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ROTATION PERIOD AND PHOTOELECTRIC LIGHTCURVES OF ASTEROID 471 PAPAGENA

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Asteroid 471 Papagena was observed during the 1976 opposition with a photoelectric photometer attached to the 61 cm Bochum telescope at the European Southern Observatory. The lightcurve shows a very unusual triple maximum and minimum. The synodic period found is $7^h09^m23^s \pm 19^s$ and the maximum amplitude of the lightcurve 0.13 mag.

Key words: asteroid – minor planet – lightcurve – photometry – 471 Papagena

1. INTRODUCTION

Ephemeris of Minor Planets for 1976 predicted the opposition for 471 Papagena on November 30, 1976 with $B = 10.2$ mag. The minor planet 471 Papagena was observed on four consecutive nights from 12 to 16 December 1976 with the 61 cm Bochum telescope at the observatory of La Silla (ESO).

No previous observations of this asteroid are reported in the literature up to now.

The measurements were performed by a photoelectric photometer equipped with an EMI 9502 photomultiplier and Schott standard filters UG2, BG12+GG385, GG495 respectively for the *UBV* magnitudes. The data acquisition was done by an electronic integrating amplifier which output is recorded on a Philips model PM 8000 potentiometric recorder.

When observing the photoelectric lightcurves of 471 Papagena we measured regularly two comparison stars chosen close to the path of the asteroid and of similar colours and magnitude (see table 1). This allowed to remove easily the small extinction effects from the lightcurves of the minor planet as well as judging the quality of the nights, rather poor during the run of these observations. The general observing routine included frequent observations of the asteroid, sky, comparison stars and some standard stars in the *UBV* system (Blanco *et al.* 1968) to determine the magnitudes of the asteroid and comparison stars. Lightcurves presented in the figures refer to the comparison star BD 15°600.

Table 2 contains the date of 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 times for the asteroid and the number of the figure relative to the corresponding date. The quantities r and α have been interpolated from the Ephemeris of Minor Planets for 1976, issued by the Institute of Theoretical Astronomy of Leningrad. The geocentric distance Δ was deduced from the elements α, r and R, which is the geocentric distance of the Sun.

2. LIGHTCURVES AND PERIOD

The V lightcurves for 471 Papagena shown in figures 1, 2, 3 and 4 are not corrected for the phase and distance effects, the abscissae are U.T. without correction for light time. In figure 4, the ordinate is a relative magnitude scale ΔV with an arbitrary zero point. After the second observing night (December 14, 1976), we thought we had recorded a full lightcurve cycle, two of the both expected maxima and minima appearing well shaped in figure 2. More puzzling was the fact that the easy slope of the first maximum in figure 1 could not be identified in figure 2. The poor quality of the two last observing nights reserved us the happy luck to point the telescope during 4^h10^m and to pick up one complete light minimum and one complete maximum, the latter being the one we were looking for. The synodic rotational period could then be deduced and it appeared that a full cycle of light variation displayed three very well distinguished maxima (M_1, M_2, M_3) and minima (m_1, m_2, m_3). These appear very well in figure 5 which shows a complete mean lightcurve of 471 Papagena, constructed from the four single night curves. The horizontal line in figure 5 indicates the mean magnitude, the areas enclosed by the mean curve above and below that line being equal.

Different superpositions of the lightcurves obtained on the four observing nights allow to derive directly the lapse of time separating two similar features in the asteroid lightcurve (for instance maximum, minimum, etc.). Location on time scale of such a feature is determined within a precision of 15 sec. Table 3 encloses the lapses of time obtained when comparing the lightcurves from December 13 and 14, 14 and 15, 13 and 16, 1976. Assigning weights proportional to the number of cycles we deduced the following mean rotational synodic period P

$$P = 7^h09^m23^s \pm 19^s = 0^d.298178 \pm 0.000200.$$

This period of rotation is the most typically representative one among the known rotational periods of minor planets (see figure 6 in Schober 1975). The maximum amplitude of the mean lightcurve in figure 5 is found to be 0.13 mag.

The magnitude differences between the maxima M_1, M_3 and M_2 are respectively 0.03 and 0.04 mag. The approximate magnitude differences between the minima m_1, m_2 and m_3 are respectively 0.03 and 0.02 mag.

The phase differences between the different maxima and between the different minima are reported in table 4. Finally, table 5 encloses the observed mean magnitudes V and the mean magnitudes at unit distances $V(1, \alpha)$ of Papagena for the three first nights of observations. The values of V were computed by planimetry.

3. DISCUSSION

The most striking feature appearing in the lightcurve of 471 Papagena is the presence of three very well distinguished maxima (M_1, M_2, M_3) and minima (m_1, m_2, m_3). If the lightcurve variation is entirely due to the changing shape of the tumbling asteroid, as seen by an observer, it is very probable that we observed something like a vestige from the Pharaon times, *i.e.* a "spinning triangular pyramid". The phase differences (see table 4) between the different maxima do not exclude such a possibility. Of course, we expect the real form of the minor planet to be a more complicated body. It is not excluded either that M_1, M_3 could be the only real maxima due to the changing shape of Papagena and the maximum M_2 to a local topographic accident (flat area, etc.). In such a case, the size L_{M_2} of that topography is directly related to the phase extension of M_2 (~ 0.24) in the mean lightcurve (see figure 5) as follows

$$L_{M_2} = 2\Pi \bar{r} \times 0.24,$$

with $\bar{r}$ being the mean radius of the asteroid. Chapman *et al.* (1975) give $\bar{r} \sim 71$ km for Papagena based on radiometric observations; so we obtain

$$L_{M_2} \sim 107 \text{ km}.$$

More generally, local variations of the albedo over the asteroid surface would also bring some variations in the lightcurve.

The $B-V$ and $U-B$ colours of 471 Papagena derived on the night of December 13, 1976 are respectively 0.79 and 0.49. These numbers are typical values among the observed colours of various asteroids (see figure 10 in Gehrels 1970). On the two following nights, the colour measurements of Papagena did not show any variation exceeding the mean scatter (0.004 mag.).

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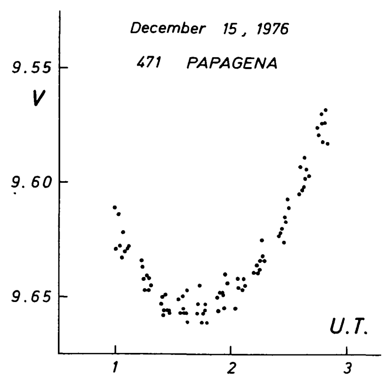

Figure 3 *V* lightcurve of 471 Papagena on December 14/15, 1976.

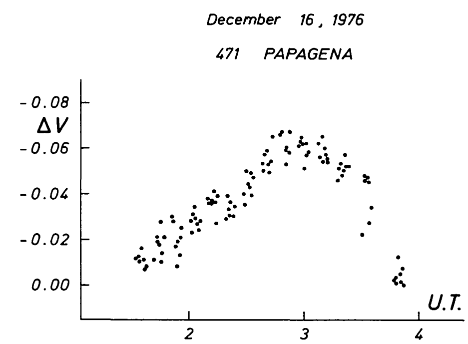

Figure 4 *V* lightcurve of 471 Papagena on December 15/16, 1976. The zero ordinate is arbitrary (see text).

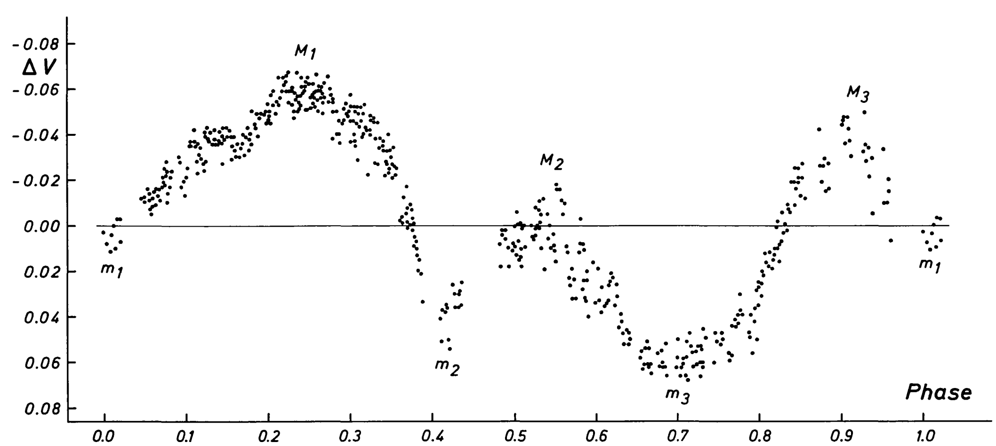

Figure 5 Mean lightcurve of 471 Papagena. The ordinates are referred to the mean magnitude line (see text).

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Table 1 V magnitudes, $B-V$ and $U-B$ colours of comparison stars

Comp. star	V	B-V	U-B
BD 15°600	10.00	0.66	0.22
BD 14°663	8.61	0.44	0.01

Table 2 Aspect data, light times and figure numbers for 471 Papagena

Obs. date (Oh. U.T.)	R.A. (1950)	Decl. (1950)	λ (1950)	β (1950)	Δ (A.U.)	r (A.U.)	α	Light time	Fig.
Dec.13,1976	$4^h09^m.6$	+14°52'	63°.24	-6°.06	1.325	2.280	7°.90	$0^d.00765$	1
Dec.14,1976	$4^h08^m.7$	+14°59'	63°.04	-5°.90	1.330	2.281	8°.34	$0^d.00768$	2
Dec.15,1976	$4^h07^m.3$	+15°06'	62°.85	-5°.75	1.335	2.282	8°.78	$0^d.00771$	3
Dec.16,1976	$4^h06^m.9$	+15°13'	62°.66	-5°.59	1.340	2.283	9°.22	$0^d.00774$	4

Table 3 Epochs and lapses of time between a similar feature appearing in a pair of lightcurves (see text)

Epoch (J.D. corrected for light time)	Lapse of time (days)	Deduced number of cycles
2443125.6590 ± 0.0002 26.5548	0.8958	3
26.6477 27.5423	0.8946	3
25.6344 28.6147	2.9803	10

Table 4 Phase differences between maxima and between minima (see figure 5)

$\Delta M_1M_2 = 0.32$	$\Delta m_1m_2 = 0.42$
$\Delta M_2M_3 = 0.37$	$\Delta m_2m_3 = 0.29$
$\Delta M_3M_1 = 0.31$	$\Delta m_3m_1 = 0.29$

Table 5 Nightly observed mean magnitudes V and mean magnitudes $V(1,\alpha)$ for 471 Papagena

Date	V	V(1,α)
Dec.13,1976	9.55	7.14
Dec.14,	9.57	7.15
Dec.15,	9.59	7.16

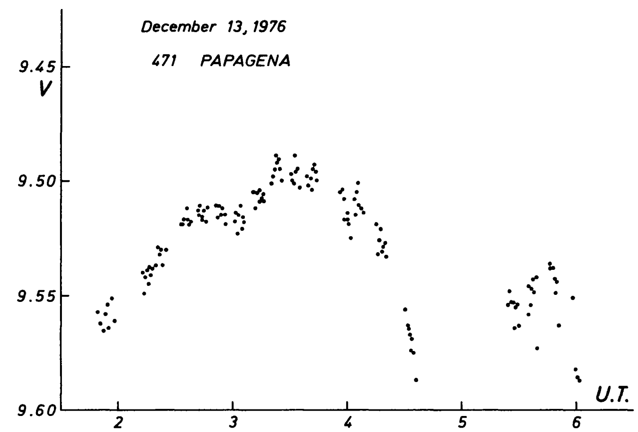

Figure 1 V lightcurve of 471 Papagena on December 12/13, 1976.

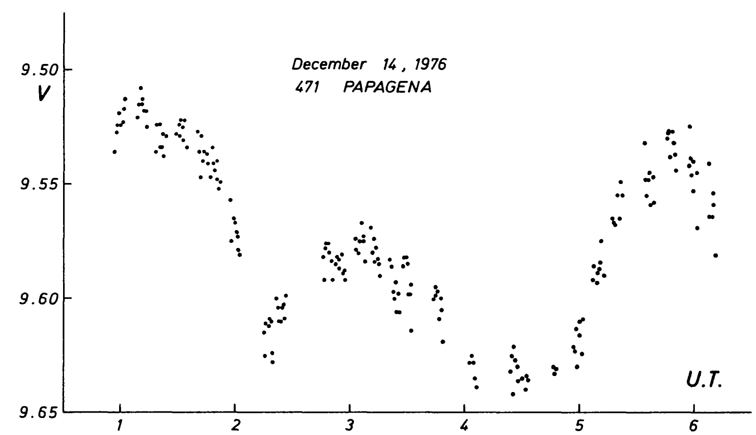

Figure 2 V lightcurve of 471 Papagena on December 13/14, 1976.