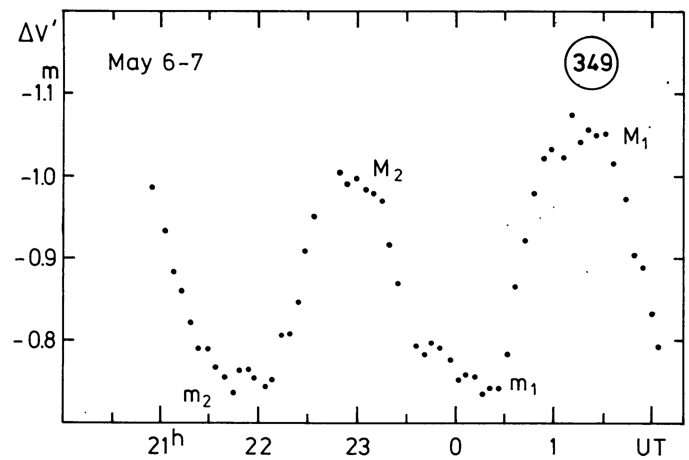

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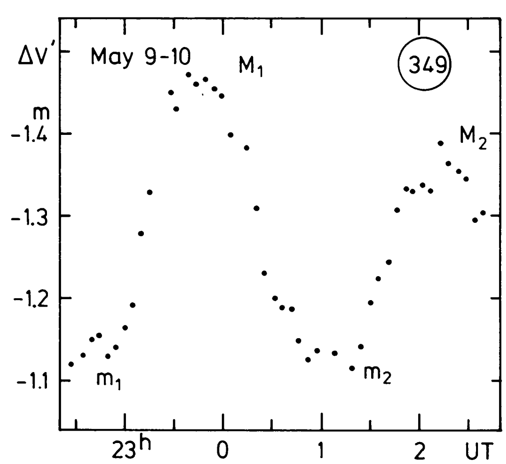


Figure 5

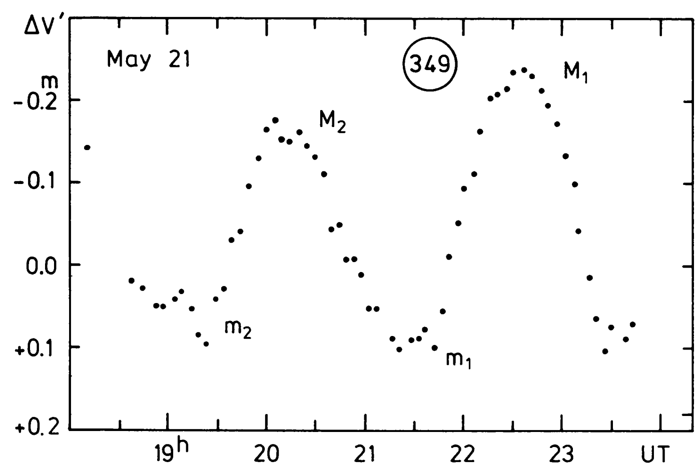


Figure 6

Figures 1-6 Light curves of 349 Dembowska for 1965 Mar 11–12, Apr 1–2, Apr 24–25, May 6–7, May 9–10, May 21.

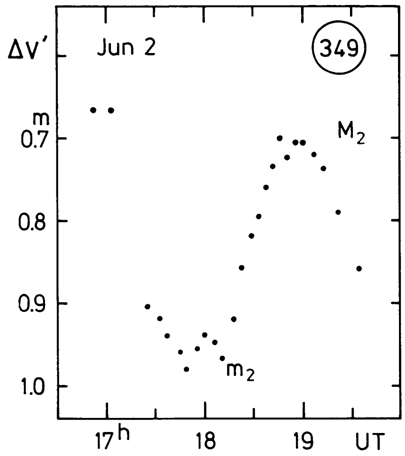
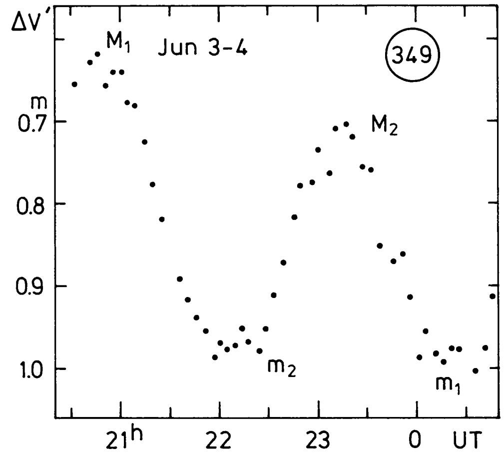


Figure 7



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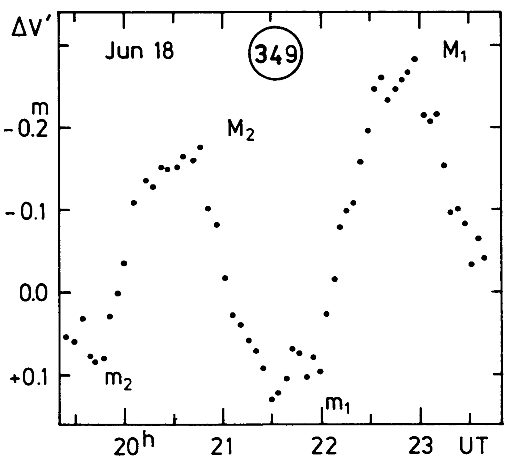

Figure 9

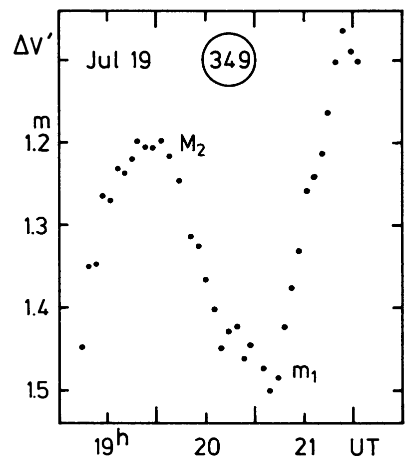

Figure 10

Figures 7-10 Light curves of 349 Dembowska for 1965 Jun 2, Jun 3–4, Jun 18, Jul 19.

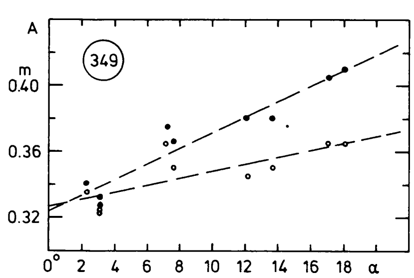

Figure 11 Variation of the amplitudes $(m_1 - M_1)$ and $(m_2 - M_1)$ with the phase angle for 349 Dembowska. Open circles are $(m_2 - M_1)$ amplitudes.

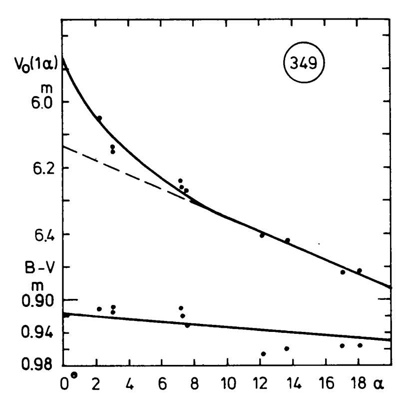

Figure 12 Magnitude-phase relation for 349 Dembowska and $B-V$ colour versus phase.

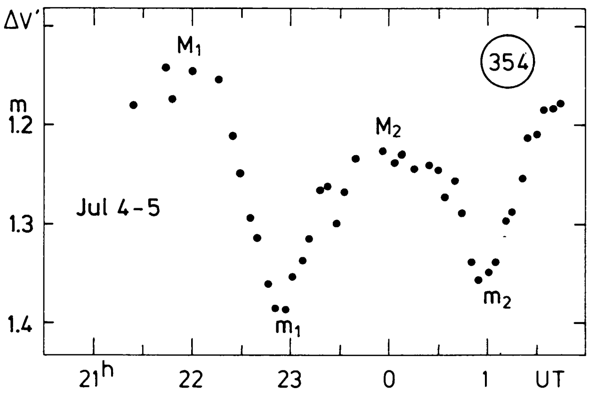

Figure 13

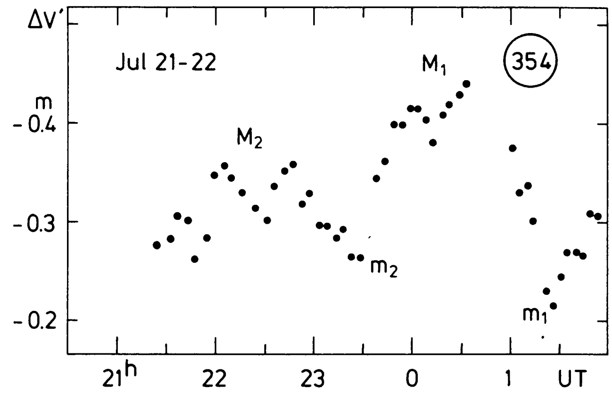

Figure 14

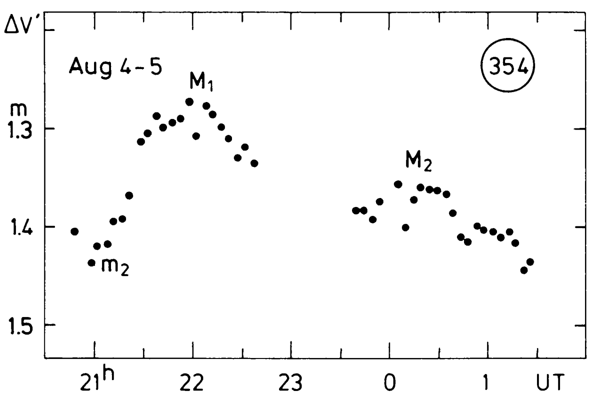

Figure 15

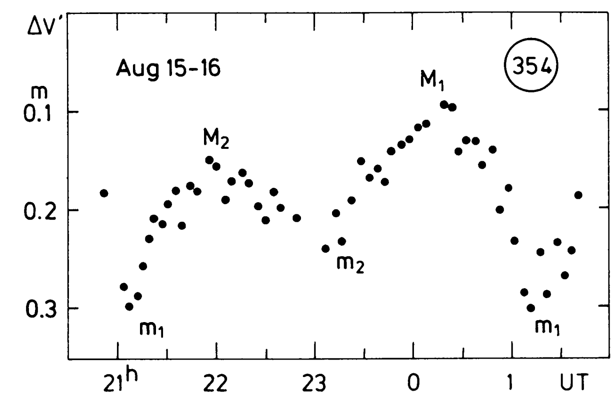

Figure 16

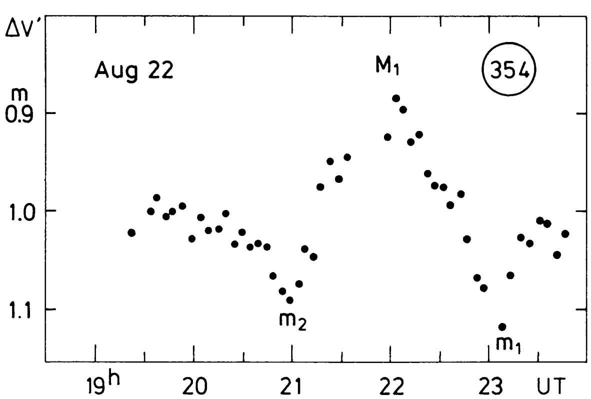

Figure 17

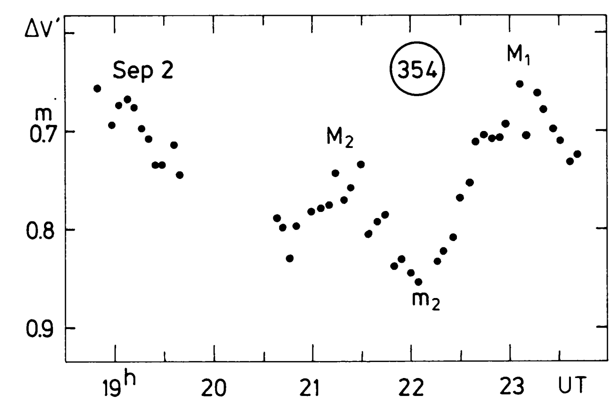

Figure 18

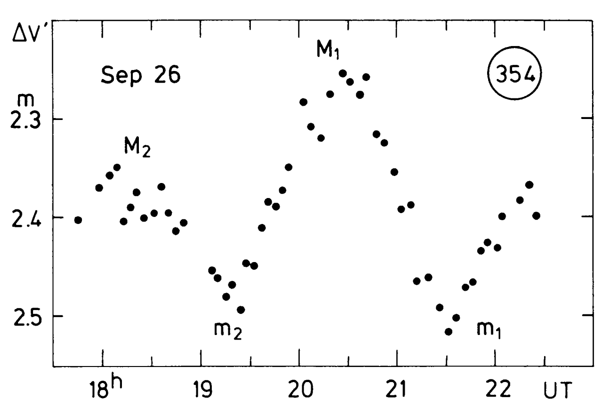

Figure 19

Figures 13-19 Light curves of 354 Eleonora for 1965 Jul 4–5, Jul 21–22, Aug 4–5, Aug 15–16, Aug 22, Sep 2, Sep 26.

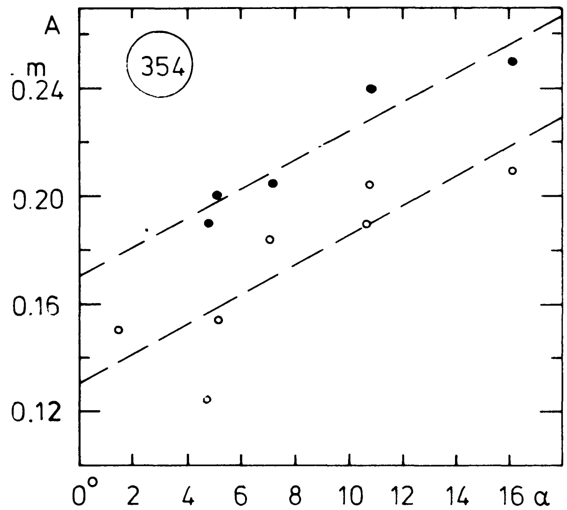

Figure 20 Variation of the amplitudes $(m_1 - M_1)$ and $(m_2 - M_1)$ with phase angle for 354 Eleonora. Open circles are $(m_2 - M_1)$ amplitudes.

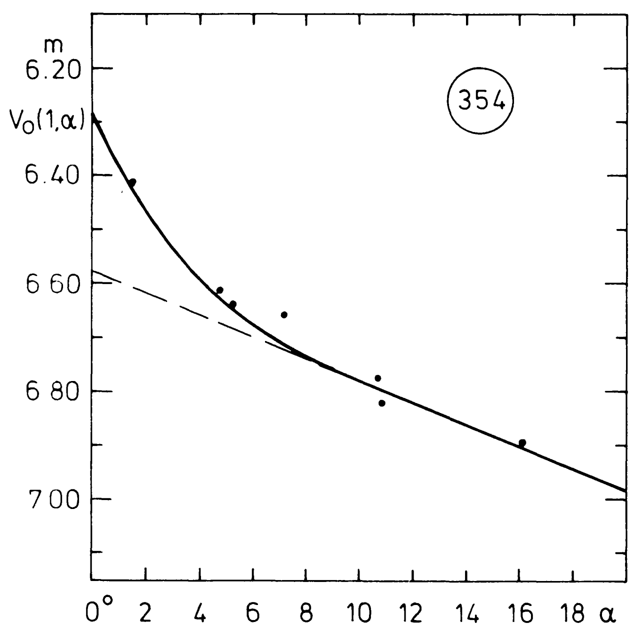

Figure 21 Magnitude-phase relation for 354 Eleonora.