Astronomical and Astrophysical Transactions, 1998, Vol. 15, pp. 219–224
Reprints available directly from the publisher
Photocopying permitted by license only

SATELLITES OF TWO LARGE ASTEROIDS

V. V. PROKOF'EVA[1] and L. G. KARACHKINA[2]

[1] *Crimean Astrophysical Observatory, Nauchny, Crimea, 334413, Ukraine*
[2] *Institute of Theoretical Astronomy RAN, Nab. Kutuzova, 10, St. Petersburg 191187, Russia*

(Received April 23, 1996)

Various observational data obtained over a period of about 100 years have led to the assumption that some asteroids have satellites. A review of publications has allowed us to compose a list of 50 asteroids that are supposed to be binary. Asteroid 243 Ida with satellite Dactil discovered by space probe Galileo became the 51st. Numerous photometric digital TV observations of two large asteroids 87 Sylvia and 423 Diotima have been performed at the Crimean Astrophysical Observatory. The shapes of the light curves show the existence of satellites. Frequency analysis of data allowed us to find the spin periods of the components. The first binary system is nearly synchronized and the second is synchronized. Both systems are stable.

KEY WORDS Photometry, binary asteroids, spin periods

1 INTRODUCTION

About 100 years have passed since the first publication on the existence of a binary asteroid. The asteroid in question was asteroid 433 Eros with light curves very similar to those of double stars (Andre, 1901). A review by Prokof'eva and Taraschhuk (1995) of published observational data showed that about 10% of photometrically investigated asteroids have some signs of binarity.

Confirmation of the existence of the system asteroid-satellite was obtained by spacecraft Galileo in August 1993 when it flew by asteroid 243 Ida. The images of the asteroid and its satellite, Dactil, were transmitted to Earth. The spin period of Ida is $4^h.63$. The satellite has a circular orbit near the equatorial plane of the asteroid. The revolution period of Dactil is about 1 d. The solar spectra scattered by the asteroid and its satellite are distinguishable, showing the different compositions of their surfaces.

2 HISTORICAL OBSERVATIONAL DATA

Information about asteroid satellites has been obtained using different methods (Prokof'eva and Taraschhuk, 1995). Below is a summary.

Observations of occultations of stars by asteroids were seen especially in the 1970s. Thirteen objects were found for which the additional short weakness of stellar brightness was recorded and interpreted as due to the passage of satellites of observed asteroids (Van Flandern *et al.*, 1979). The occultation of asteroid 532 Herculina caused several additional decreases of stellar brightness, which were registered by different observers; professionals and amateurs.

Photometric evidence of the binarity of asteroids, research into their light curves and calculation of their periods have given provided the richest material for determination of the composite structure of asteroids — 30 asteroids were suspected to have satellites (Tedesco, 1979).

Radar observations of asteroids, obtained for about 70 asteroids, have given double echos for nine objects (Ostro, 1993).

Direct registration of asteroids' satellites by ground telescopes is almost impossible on account of insufficient angular resolution. However, we should note the little known fact that two double stars were discovered during visual observations, but it was found they were asteroids 433 Eros and 2 Pallas (Innes, 1926). In 1980 in China photographic observations of asteroid 9 Metis (geocentric distance 1.23 a.e.) were obtained with excellent quality of images (Sichao *et al.*, 1981). The satellite position changing with respect to the asteroid was recorded. The diameter of Metis is 153 km, and diameter of its satellite is 60 km. This coincides with the dimensions obtained from the occultations of stars. The spin period of Metis is $5^h.078$ and the revolution period of its satellite is estimated as 4.61 d.

Speclinterferometric observations have confirmed the probable binarity of six asteroids, but unequivocal results were not obtained on account of the complexity of this method and the rapid rotation of asteroids (Drummond and Hege, 1989).

Indirect evidence for the binary or more composite structure of asteroids was obtained from the often observed disintegration of comet nuclei, as well as from investigations of craters, caused by small bodies falling onto the surfaces of large planets and their satellites. The latter have shown an increased number of compound structures consisting of two or more craters (Woronov, 1978; Melosh and Stansberry, 1991). This cannot be incidental, and appears to be caused by falling bodies comprising several components (Hut and Weissman, 1985).

3 RECENT INVESTIGATIONS

Photometric observations of asteroids, carried out with optical image detectors have allowed us to obtain some hundreds of brightness measurements of studied objects relative to stars in the field of view during the night (Abramenko *et al.*, 1984; Batrakov *et al.*, 1992; Prokof'eva *et al.*, 1992, 1994; Prokof'eva and Pavlenko, 1993;

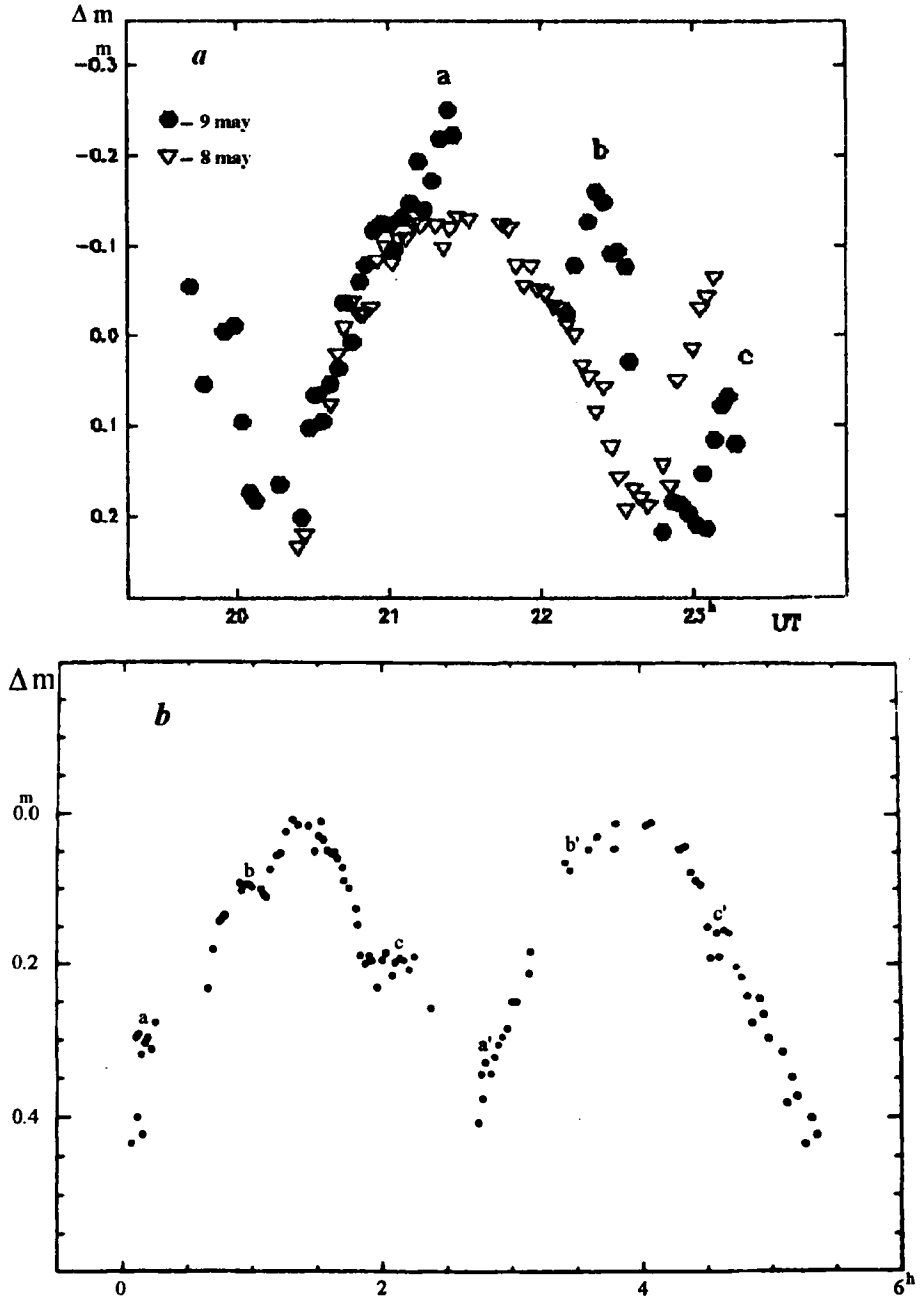

Figure 1 Light curves of asteroid 87 Sylvia demonstrate a periodic short increase of brightness at moments pointed out on the figure by letters. *a*, Observations of the same half periods of light curves obtained on May 3 and 8, 1989 with the 0.5-m telescope of the Crimean Astrophysical Observatory digital television complex. *b*, Light curve obtained by Blanco *et al.* (1989) January 26–27, 1988 with the 0.91-m Catania telescope with CCD.

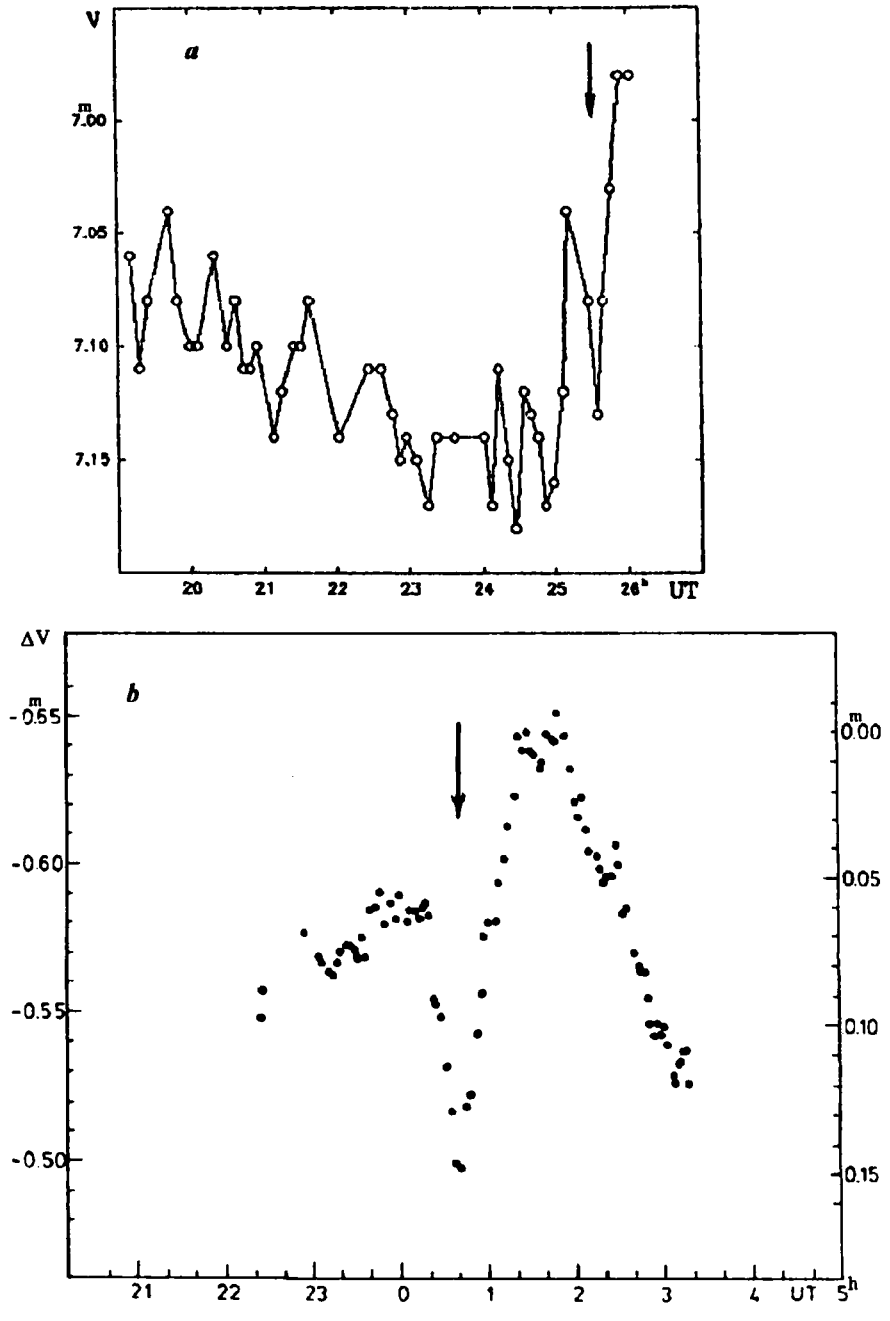

Figure 2 Light curves of asteroid 423 Diotima with thin photometric effects (arrows) led us to suspect the existence of a satellite: *a*, Absolute V-magnitudes obtained differential method March 22, 1990 with TV apparatus using the 0.5-m telescope of the Crimean Astrophysical Observatory (Batrakov *et al.*, 1992). *b*, Differential *V*-magnitudes obtained with a *V*-filter by Schober (1983) on November 10–11, 1982 with the 1-m telescope at the Observatoire de Haute Provence, France.

Prokof'eva, 1995). Differential observations eliminate fluctuations of the Earth's atmospheric extinction during the night. This increases the accuracy and reliability of data. It makes if possible to observe small photometric effects on individual light curves of asteroids. The light curves of asteroid 87 Sylvia (see Figure 1) were obtained at two observatories by differential methods with different detectors. They demonstrated the observed effects of sharp increases and decreases of asteroid brightness relative to ordinary light curves. These flashes were repeated regularly.

The main principle of asteroid-satellite investigation by frequency analysis is the supposition that the asteroid brightness is modulated at the frequencies of their rotations. These modulations may be obtained if there are numerous measurements of the asteroid that allow the construction of a good composite light curve. Subtraction of it from the observational data is performed and the residual data are analysed again. The existence of multiperiodicity indicates a binary or more composite structure of the asteroid.

Analysis of photometric B-observations of asteroid 87 Sylvia enabled us to obtain four periods: known period $0^d.215985$; $\sim 30^d$, $^d.221$, $0^d.12$. Analysis of colour indexes $B-V$ and $V-R$ confirmed the period of $0^d.221$, gave a period of $0^d.07$ and showed the absence of known period $0^d.215985$ (Prokof'eva and Demchik, 1992, 1994).

The frequency analys of effects demonstrated in Figure 1*a* (Blanco *et al.*, 1989) showed a period $0^d.08$, near to our period $0^d.07$. The assumption was made that the known period actually is orbital, and the two others are spin periods of the asteroid components.

The light curves obtained for Diotima (Figure 2) showed the existence of a satellite also (Schober, 1983). Analysis of observations of asteroid 423 Diotima enabled us to obtain two periods of $0^d.62$ and $0^d.19$ (the latter coincided with the known period $0^d.192583$) and to suspect a period of about 200^d. The assumption was made that the first two periods are the spin periods of the components, and one of them coincides with the orbital period and the latter is caused by precession (Prokof'eva *et al.*, 1995).

Both asteroids belong to the class of large asteroids. They have the greatest probability of collisions and destruction (Farinella and *et al.*, 1992). The first of them is a nearly synchronized system, and the second is a synchronized system. These systems are atable.

4 CONCLUSION

The questions of origin, stability and dynamics of satellites of asteroids have been considered repeatedly (Weidenschilling, 1985; Zhang and Innanen, 1988; Weidenschilling *et al.*, 1989; Chauvineau and Mignard, 1990a, b). Theoretical works confirmed that such systems are steady on the Solar System scale of time. N. N. Gorkavyi in review (Prokof'eva *et al.*, 1995b) has made estimates of characteristic time intervals for the changes of orbits of satellites for 12 asteroids with known sizes of satellites and their orbits and has obtained values from units to hundred of millions

of years. Satellites of asteroids, it appears, were formed at a stage of evolution of the Solar System when relative velocities of bodies in the asteroid belt were small and formation of satellites occurred by accretion on two bodies.

References

Abramenko, A. N., Agapov, E. S., Anisimov, V. F. *et al.* (1974) In *Television Astronomy*, V. B. Nikonov (ed.), Ist Edn (1984, 2nd Edn), Nauka, Moscow.
Andre, C. (1901) *Astron. Nachr.* **155**, 27.
Batrakov, Yu. V., Karachkina, L. G., Prokof'eva, B. V., and Pavlenko, E. P. (1992) In *Proc. All-Union Conf. Asteroid Hazard*, A. G. Sokolsky (ed.), ITA, St. Petersburg, p. 134.
Blanco, C. (1988) *Mem. Soc. Astron. Ital.* **60**, 195.
Chauvineau, B. and Mignard, F. (1990a) *Icarus* **83**, 360.
Chauvineau, B. and Mignard, F. (1990b) *Icarus* **87**, 377.
Drummond, J. D. and Hege, E. K. (1989) In *Asteroids*, R. P. Binzel *et al.* (eds.), Arizona Press, University of Tucson II, p. 171.
Farinella, P., Paolicchi, P., and Zappala, V. (1982) *Icarus* **52**, 409.
Hut, P. and Weissman, P. (1985) *Bull. Am. Astron. Soc.* **17**, 690.
Innes, R. T. A. (1926) *Mon. Not.*, No. 4, 209.
Melosh, H. J. and Stansberry, J. A. (1991) *Icarus* **94**, 171.
Ostro, S. J. (1993) *Rev. Mod. Phys.* **65**, 1235.
Prokof'eva, V. V. (1995) *Izv. Krym. Astrofiz. Obs.* **90**, 93.
Prokof'eva, V. V. and Demchik, M. I. (1992) *Astron. Tsirk.* **1552**, 27.
Prokof'eva, V. V. and Pavlenko, V. P. (1993) *Izv. Krym. Astrofiz. Obs.* **88**, 102.
Prokof'eva, V. V. and Demchik, M. I. (1994) *Pis'ma Astron. Zh.* **20**, No. 4, 299.
Prokof'eva, V. V. and Tarashchuk, V. P. (1995) *Astron. Vestn.* **29** No. 2, 123.
Prokof'eva, V. V., Demchik, M. I., Karachkina, L. G., and Pavlenko, E. P. (1992) *Astron. Vestn.* **26**, No. 5, 3.
Prokof'eva, V. V., Pavlenko, E. P., Tarashchuk, V. P., and Karachkina, L. G. (1994) *IAU Working Group on Wide-field Imaging Newsletter* **5**, 41.
Prokof'eva, V. V., Demchik, M. I., and Karachkina, L. G. (1995a) *Astron. Astrophys. Trans.* **8**, 291.
Prokof'eva, V. V., Tarashchuk, V. P., and Gor'kavyi, N. N. (1995b) *Usp. Fiz. Nauk* **165**, No. 6, 661 (*Physics–Uspekhi* **38**, No. 6, 623).
Schober, H. J. (1983) *Astron. Astrophys.* **127**, 301.
Sichao, W., Yuezhen, W., Mengxian, B. *et al.* (1981) *Icarus* **46**, 285.
Tedesco, E. F. (1979) *Science* **203**, 905.
Van Flandern, T. C., Tedesco, E. F., and Binzel, R. P. (1979) In *Asteroids*, T. Gehrels (ed.), University of Arizona Press, Tucson, p. 443.
Weidenschilling, S. J. (1985) *Bull. Am. Astron. Soc.* **17**, 731.
Weidenschilling, S. J., Paolichi, P., and Zappala, V. (1989) In *Asteroids* R. Binzel *et al.* (eds.), University of Arizona Press, Tucson II, p. 643.
Woronov, A. (1978) *Icarus* **34**, 324.
Zhang, S. P. and Innanen, K. A. (1988) *Icarus* **75**, 105.