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The spin vector of asteroid 10 Hygiea *

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Abstract. — Photoelectric lightcurves of asteroid 10 Hygiea from the 1985, 1988 and 1989 apparitions are presented. A sidereal rotation period of $27^{h}.65909$ was obtained. This is much longer than previously published values. The spin vector has ecliptic coordinates close to one of the two solutions ($\lambda_0 = 299°$, $\beta_0 = -39°$) and ($\lambda_0 = 112°$, $\beta_0 = -41°$). An ellipsoidal model of Hygiea has axis ratios of about $a/b = 1.36$ and $b/c = 1.04$.

Key words: asteroids — photometry — rotation.

1. Introduction.

Although 10 Hygiea is one of the four largest asteroids, relatively little was known about its rotation prior to this study: Groeneveld & Kuiper (1954) obtained two lightcurves and provisionally adopted a period of 18 hours; A value often quoted in the literature is the 17.495 hour period tabulated by Harris & Young (1983); Vesely & Taylor (1985) observed Hygiea in 1970 and 1973 and suggested a period of 18.4 ± 0.01 hours. In addition, Lagerkvist *et al.* (1987) obtained a short lightcurve indicating an amplitude of about $0^{m}.3$ or more.

2. Observations.

Our observations were obtained during the 1985, 1988 and 1989 apparitions of 10 Hygiea. The aspect data are summarized in Table 1. The last column of the table refers to the three observation sites: *Kha* for the 70 cm telescope of Kharkov Observatory; *Upp* for the 40 cm telescope at the Kvistaberg station of the Uppsala Observatory; *ESO* for the 1 m telescope of the European Southern Observatory on La Silla.

An absolute magnitude scale was derived for all observations except for the lightcurve of 15 February 1988. For the Kharkov observations, this calibration was achieved by photometry relative to nearby comparison stars and standards. The Kvistaberg observations were made relative to a nearby standard star. A large set of standard star observations at different air masses were fed into ESO's standard reduction program for the calibration of the La Silla observations.

3. Period determination.

Naturally, we first tried to make composite lightcurves of our observations using the previously suggested periods of rotation (see Sect. 1). None of them was consistent with our observations. We therefore made a systematic search of periods corresponding to integer and half integer number of rotation cycles between similar lightcurve features occuring on different nights. The only period with a plausible number of extrema and consistent with all observations was 27.63 ± 0.02 hours (an improved value is given in the next section).

Figures 1-7 show composites of both previous and present observations based on the above period. The former data were obtained digitally from the Uppsala version (Magnusson & Lagerkvist (1990) of the *Asteroid Photometric Catalogue* (Lagerkvist *et al.* 1987).

4. Pole determination.

Based on all available lightcurves, and the synodic period discussed in the previous section, we have made a pole

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* Based on observations at the European Southern Observatory, Kharkov Observatory and Kvistaberg Observatory.

determination for Hygiea using the method described by Michałowski (1988) and Michałowski & Velichko (1990). This method fits the observed amplitudes (Fig. 8) to amplitudes predicted from geometrically scattering ellipsoids, and minimizes shifts of lightcurve extrema in rotational phase. Table 2 shows the data used in the calculation. It tabulates identifying numbers, dates of observations, geocentric ecliptic longitudes (λ) and latitudes (β), solar phase angle (α), reference codes, lightcurve amplitudes, times of lightcurve extrema expressed in Julian Days corrected for light time (T_c), and the number of synodic cycles (N). Integer N-values correspond to primary extrema and half integer to secondary extrema, with separate counting sequences for maxima and minima. These are based on a mean synodic period of $1^{\mathrm{d}}.151805 = 27^{\mathrm{h}}.64332$ (see Michałowski 1988). We used 17 pairs of epochs: 12-9, 12-6, 12-2, 12-1, 9-6, 9-2, 9-1, 6-2, 6-1 (minima); 13-11, 13-7, 11-7, 10-5, 10-4, 8-5, 8-4, 5-4 (maxima), and only four amplitudes from 1970, 1973, 1985 and 1988.

The results were two solutions with retrograde sense of rotation. The sidereal period of rotation (P_{sid}), the ecliptic spin vector coordinates (λ_0, β_0), and the ellipsoidal model axis ratios (a/b, b/c) for the two solutions are given in Table 3.

5. Discussion.

Asteroid 10 Hygiea is a good example of the difficulties that arise for slowly rotating asteroids. Individual nights of observations cover only small fractions of the rotation cycle and the period determination often becomes ambigous, unless several weeks of observations are available. Coordinated international campaigns for such objects is the obvious remedy.

Hygiea seems to be the largest asteroid clearly rotating in the retrograde sense; Ceres and Vesta both rotate in the prograde sense, and the spin axis of Pallas is close to the ecliptic plane (see the tabulation by Magnusson 1989).

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References

Groeneveld I., Kuiper G.P. 1954, ApJ 120, 529
Harris A.W., Young J.W. 1983, Icarus 54, 59
Lagerkvist C.-I., Hahn G., Magnusson P., Richman H. 1987, A&AS 70, 21
Lagerkvist C.-I., Barucci M.A., Capria M.T., Fulchignoni M., Guerriero L., Perozzi E. and Zappalà V. 1987, Asteroid Photometric Catalogue, Consiglio Nazionale della Ricerche, Roma
Magnusson P. 1989, In Asteroids II, R.P. Binzel, T. Gehrels, M. Matthews, Eds., pp. 1180-1190 (University of Arizona Press)
Magnusson P., Lagerkvist C.-I. 1990, A&AS 86, 45
Michałowski T. 1988, Acta Astron. 38, 455
Michałowski T., Velichko F.P. 1990, Acta Astron. 40, 321
Vesely C.D., Taylor R.C. 1971, Icarus 64, 37

TABLE 1. *Aspect data.*

Date	r	Δ	phase	λ (1950)	β	Obs.
1985 Aug 15	3.377	2.875	16.2°	31.2°	4.5°	Kha
1985 Aug 18	3.379	2.839	15.9°	31.3°	4.6°	Kha
1985 Sep 15	3.401	2.551	10.5°	30.0°	5.1°	Kha
1985 Oct 6	3.416	2.443	4.4°	26.9°	5.3°	Kha
1986 Dec 10	3.469	2.498	2.5°	86.7°	1.7°	Kha
1988 Feb 15	3.066	2.092	3.7°	156.8°	-4.3°	Kha
1988 Mar 14	3.033	2.094	7.4°	151.2°	-4.6°	Upp
1988 Mar 15	3.032	2.098	7.7°	151.0°	-4.6°	Upp
1988 Mar 20	3.026	2.121	9.5°	150.2°	-4.6°	Upp
1988 Mar 21	3.025	2.128	9.7°	150.1°	-4.6°	Upp
1989 Jun 1	2.770	1.761	2.4°	255.9°	-3.0°	ESO
1989 Jun 3	2.771	1.759	1.7°	255.5°	-2.9°	ESO
1989 Jun 4	2.771	1.758	1.4°	255.3°	-2.9°	ESO
1989 Jun 5	2.771	1.757	1.2°	255.0°	-2.9°	ESO

TABLE 3. *Results.*

		Solution 1	Solution 2
Sidereal Period	P_{sid} (days)	1.152462 ± 0.000003	1.152462 ± 0.000003
Spin-vector	λ_0	299° ± 5°	112° ± 6°
	β_0	-39° ± 9°	-41° ± 8°
Model shape	a/b	1.35 ± 0.03	1.37 ± 0.03
	b/c	1.04 ± 0.04	1.05 ± 0.04

TABLE 2. *10 Hygiea. Data used in calculations.*

No	Date	λ (1950.0)	β (1950.0)	α	Ref.	Ampl. [mag]	Minima T_c[J.D.] 2400000 +	Minima N	Maxima T_c[J.D.] 2400000 +	Maxima N
1	31 Dec 53	116°8	−0°7	5°1	A	≥ 0.11	34 742.763	0		
2	1 Jan 54	116.6	−0.7	4.8	A		34 743.914	1		
3	2 Jan 70	60.8	2.7	10.5	B	0.25	40 588.787	5 075.5		
4	3 Jan 70	60.7	2.6	10.8	B				40 589.652	0
5	25 Jun 73	325.6	2.3	15.7	B	0.17			41 858.856	1 102
6	27 Jun 73	325.6	2.3	15.3	B		41 860.854	6 180		
7	18 Mar 83	211.4	−5.5	11.7	C	> 0.28			45 411.738	4 186.5
8	15 Aug 85	31.3	4.5	16.2	D				46 293.358	4 952
9	18 Aug 85	31.4	4.6	15.9	D	0.33	46 296.477	10 031		
10	15 Sep 85	30.1	5.1	10.4	D				46 324.442	4 979
11	15 Feb 88	156.8	−4.3	3.8	D	0.21			47 207.330	5 745.5
12	14 Mar 88	151.2	−4.6	7.4	D		47 235.266	10 846		
13	3 Jun 89	255.4	−2.9	1.6	D	≥ 0.25			47 680.836	6 156.5

A: Groeneveld and Kuiper (1954)
B: Vesely and Taylor (1985)
C: Lagerkvist *et al.* (1987)
D: This paper.

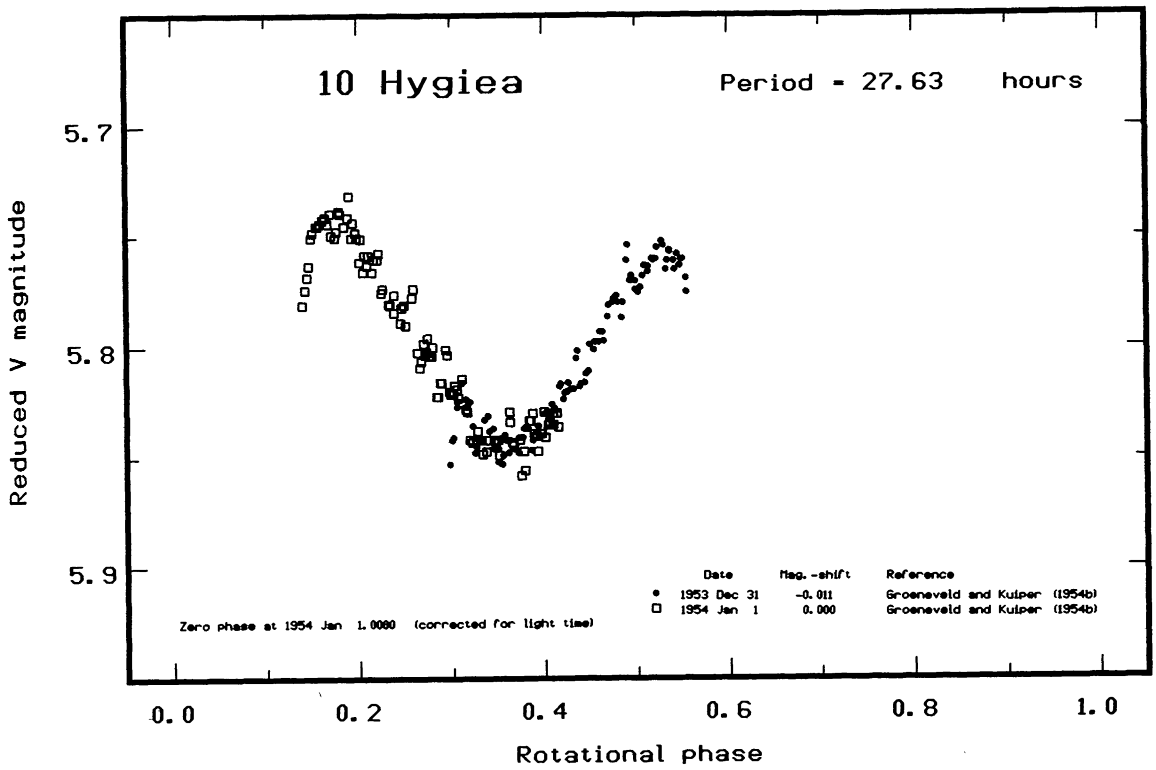

FIGURE 1. Two lightcurves published by Groeneveld & Kuiper (1954) replotted as a composite with our new rotation period.

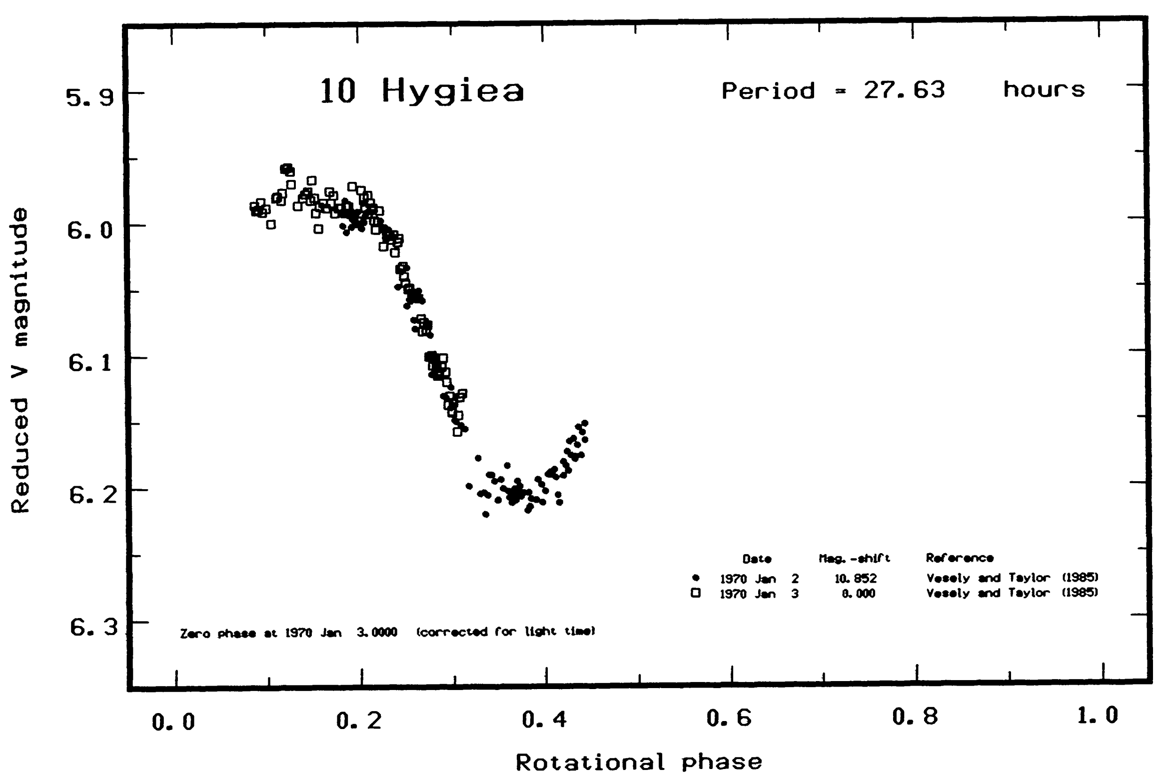

FIGURE 2. Two lightcurves published by Vesely & Taylor (1985) replotted as a composite with our new rotation period. The photometry on January 2 is relative. It has been shifted vertically to give a good fit with the absolute photometry on the following night.

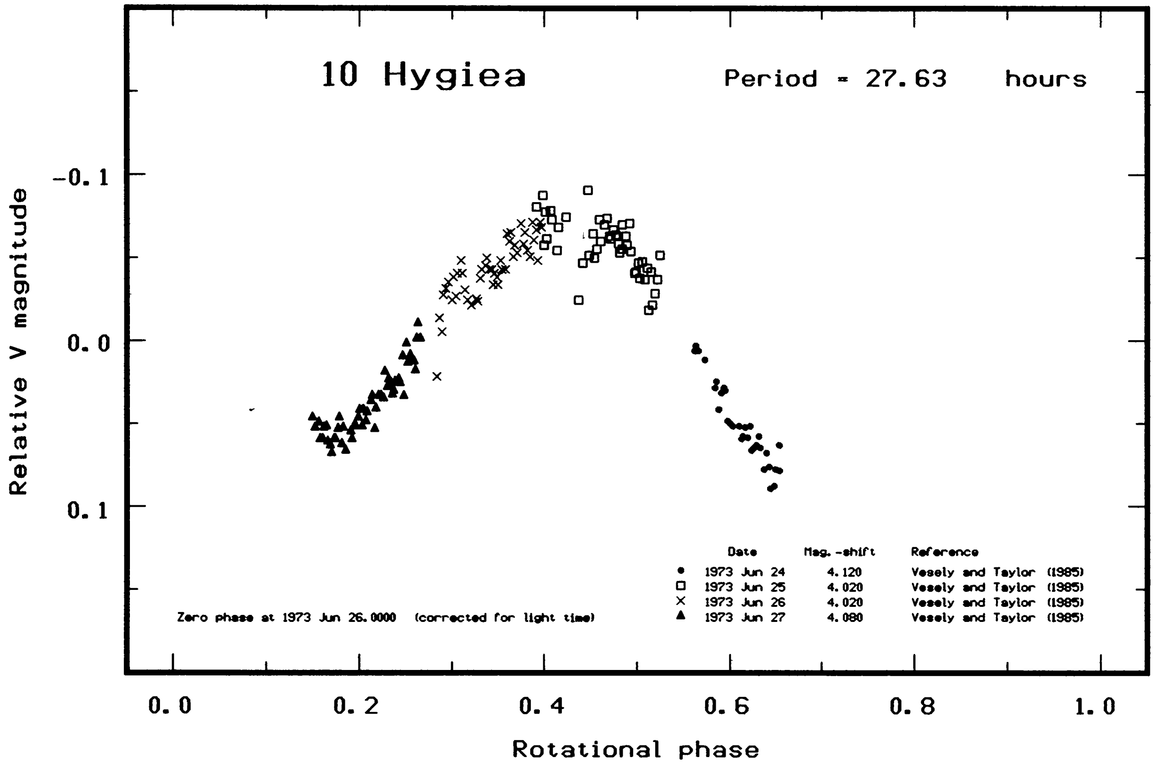

FIGURE 3. Four lightcurves published by Vesely & Taylor (1985) replotted as a composite with our new rotation period. The photometry for each night is relative. Since there is almost no overlap in rotational phase coverage between the nights, the vertical shifts are arbitrary and set to give a smooth composite to the eye. The amplitude at this apparition is therefore quite uncertain.

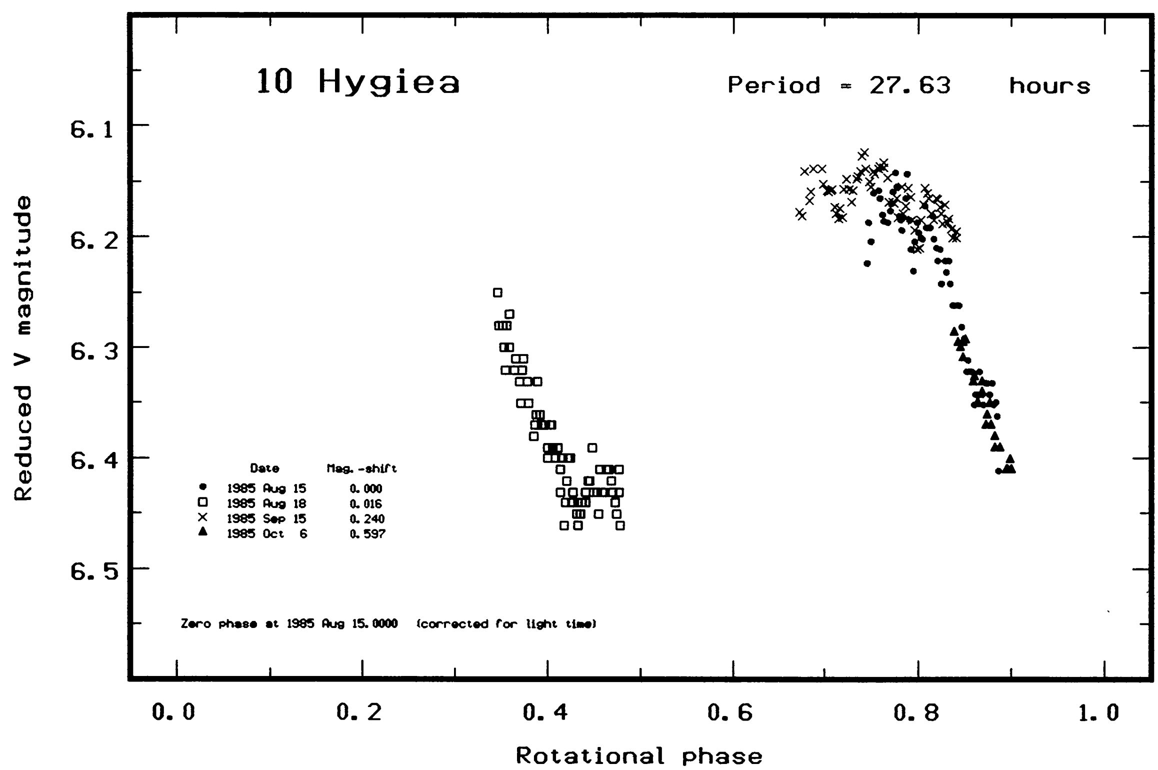

FIGURE 4. Four new lightcurves which give good constraints on the synodic period of rotation. The data was transformed to the level of August 15 using an assumed G-value of 0.04.

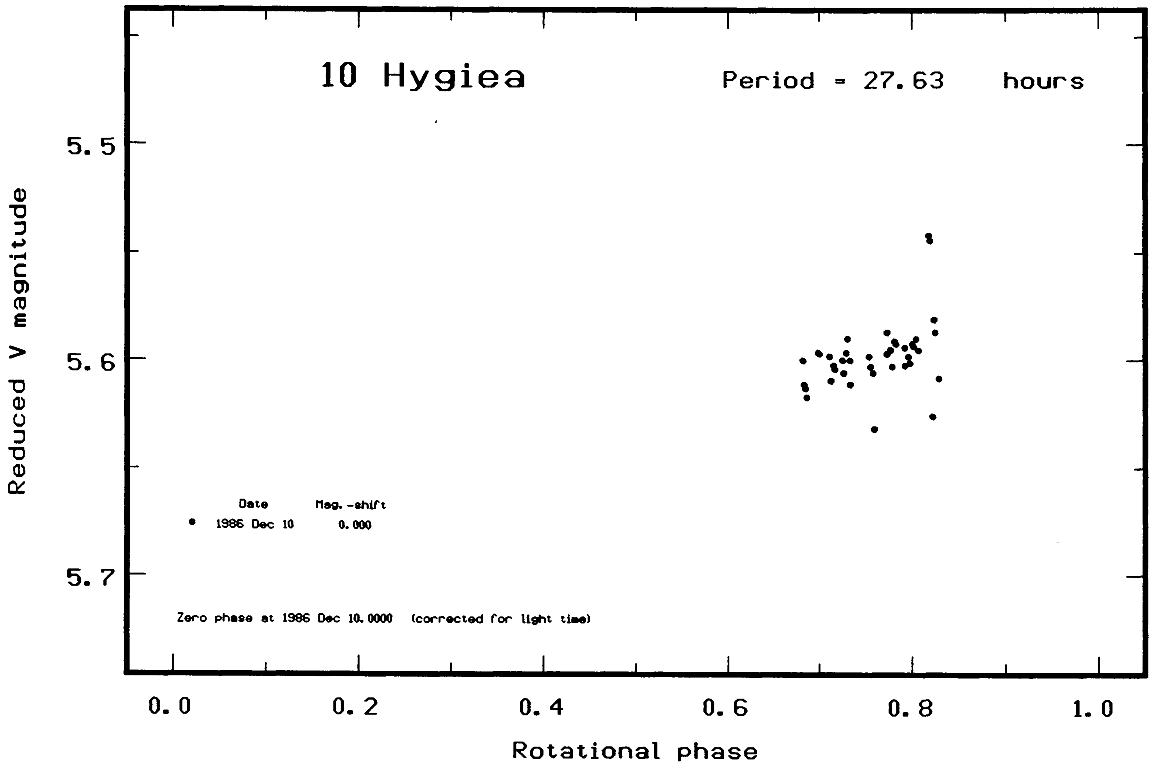

FIGURE 5. A single lightcurve from the 1986/87 apparition.

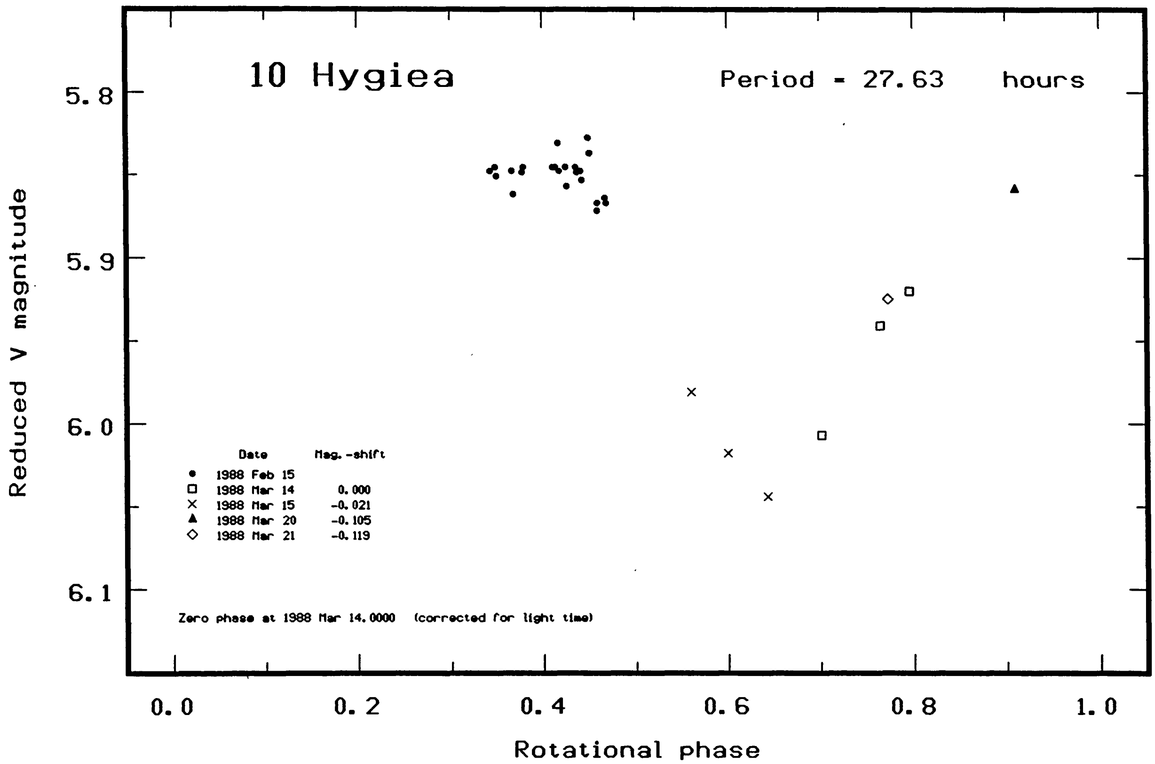

FIGURE 6. Five new lightcurves from the 1988 apparition. The photometry on February 15 is relative and these points have been placed on an arbitrary vertical level. The remaining data is absolute and was transformed to the level of March 14 using an assumed G-value of 0.04.

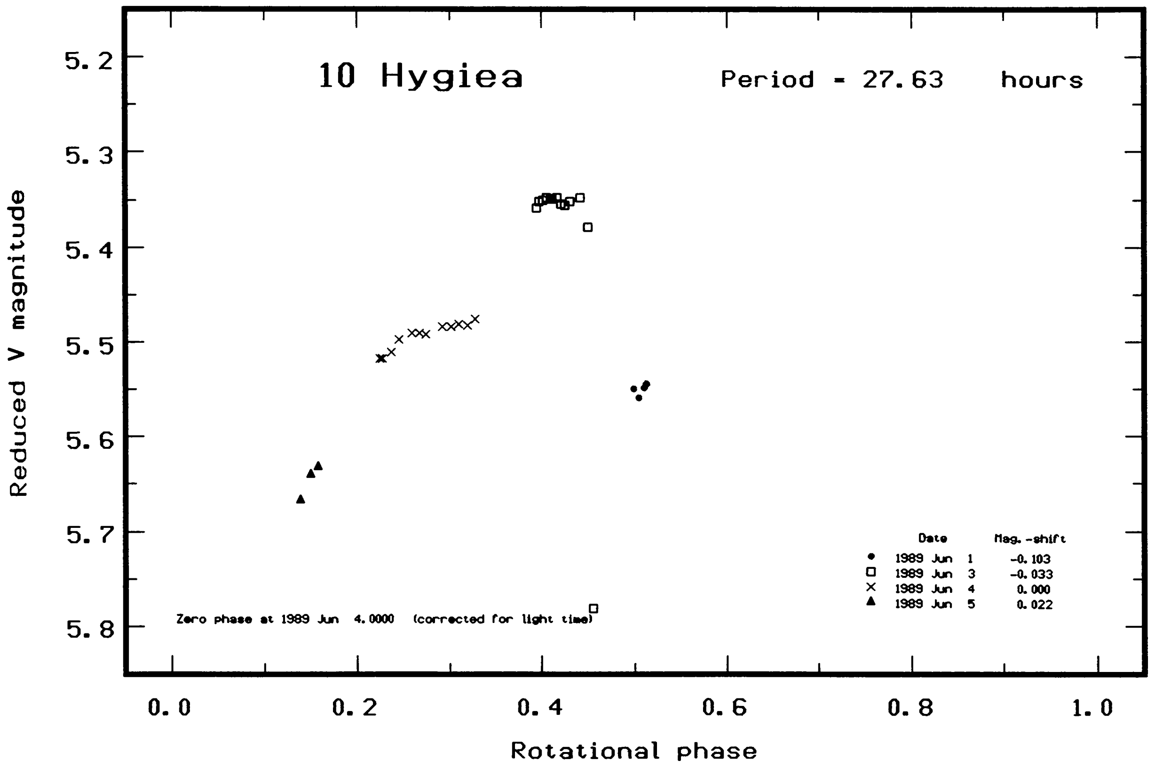

FIGURE 7. Four new lightcurves from the 1989 apparition. The data was transformed to the level of June 4 using an assumed G-value of 0.04.

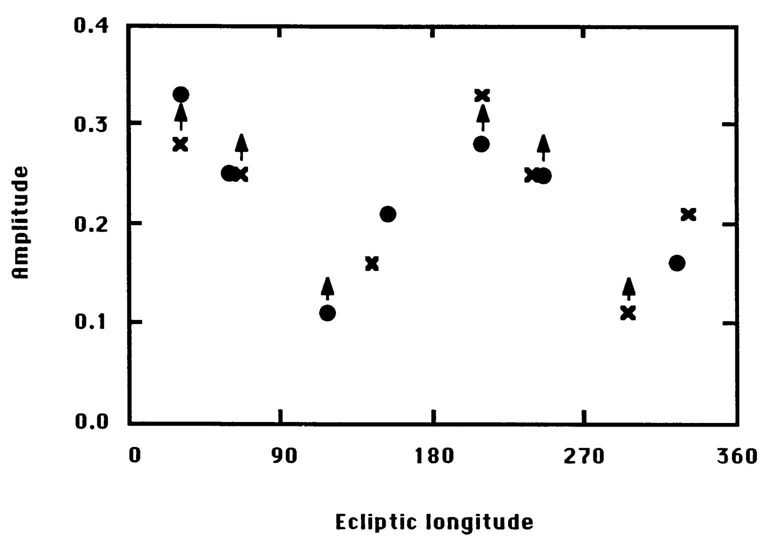

FIGURE 8. Amplitude-longitude relation for 10 Hygiea obtained from seven apparitions. Dots represent observed amplitudes, while crosses were obtained by shifting the observations 180° in longitude, as appropriate if there is symmetry between the north and south hemispheres. The arrows indicate amplitudes that may be larger than the values obtained from the incomplete lightcurves.