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LIGHTCURVES AND POLE DETERMINATIONS FOR ASTEROIDS 31 EUPHROSYNE, 196 PHILOMENA, AND 471 PAPAGENA

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RESUMEN

Se presentan curvas de luz de los asteroides 31 Euphrosyne, 196 Philomena y 471 Papagena y se aplican dos métodos diferentes del tipo amplitud-aspecto para determinar su polo y forma.

ABSTRACT

We present lightcurves of asteroids 31 Euphrosyne, 196 Philomena and 471 Papagena and apply two different amplitude-aspect methods for pole and shape determination.

Key words: **MINOR PLANETS**

1. OBSERVATIONS

We did photoelectric photometry of the asteroids 31 Euphrosyne with the 60-cm Lowell Telescope at CTIO in October 1988, and 196 Philomena and 471 Papagena with the 76-cm telescope of the Estación Astronómica "Dr. Carlos U. Cesco" of Félix Aguilar Observatory (OAFA), San Juan, Argentina, in May 1989. The new and the already published lightcurves are used for determining the poles and shapes of the asteroids. The pole determination methods are described elsewhere (Tancredi & Gallardo 1991; hereafter Paper I).

We used a field diaphragm of 30″ and an integration time of 10 seconds. Photomultipliers RCA 31034 cooled by a Peltier effect at OAFA and by dry ice at CTIO were used. We did differential photometry in B and V filters. In Table 1 we present the observing conditions. The composite lightcurves for the three asteroids are in Figures 1, 2 and 4 and they were obtained looking for the best fit of the different fragments. In these figures we plot $\Delta V(1,\alpha_1)$ as a function of time, where $\Delta V(1,\alpha_1)$ is computed by:

$$\Delta V(1,\alpha_1) = \Delta V - 5\ log(\mathrm{r}\ \Delta) + F(G, \alpha, \alpha_1)\ , \quad (1)$$

where $\Delta V = V_{ast} - V_{com}$ corrected by differential extinction; r and Δ are the heliocentric and geocentric distances respectively and F is the phase correcting function as defined in equation (2) of Paper I. The phase angle α_1 for each lightcurve corresponds to the first observed night. The values of G were taken from the 1990 Ephemerides of Minor Planets.

All the lightcurves were corrected for light-time.

2. POLE AND SHAPE DETERMINATIONS

We use two amplitude-aspect methods as are described in Gallardo & Tancredi (1989) and Paper I. Both methods assume a triaxial ellipsoidal shape for the asteroid, but make use of the observed data in two different ways and apply two different numerical methods in order to solve for the poles. One belongs to the group of methods which use the amplitude (A) as the input data, similar to the one developed by Magnusson (1986) (i.e., a least squares fit of the amplitude) (*LSA* method), but we did not consider the phase angle correction to the amplitude because that implies the introduction of an extra unknown (β_A). The other method adjusts all the points of the lightcurve to the adopted model, not only the maximum and the minimum as in the previous case (Pospieszalska-Surdej & Surdej 1985; Surdej et al. 1986) (*PS* method). The fit of the lightcurve to the model gives a correlation coefficient D, which can be related to the observed amplitude, under the assumption of a perfect triaxial ellipsoidal shape, by the following relation

$$A = 1.25 \log (1 + D) \quad (2)$$

In order to compare the influence of the different numerical methods on the solutions and its coupling with the input data, we combine, as in Paper I, numerical methods and different sets of input data. For the *LSA* method we use two differ-

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TABLE 1

OBSERVING CONDITIONS[a]

Ast.	Year	Mo.	Day	HS	q	r	Δ	phase	λ (Geoc.	β 1950.0)
31	1988	10	6.2	2.7	9	3.217	2.407	12.06	337.27	–25.12
31	1988	10	7.2	6	11	3.215	2.412	12.25	337.13	–24.96
196	1989	05	7.0	2	9	3.116	2.294	12.55	184.45	8.13
196	1989	05	9.1	5.7	9	3.116	2.313	13.07	184.29	8.03
471	1989	05	6.4	1.5	9	3.496	2.526	5.47	242.26	9.43
471	1989	05	7.2	7.6	13	3.496	2.523	5.24	242.07	9.40

[a] The data correspond to the middle of the observation. After that we show the number of observed hours HS, and the number of data per hour q, r and Δ are the heliocentric and geocentric distances in AU.

TABLE 2

PARAMETERS USED FOR THE COMPUTATION OF THE POLES[a]

Ast.	Year	Mo.	Day	phase	λ (Geoc.	β 1950.0)	A_0	D	w	References
31	1977	09	24.3	7.4	353.8	–22.8	0.080	0.0953	1	Schober et al. (1980)
31	1978	11	14.0	21.6	111.5	30.7	0.065	0.0759	0.2	"
31	1978	11	16.0	21.4	111.6	31.3	0.070	0.0697	0.2	"
31	1978	11	19.0	21.0	111.8	32.0	0.065	0.0473	0.2	"
31	1979	01	01.3	15.3	107.0	40.3	0.070	0.0859	0.4	"
31	1983	10	28.9	2.0	28.9	0.2	0.085	0.0992	0.5	Barucci et al. (1985)
31	1983	11	25	13.5	23.3	4.4	0.090	0.1296	0.5	Mc Cheyne et al. (1985)
31	1988	10	7	12.1	337.2	–25.0	0.095	0.1125	1	this paper
196	1964	11	1.6	2.2	35.9	–6.2	0.31	0.539	1	Yang et al. (1965)
196	1981	11	29.9	3.5	78.4	0.5	0.09	0.122	1	Zappalà et al. (1983)
196	1989	05	8.2	12.9	184.3	8.1	0.42	0.870	1	this paper

[a] A_0 is the Mean Observed Amplitude; w is the Assigned Weight of the lightcurve.

ent sets of data: one with the observed amplitude ($LSA+A$) and the other with the amplitudes calculated by equation (2) with the D coefficients ($LSA+D$). For the PS method we follow a similar procedure, the following data sets are used: the D coefficients ($PS+D$) and D values calculated by equation (2) with the observed amplitudes ($PS+A$).

In both LSA and PS methods another equation exists that is used to determine the b/c value but it is necessary to have accurate values of the standard V magnitude of the asteroid. We do not use this equation because the sample of data is small and it could introduce large errors.

A list of all the published lightcurves used in computing the pole's solutions is presented in Table 2. We determine the coordinates of the asteroid during each observation referred to the bisector as it was suggested by Harris, Scaltriti, & Zappalà (1984) and Magnusson (1984). The same lightcurves and weights are used in both methods.

As in general b/c is poorly determined by these methods (see discussion in Paper I), we look for minimum residual solutions for fixed values of b/c.

We assume that the pole must be in the north celestial hemisphere because these methods do not solve the ambiguity in the spin sense.

3. RESULTS

3.1. *31 Euphrosyne*

31 Euphrosyne is classified as a *C*-type asteroid holen 1989) with a diameter of 248 km (Tedesco 989). Its composite lightcurve is shown in Fig- re 1 where the best fit was obtained with a previ- usly determined period of 5.531 hs (Schober et al. 980). As in the other three oppositions the light- rve appears asymmetric. All the lightcurves resent two different maxima and minima so it possible to define a maximum and a minimum nplitude. In our search of the pole's coordinates e averaged the two amplitude values. We tried ith different definitions of amplitude values and en when we used the maxima and minima nplitudes the solutions were similar. Independent f the amplitude definition we got values ≤ 0.1 mag, $a \simeq b$.

The lowest residuals correspond to $a/b = 1.08 \pm$ .02 independently of the method. For this value of b and different values of b/c we obtained very flat inima allowing small differences in the residuals rresponding to extended regions of the (λ, β) lane. One of these regions is for mean latitudes nd the other is for high latitudes. The two methods ive solutions that are inside the following regions:

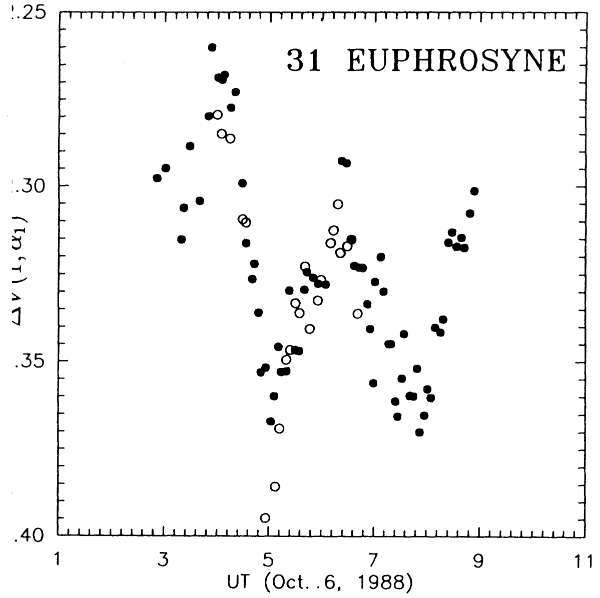
Solution 1: $\lambda_1 = 282° \pm 5°$, $\beta_1 = 30° \pm 10°$;
Solution 2: $\lambda_2 = 300° \pm 60°$, $\beta_2 = 75° \pm 15°$.

The uncertainities in λ_2 are mainly due to the high latitude and to the discrepancies in the solutions obtained by the different methods.

The previous pole's coordinates determined by Barucci et al. (1985) and Mc Cheyne, Eaton, & Meadows (1985) are not included in these regions. Nevertheless the shape they obtained (1.12:1:1) is compatible with our a/b value. They worked independently and basically with the same three oppositions and obtained both the same pole position and shape for this asteroid. Michalowski (1993) using a method that combines amplitude-aspect, magnitude-aspect and photometric astrometry methods, found for this asteroid a pole with coordinates (126, −31) which corresponds with our *Solution 1*. His solutions for the axial ratios are $a/b = 1.14$, $b/c = 1.59$. It is important to see that we are seemingly dealing with an oblate asteroid (two quasi-equal major axes and one shorter minor axis) and then it is natural to have some difficulties in the pole determination. We return to this point in § 4.

3.2. *196 Philomena*

196 Philomena is classified as an *S*-type asteroid (Tholen 1989) with a diameter of 146 km (Tedesco 1989). The composite lightcurve is shown in Figure 2 where the best fit was obtained with a previously determined period of 8.333 hs (Yang, Zhang, & Li 1965). It presents two clear maxima and one minimum. As suggested by Zappalà, Scaltriti, &



g. 1. *31 Euphrosyne*. Composite lightcurve with a pe- od of 5.531 hours. Abscissas are in UT corrected by ght-time from October 6, 1988. Comparison star: SAO 4477. Open circles: October 6; black dots: October 7.

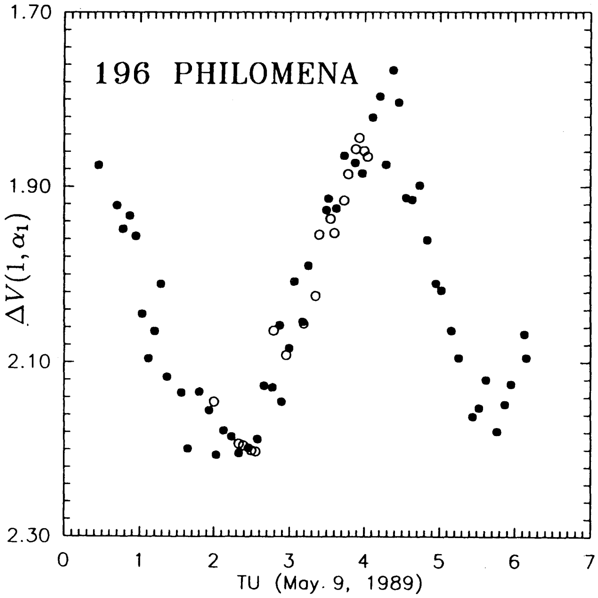


Fig. 2. *196 Philomena*. Composite lightcurve with a period of 8.333 hours. Abscissas are in UT corrected by light-time from May 9, 1989. Comparison star: SAO 119434. Open circles: May 7; black dots: May 9.

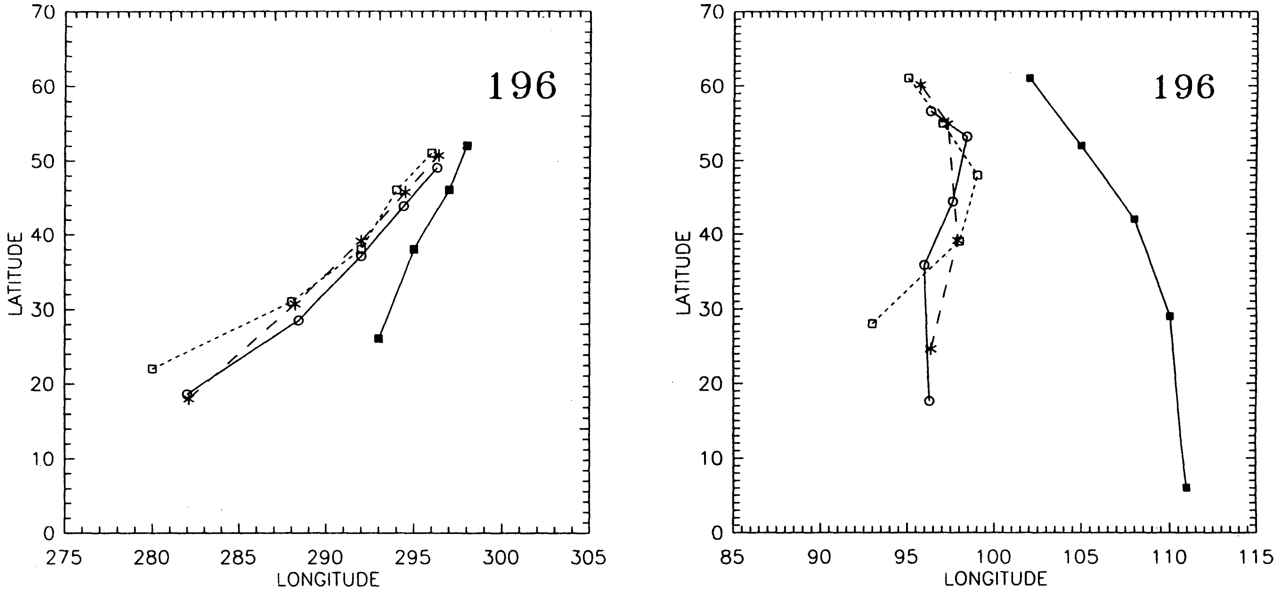


Fig. 3. Plot of the pole's coordinates of asteroid *196 Philomena* varying *b/c* from 1 to 2.5 (step 0.5). The lowest value of the latitude corresponds to the lowest value of *b/c*. Open square: *LSA+A* method; full square: *LSA+D* method; open circle: *PS+D* method; star: *PS+A* method.

Di Martino (1983), the observed amplitude of the asteroid in the observed longitude is 0.42 mag.

Figure 3 shows the pole's coordinates for different values of *b/c*. We obtained very little variations in the pole's longitude with *b/c* and both solutions differ by approximately 180 degrees in longitude as it was expected. For values of *b/c* between 1 and 1.8, we can define two regions of most probable solution. They are as follows:

Solution 1: $\lambda_1 = 287^o \pm 7^o$, $\beta_1 = 26^o \pm 10^o$;
Solution 2: $\lambda_2 = 102^o \pm 9^o$, $\beta_2 = 26^o \pm 20^o$.

These solutions are in good agreement with the ones obtained by Michalowski (1993) using the method mentioned above: (99, −16) and (273, −22).

The values of the *a/b* ratio obtained were

$$a/b = 1.50 \pm 0.03 \ ,$$

for all the methods, except for the *LSA+D* method where we found

$$a/b_{LSA+D} = 1.27 \pm 0.02 \ .$$

Michalowski found that $b/c = 1.17$ and $a/b = 1.33$; a result in between our two solutions.

After we obtained our pole and shape determination of this asteroid we learned about the existence of another lightcurve (Erikson et al. 1991) obtained two months before our observation. Both the observing conditions and lightcurve were similar to ours. In fact it was the same opposition. Hence, we do not recompute the results because it would be the same with one data set or the other.

3.3. 471 Papagena

471 Papagena is classified as an *S*-type asteroid (Tholen 1989) with a diameter of 139 km (Tedesco 1989). The composite lightcurve is shown in Figure 4 where the best fit was obtained with a pre-

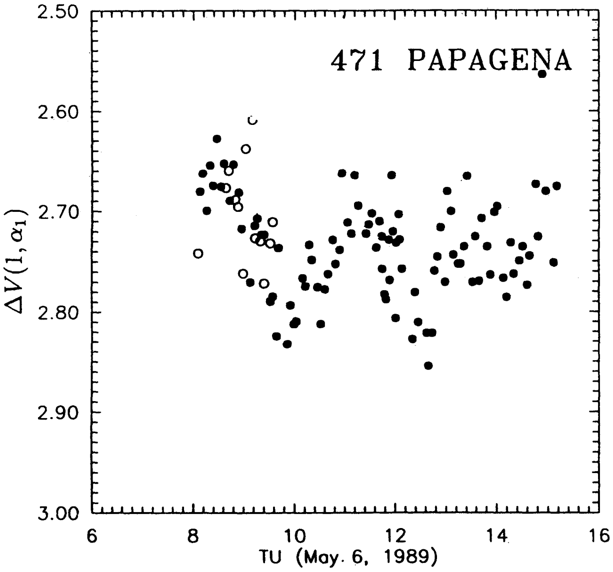


Fig. 4. *471 Papagena*. Composite lightcurve with a period of 7.105 hours. Abscissas are in UT corrected by light-time from May 6, 1989. Comparison star: SAO 159749. Open circles: May 6; black dots: May 7.

viously determined period of 7.105 hs (Di Martino & Cacciatori 1984). Three maxima and minima are presented as in previous oppositions (Di Martino & Cacciatori 1984; Scaltriti & Zappalà 1978), implying very irregular shape and/or the existence of albedo spots on their surface.

Both pole determination methods assume a triaxial ellipsoidal shape for the asteroids with no variations in albedo implying a 2 maxima – 2 minima lightcurve. The fact that the lightcurves at different oppositions have 3 maxima and minima inhibit us to attempt a pole determination based on these methods.

4. DISCUSSION AND CONCLUSIONS

Lightcurves of three main belt asteroids (31 Euphrosyne, 196 Philomena and 471 Papagena) have been presented and discussed. Two different amplitude-aspect methods for pole determination were applied to two of the three asteroids. In the case of 471 Papagena the methods could not be used due to the 3 maxima – 3 minima lightcurve observed in different oppositions contradicting the basic assumptions of both methods.

The always small observed amplitude of 31 Euphrosyne prevents us from finding an accurate pole position. We did find some extended low-residual regions in the (λ, β) plane in agreement with some but not all the previous attempted pole solutions. We argue that the difficulty in the determination of the solutions for this asteroid arises from its nearly axially symmetric shape. We observe $A \simeq$ *constant*, and if we assume $A_{max} \simeq 0.1$ then $a/b \simeq 1.1$ which is similar to the value obtained by the methods we used. This value of a/b implies that the pole position will be poorly determined except for highly accurate determinations of amplitude values, which is difficult in an irregular lightcurve as 31 Euphrosyne has. That can be shown by using equation (6) of Magnusson (1986) that give us the observed amplitude as a function of the aspect angle (ψ) and axis ratios. If we differentiate this equation we obtain the relationship between the error in the assumed amplitude (dA) and the error in the determined aspect angle ($d\psi$) assuming the other parameters are well determined:

$$dA = (2.5/ln\,10)\left\{\cos\psi \sin\psi (b/c)^2[1-(b/a)^2]\right\} \times \times \left\{[(b/c)^2\cos^2\psi + \sin^2\psi]\ [(b/c)^2\cos^2\psi + (b/a)^2\sin^2\psi]\right\}^{-1} d\psi \ . \Big| \qquad (3)$$

Consider two asteroids with identical pole coordinates, observed in identical conditions ($\psi_1 = \psi_2, dA_1 = dA_2$) and differing only in their a/b value. According to the values of a/b they will have different errors ($d\psi_1, d\psi_2$) in the determined aspect angle ($d\psi$)

$$\frac{d\psi_1}{d\psi_2} = = \frac{[1-(b/a)_2^2]\,[(b/c)^2\cos^2\psi + (b/a)_1^2\sin^2\psi]}{[1-(b/a)_1^2]\,[(b/c)^2\cos^2\psi + (b/a)_2^2\sin^2\psi]} \ . \qquad (4)$$

For example we can compare the error in ψ for $a/b = 1.1$ (e.g., 31 Euphrosyne) with an asteroid having $a/b = 1.5$:

$$\frac{d\psi(1.1)}{d\psi(1.5)} \geq 3.2 \ ;$$

in fact for $b \simeq c$ this factor is between 4 and 6. That means the error in ψ is considerably greater for 31 Euphrosyne than for a typical asteroid. That is the reason for the undefined position of the pole. Even with these constraints the coincidence of our solution with Michalowski's is encouraging.

In the case of 196 Philomena all four methods give similar solutions, in spite of the very few observed oppositions which may be due to the regularity of the ligthcurves and to the ratio a/b clearly greater than 1.

This work is part of a continuing campaign to increase the available photometric data set of the asteroidal population, concentrating especially on those asteroids with two or three already existing lightcurves for which additional observations could provide preliminary pole determinations.

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