A COMPARISON BETWEEN BINARY STAR LIGHT CURVES AND THOSE OF POSSIBLE BINARY ASTEROIDS*

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Abstract. Since about ten years coordinated programs of photoelectric observations of asteroids are carried out to derive rotation rates and light curves. Quite a number of those asteroids exhibit features in their light curves, with similar characteristics as variable stars and especially eclipsing binaries. This would allow also an interpretation that there might be an evidence for the binary nature of some asteroids, based on observational hints. A few examples are given and a list of indications for the possible binary nature of asteroids, based on their light curve features, is presented.

1. Introduction

Right from the beginning, I should state that if we observe asteroids, variable stars, or eclipsing stars, using photoelectric photometry, there is no difference in the technical procedure to do that – or in reducing the photometric data. And as we shall see, asteroid light curves easily can be interpreted as binary light curves in a number of cases.

In the last *Ephemerides of Minor Planets for 1983* the number of asteroids with known orbits was given with about 2500. Roughly the major part of orbits is found to be in between Mars and Jupiter (semi-major axis $a = 1.52$ AU and $a = 5.20$ AU), but meanwhile we do know a few asteroids with exceptional orbits – e.g., closely approaching the Earth as 1566 Icarus with $a = 1.08$ AU, 1620 Geographos, $a = 1.24$ AU or 433 Eros with $a = 1.46$ AU. A group of new discovered objects are called Atens and they have orbits completely inside of that of the Earth (2062 Aten, $a = 0.97$ AU or 2100 Ra-Shalom with $a = 0.83$ AU). Further out of the general system of asteroids there is 944 Hidalgo at $a = 5.79$ AU, but with a very eccentric orbit, and far from that a new type of asteroid (or planet?) 2060 Chiron with a semi-major axis of $a = 13.70$ AU was discovered; this either proves that we are starting to see another 'asteroid belt' between Jupiter and Saturn, or that there are more planets than we do know; this would be a matter of where to put the lower limit for the diameter of a solar-system planetary object, of course.

From the physical observations of asteroids since about 1970, when we started really to consider physics of asteroids to be more important, photometry and spectrophotometry was applied and a new picture was developed; compositional types could be defined as *C* (carbanaceous, dark), *S* (stony, metallic, high albedo), *M* (metallic), *E* (enstatic), *R* (reddish), and *U* (unknown, unusual) as given by Bowell *et al.* (1978). Also the bimodality due to the albedo for *C*- and *S*-types was established. The distribution

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in different orbital zones, their correlation with diameters, rotational periods, light curve amplitudes as an indication for the irregularities of the geometric forms might be a basic clue to the understanding of the origin and formation of the asteroid belt as well as possibly for the solar system in future.

From the combination of radiometry in the infrared, polarimetry, and *UBV* photometry in addition we know diameters and albedos of about 800 asteroids, now (1500 with good *UBV*-data), among them approximately 250 with well determined diameters of 10% accuracy, as listed by Bowell *et al.* (1979). Spectrophotometric data in a 11-filter system we do have for about 300 asteroids.

From photoelectric light-curve observations, usually done in *UBV*, we have now a statistical sample of 350 (300 well-) known rotation periods of asteroids, ranging between 2 hr up to 145 hr (six days) with an asteroid, which probably has 48 days of rotation period; a histogram of rotation rates was given by Schober *et al.* (1982). The light variations are mostly due to irregular shape, albedo differences on the surface for nearly spherical object like 1 Ceres, but there are also very elongated (or binary?) asteroids like 1620 Geographos with a cigar-shape form of 1 : 6 axial ratio. Also the spin axis orientation in space was measured, but only for a very small number of asteroids.

Usually the light curves of asteroids show a double wave characteristic, like eclipsing binaries, especially close ones, with two maxima M1, M2, and two minima m1, m2, sometimes with additional features in the light curves. A typical example is shown in

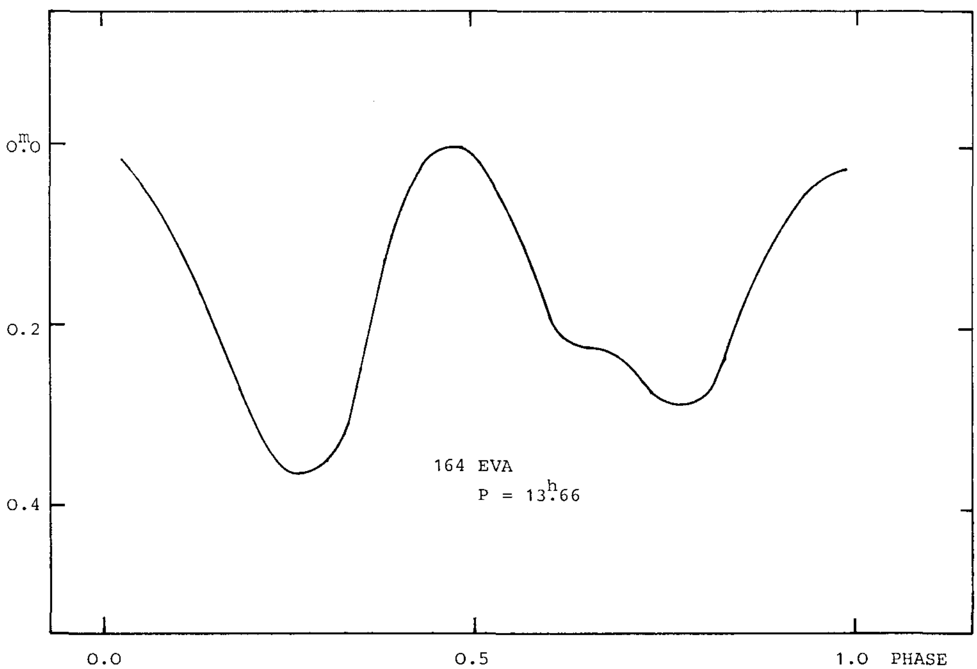

Fig. 1. Typical light curve of a rotating asteroid (164 Eva), which also can be interpreted as a binary-object light curve.

Figure 1 with the light curves of the asteroid 164 Eva, obtained by Schober (1982), which easily can be interpreted as a binary-star light curve as well.

2. Existence of Binary Asteroids or Satellites of Asteroids?

Up to the present date there never was discovered a binary asteroid or a satellite of an asteroid on photographic plates. But, of course, in the past there was no need to look systematically for such a phenomenon; and searches initiated in the last years also were not successful.

The first indications for a possible satellite of an asteroid were given in an occultation report by Bowell *et al.* (1978). Before and after the occultation of the bright SAO star 120774 on 7 June, 1978 by the asteroid 532 Herculina with 20.6 s duration, secondary events within two minutes of each 0.5–4.0 s duration were reported, and observed photoelectrically – but only two degrees above the horizon. A model was given, that the major-secondary occultation was caused by a satellite: 532 Herculina with a mean diameter of 220 km should have a satellite with 50 km diameter in a distance of about 1000 km from the asteroid center. This distance corresponds to about 0.7 arc sec if observed from the Earth at 2 AU.

Evidences for satellites were found from occultations also for other asteroids, e.g., 18 Melpomene, 2 Pallas, or 65 Cybele (?), but the occultation measurements are difficult to obtain, to organize and to predict for a certain observatory. Observatories, where precise measurements can be made are not distributed well enough, so a real confirmation of a binary asteroid or a satellite by direct observations never was possible.

3. Evidences for the Binary Nature of Asteroids from Photoelectric Light Curves

In the last years we have given high priority to observe light curves of asteroids to derive rotation rates for the statistical purposes. But it turns out that this kind of observation still delivers the best indication to detect possible binary objects. On the other hand, also the number of asteroids already observed is rather large now, a few of them were observed even during several oppositions.

Binary asteroids, or satellites of asteroids with a relative large size compared with the major body, should show some details in the light curves, if observed in a suitable geometric configuration between Earth-Sun-asteroid-satellite. Striking similarities of light curves were stated by van Flandern *et al.* (1979); the light curve of 433 Eros is similar to that of β Lyrae type variables, that of 44 Nysa is strikingly similar to the contact binary light curve of W Ursae Majoris stars. Algol like light curves of 171 Ophelia, 49 Pales, or 46 Hestia are remarked, with flat constant parts in the extrema and sometimes with very deep and sharp minima in the light curve. This has drawn attention to the fact that asteroids also can be interpreted as binary systems.

Van Flandern *et al.* (1979) have summarized the problem of satellite of asteroids and gave a list of six points for asteroid light curves (1)–(6), where the possibility is high to have observed two bodies instead of a single one during a rotational cycle. Based on my own observing experience I have added four more indications (7)–(10) as a hint for possible binary nature:

(1) light curve maxima sharper than minima: e.g., 129 Antigone;

(2) complex light curves: e.g., 24 Themis, 29 Amphitrite, 51 Nemausa;

(3) increase in light curve amplitude with increasing solar phase angle: e.g., 349 Dembowska, 944 Hidalgo;

(4) light curves with two maxima and minima per rotational cycle at one opposition, but only one of each at another: e.g., 532 Herculina;

(5) triple maxima and minima in the light curve per rotation cycle: e.g., 1580 Betulia, 337 Devosa, 37 Fides (quadruple ?), 51 Nemausa; assuming bound rotation;

(6) contact binary light curves: e.g., 44 Nysa;

(7) nonperiodic irregular features in the light curves, or showing up with periods different from the rotation rate: e.g., 37 Fides, 423 Diotima;

(8) color variation during rotation, if not interpreted as spotted surface: e.g., 48 Doris;

(9) slowly spinning asteroids with rotation periods of 2–6 days instead of the usual range of hours: e.g., 1689 Floris-Jan (possible tidal evolution of binary systems);

(10) large light curve amplitudes (1–2 mag.): e.g., 433 Eros, 216 Kleopatra.

In Figure 2 there is shown the example of the triple light curve of 51 Nemausa, a very important object for which an international campaign is running, as obtained by Gammelgaard and Kristensen (1983). In Figure 3 the most recent example for a possible

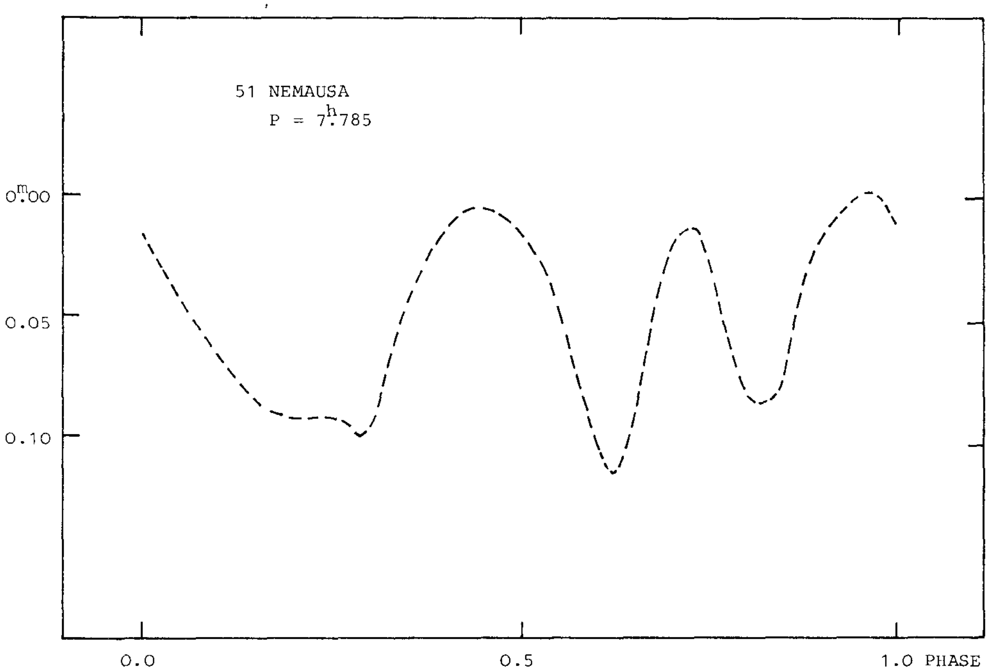

Fig. 2. The complex light curve of the asteroid 51 Nemausa with triple extrema.

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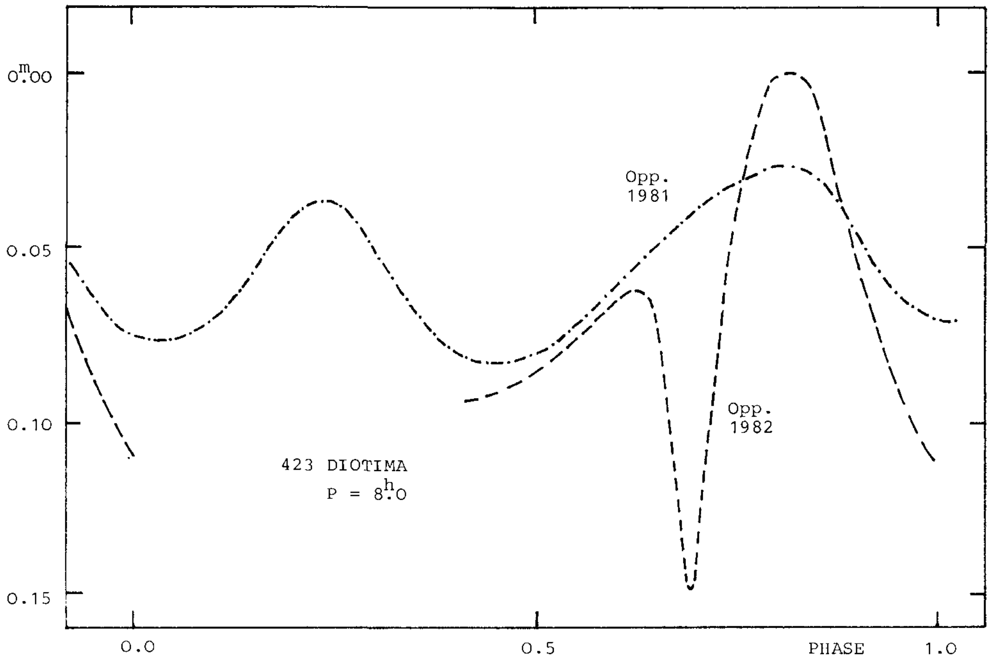

Fig. 3. Light curves of the asteroid 423 Diotima obtained during two different oppositions; the additional 'absorption' feature might give an indication for the possible detection of a satellite of 423 Diotima.

satellite is shown for 423 Diotima, as obtained by Schober (1983), where an additional 'absorption' is remarked in a different opposition, which looks like an occultation of the major body of 423 Diotima by a satellite.

4. Concluding Remarks

Of course, the presented list of hints does supply only indications for a possible binary nature of asteroids; multiple asteroids cannot be observed directly with convential techniques, but might be detected in future using the space telescope or the astrometric satellite Hipparcos; but also more sophisticated methods can be used, such as speckle interferometry in all available wavelengths (the best would be in infrared), radar scatter measurements – or excellently organized occultation-measurements (weather conditions and participation must be granted!), if the worldwide interest would be high enough.

Due to van Flandern *et al.* (1979) the gravitational boundary sphere before perturbations begin to dominate, should be roughly hundred times the mean diameter of the asteroid; this would give for 532 Herculina a distance of about 25000–30000 km, e.g.

In the future high preference should be given to observe large asteroids in detail for satellites, and small asteroids for binary nature. They could be very elongated solid bodies or 'ribble-piles', but also 'semi-detached binaries' as it might be concluded on the base of their light curves.

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