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PHOTOMETRIC EVIDENCE OF THE COMPLICATED STRUCTURE OF ASTEROID 4179 TOUTATIS

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Asteroid 4179 Toutatis belongs to a group of asteroids undergoing close encounters with Earth. We discuss the problem of its binarity from the point of view of its photometrical features. Photometric observations of Toutatis were made at the Crimean Astrophysical Observatory during 1992–1993. The frequency analysis of brightness variability revealed many periods. It is likely that it consists of two components. It was supposed that the orbital period is equal to $7^{d}_{.}48$, the period nearly 62^{d} might be caused by precession, spin periods of the components are $2^{d}_{.}85$ and $1^{d}_{.}66$, respectively. Within our error limit the peroid $7^{d}_{.}48$ is in good accordance with the period $7^{d}_{.}35$ found from radar observations, period $2^{d}_{.}85$ is about half of the radar period $5^{d}_{.}41$. Discussion of our photometric data suggests some signs of the existence of satellites.

KEY WORDS Asteroid photometry, binarity, asteroid satellite

1 INTRODUCTION

Asteroid 4179 Toutatis belongs to a group of asteroids undergoing close encounters with the Earth. In 1992–1993, extensive studies of this object were made during its passing Earth at a distance of 3.6 million kilometres. Photometric and radar observations were performed at many observatories.

The problem of the structure of this asteroid is discussed below on the basis of the photometrical observations obtained at the Crimean Astrophysical Observatory. There are many facts now that force us to change generally accepted concept of mono-asteroids. The problem of asteroid satellites is considered in papers by Prokof'eva and Tarashchuk (1995) and Prokof'eva *et al.* (1995b).

2 PHOTOMETRIC SIGNS OF BINARY ASTEROIDS

The success of photometric studies of asteroids — a large amount of published light curves — has allowed us to find distinctive photometric signs of asteroid binarity or more complicated structure. The work was performed by Hartmann (1979), Weidenschilling (1980), Cellino *et al.* (1985), Binzel (1985) and others. Our own experience of the study of binary asteroids allows us to present a generalization of the photometric criteria of the multiplicity of asteroids. We formulate them briefly below.

(1) The value of the spin period can be considered as one of the indexes of the complex structure of an asteroid. Harris (1983) supposed that the main-belt asteroids with periods of more than 2 d could be binary systems. As follows from equilibrium model calculations made by Leone *et al.* (1984), asteroids with periods of more than 6 h can be binary systems. Asteroids with periods between 5 and 6 h could be either binary or single rotating bodies.

(2) The presence of a multiperiodicity in asteroid brightness variations may indicate binary or more complex asteroid structure as supposed by Prokof'eva (1995), Prokof'eva and Demchik (1992), and Prokof'eva *et al.* (1994, 1995a).

(3) Amplitudes greater than one stellar magnitude indicate possible binarity of the asteroid.

(4) Sharp regular or irregular minima or short regular flashes may indicate the existance of a satellite (Prokof'eva and Karachkina, this issue).

(5) There are strong variations of the light curve shapes observed on a short time-scale when the asteroid aspect is nearly constant.

(6) Significant changes of slopes of ascending and descending branches of light curves from cycle to cycle, which is due to changing moments of the start and the end of eclipse.

(7) The changed rotational axis precession of an asteroid suggests the presence of a satellite.

3 PHOTOMETRIC SIGNS OF BINARITY OR MORE COMPLICATED STRUCTURE OF ASTEROID TOUTATIS

Changes in amplitudes and shapes of light curves are pronounced mostly in the case of close binary asteroids which have components comparable in size. The binarity signs 1–4 are fulfilled for Toutatis.

(1) The period of light variations is $7\overset{d}{.}48$. This means that we can suspect a binary or more complicated structure for Toutatis.

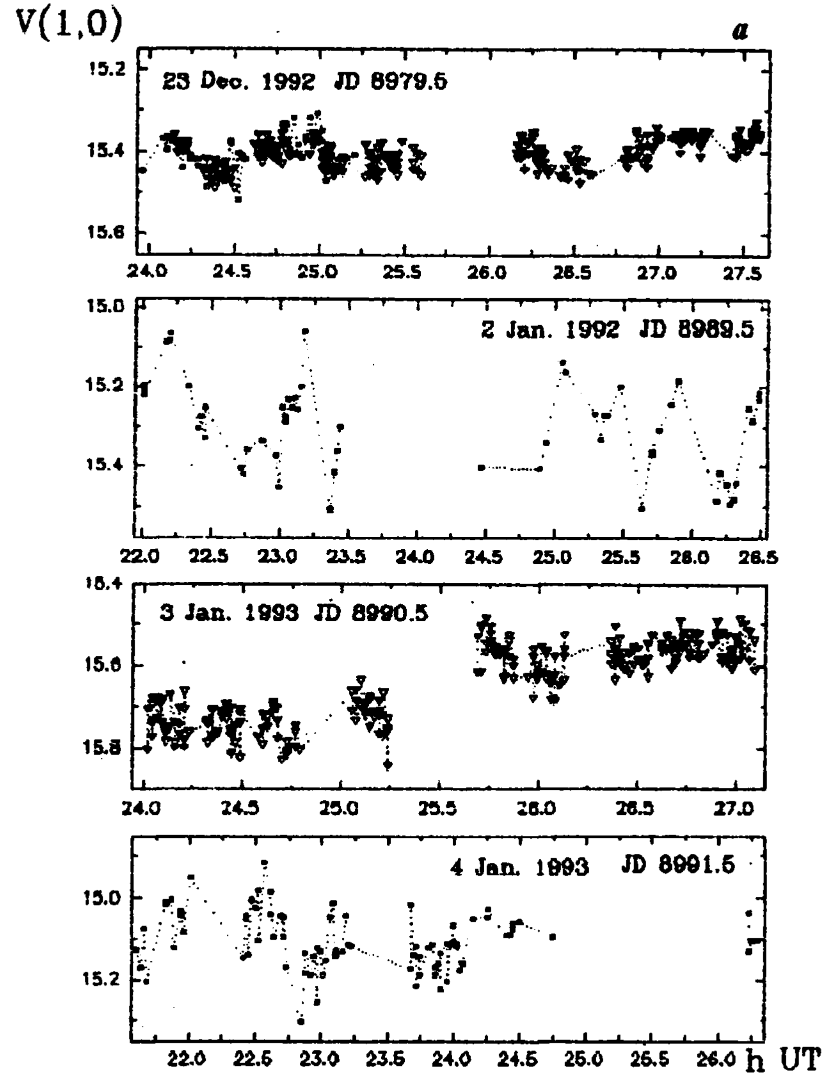

Figure 1 *a* and *b*, The long sets of Toutatis observations that show the variations of $V(1,0)$ magnitudes during short time interval. Photoelectric observations are plotted as small triangules, TV observations as small squares. For all observations $JD = 2440000 + JD(Fig.) + h(UT)$.

(2) The multiperiodicity in brightness variations was investigated at the Crimean Astrophysical Observatory (Prokof'eva *et al.*, 1995b). 314 absolute mean values V(1,0) were calculeted at phase angle 0°. The accuracy was better than 0.02 mag and time resolution of 10–30 min. Many different periods were found. A recurrence cleaning (whitening) of the data from the periods found was performed. The following main periods were distinguished: $7^{d}_{.}48$,

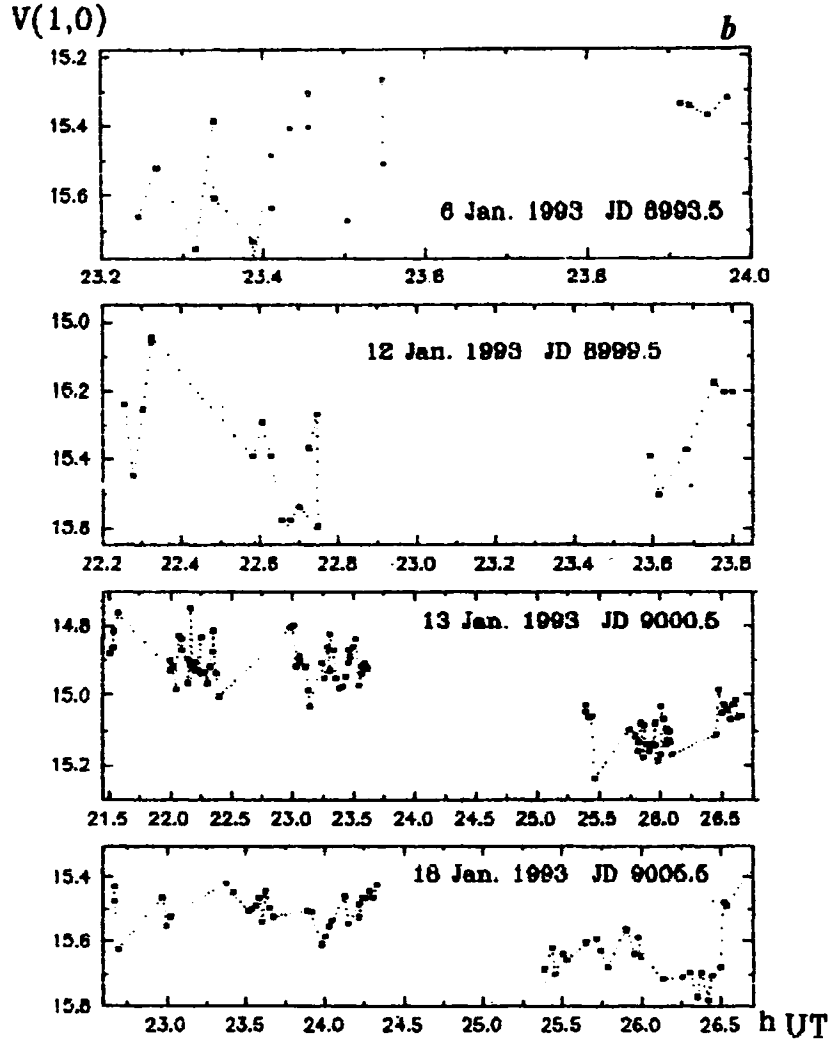

Figure 1 Continued.

62^d, 2$^d_.$85 and 1$^d_.$66. Nine and seven harmonics were obtained for the third and fourth periods, respectively, that were assumed to be the components spin periods. The amplitudes were found to be about 0.2 mag should. It be noted that we found the period 2$^d_.$71 also but its harmonics were absent.

(3) The amplitude of the 7$^d_.$48 period light curve was 1.2 mag. This is in agreement with the assumption of the binarity of Toutatis.

(4) The individual light curves of Toutatis are very complicated. Our $V(1,0)$ data obtained during nights with a lot of observations are shown in Figures 1*a* and

b. They show variations in time-scale of about 2–3 h with amplitudes of about 0.2–0.3 mag, slow brightness decrease or increase with amplitudes 0.1–0.2 mag or nearly constant brightness during the night. All rapidly decreasing and increasing brightnesses occur at different phases of the periods found. This may be caused by the appearance of one component's shadow on the surface of the other body.

4 DISCUSSION

Frequency analysis of $V(1.0)$ Toutatis magnitudes revealed the existence of four different periods and their numerous harmonics. If we deal with Euler motion of a single body no more than three periods may be obtained. $P \doteq 7\overset{d}{.}48 \pm 0\overset{d}{.}1$ was assumed to be the orbital period of a double asteroid, $P = 2\overset{d}{.}85 \pm 0\overset{d}{.}05$ and $P = 1\overset{d}{.}66 \pm 0\overset{d}{.}03$ and their harmonics apparently are periods of components. The harmonics indicate a complex structure of the surface of Toutatis with many details.

Radar observation of Toutatis has made it possible to determine the dimension and rotational periods of the asteroid. Initially, Toutatis was represented by 1.5 and 2.5 km spheres in close contact (Ostro, 1993). The subsequent data analysis allowed Hudson and Ostro (1995) to propose for its interpretation a new model of asteroid shape. It consists of one monolitic body. A dynamically equivalent equal-volume ellipsoid has overall dimensions (1.92, 2.29 and 4.60) ±0.10 km. The asteroid rotates about the long axis with $P = 5\overset{d}{.}41$ and complete motion consists of non-linear periodic variations every $7\overset{d}{.}35$ (it is analogous to precession). The period values obtained from radar and photometric observations agree well within the error limit. It should be noted that the period $5\overset{d}{.}41 =\sim 2 \times 2\overset{d}{.}85$.

There can be no question about the high quality and importance of radar observations. However, we doubt Hudson's and Ostro's final interpretation and their Toutatis model, because the authors ignored the photometric picture of the brightness changes. If Toutatis is a close binary system the picture of the echo-signal remains valid without modification. Thus, the components are in a position with one of them ahead of the other (line of sight coincides with the general axes) producing minimum Doppler shift. The photometric picture varies with the position of the components too. It is interesting that photometric $P = 1\overset{d}{.}66$ and its harmonics were absent when the components were screened by one another during the main minimum of $P = 7\overset{d}{.}48$ light curve.

We suppose that in the case of both components visibility the echo-signal shows different Doppler shifts due to the different rotation speeds of the components. Theoretical investigation of ellipsoid rotation indicates that the time-scale of precessiom must be within a factor of 10 of the rotation time-scale. However, the data of radiolocation show a time-scale of the order of days. It can hardly be supposed that $P = 7\overset{d}{.}35$ is the precession period. There is good reason to beleive that four periods clearly agree with binary or more complicated structure of asteroid 4179 Toutatis and the latter interpretation of radar data is open to question.

5 CONCLUSIONS

The problem of the evolution of earth-crossing binary asteroids was discussed by Farinella (1992). It was shown that such asteroids changed their orbital energy due to Earth's tidal forces. The results are both increased and decreased separation. The smaller orbital distances created contact binary systems. We supposed that asteroid 4179 Toutatis is in this stage of its evolution. We assume that discussion of the problem of the complex structure of Toutatis is not yet over. It should be very interesting to investigate it during its approach to Earth in 1996.

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