Difficult cases in photometric studies of asteroids

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We present a photometric campaign targeted at asteroids that display both long periods of rotation and small amplitudes of brightness variations. Our aim is to debias available sample of spin and shape modelled asteroids and to correct previous wrong period determinations. Our newest findings are corrected period determinations for asteroids (279) Thule (P=23.896h ± 0.005 h), (673) Edda (P=22.340h ± 0.004 h), and (737) Arequipa (P=7.0259h ± 0.0003 h). Supporting lightcurves are presented in this paper.

1 Introduction

Asteroids conserve the features of the early Solar System as well as record its consecutive evolution. Photometric studies of asteroids are the basis for physical studies of their spins and shapes, what enables drawing conclusions about their internal structure, and both collisional and thermally driven evolution.

Lightcurve parameters (synodic rotation period and lightcurve amplitude) have been determined for thousands of asteroids and have been collected and evaluated in Lightcurve Database (LCDB) maintained by Warner et al. (2009), with regular updates (also available at IAU Minor Planet Center webpage). However this sample is burdened with certain selection effects favouring large, bright (high albedo), and close targets. Other less obvious selection effects favour targets with relatively quick rotation (P<12 hours) and large lightcurve amplitudes (a_{max}>0.25 mag).

The spin parameter survey is complete only for the relatively bright asteroids, those with absolute magnitude H≤11 mag, i.e., objects with diameters over 12 - 37

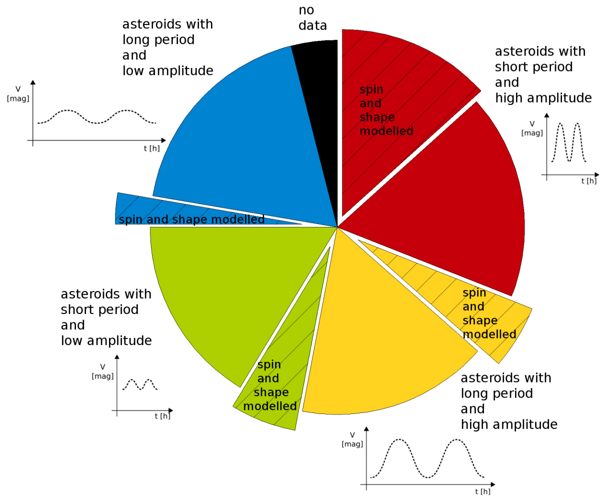

Fig. 1: Distribution of periods and maximum amplitudes among 1230 brightest main belt asteroids (based on data from LCDB). Division values are: P=12 hours, and a_{max}=0.25 mag. The amount of spin and shape modelled targets is marked within each group.

km, depending on the albedo. The pie chart in the Fig. 1 summarises these parameters for brightest targets.

As the figure 1 shows, spin and shape studies based on photometric data gathered over many apparitions are even more influenced by the aforementioned selection effects. The picture emerging from recent studies suggests that spin axes of small asteroids (less than 30 km in diameter) largely avoid the proximity of the ecliptic plane (see Hanuš et al., 2013, for example). In other words, almost all small asteroids, for which we know spin parameters seem to have their axis of rotation roughly perpendicular to the ecliptic. Such a spin axes distribution can be explained by a subtle thermal force - the YORP effect acting on small asteroids, pushing their spin axes towards extreme obliquities, also influencing spin periods (Vokrouhlický & Čapek, 2002). However the real picture of spin axis distribution is probably more complicated, as there are various timescales involved, depending on target size, shape, and collisional history.

Asteroids with long rotational periods and small amplitudes of their lightcurves at the same time, although numerous, are seriously underrepresented in the sample of spin and shape modelled targets. This was the motivation for starting our photometric campaign of around 120 such asteroids. Details of the campaign can be found in Marciniak et al. (2015). In the course of the campaign, conducted from about 10 stations around the world, we found that synodic periods determined previously within this asteroid group were often questionable. In the aforementioned paper, we have shown that within this group of asteroids a quarter of periods previously accepted in Lightcurve Database by Warner et al. (2009) have actually completely different values. Here we present another three cases of long-period low-amplitude asteroids with corrected period determinations. We also provide a corrigendum pertaining one case, where the new period determined by us was not confirmed in a subsequent apparition.

2 Results

The results are presented in a form of composite lightcurves folded with the best fitting period in terms of minimum χ^2 value. The average noise in the data was at the level of a several thousandths of a magnitude, while target brightnesses ranged from 12.5 to 15.5 mag. The data were averaged by 2 or 3 to make them easier to track. The observatories which provided most of the data presented here were Montsec Astronomical Observatory in Catalonia (Spain), where the robotic 0.8 m telescope was used, and Organ Mesa Observatory in Mew Mexico (USA), equipped with 0.35 m telescope. Other observatories were: Winer Observatory in Arizona (USA), Bisei Spaceguard Center in Japan, Derenivka Observatory in Ukraine, and Borowiec, Mt. Suhora, and JKU Astronomical Observatories in Poland.

2.1 (279) Thule

This asteroid has been previously observed in six apparitions, and as many as five different determinations for its period were published. Zappala et al. (1989) observed Thule in the year 1985 and, from three small-amplitude (0.06 mag) fragments, determined a period of 7.44 hours. Basing on observations made in 2007, Sauppe et al. (2007) provided the lower limit for an amplitude (0.14 mag), but no period determination. In the next year apparition in 2008, Thule was observed by three groups, Behrend et al. (2015), Pravec et al. (2008), and Pilcher (2014), who provided the period values of 5.75, 11.942, and 7.970 hours respectively. The lightcurve variations were at a very low level again (0.06 mag amplitude), that can partially explain these discrepancies. In 2010, Thule displayed 0.10 mag amplitude lightcurve that was folded with 15.962 hours period by Warner et al. (2010), and provided better fit to the data than 7.979 hours period. Other values for the period were also excluded by this study. The final period determination (15.962 h) was accepted in LCBD summary line with a quality code 2+, which means that the period was somewhat likely to be in error. In 2013, Thule displayed very small amplitude again (0.02 mag) and obtained data were fitted with the period 15.85 hours (Pilcher, 2014). Finally, data gathered by Pilcher (2015) in 2015 showed larger (0.08 mag) amplitude and provided the best fit with 15.931 hours period. The two maxima of such a composite lightcurve looked very symmetric.

We observed Thule from a few stations largely separated in longitude (Spain, Arizona and Japan) and found that obtained extensive dataset can only be folded with the period of 23.896 ± 0.005 hours, resulting in a somewhat asymmetric, bimodal lightcurve (Fig. 2). The proximity of the period to 24 hours can explain previous failures to correctly identify it. Previous authors usually saw the same lightcurve fragments each time and were mislead by an assumption of the regular, bimodal character of the lightcurve. Moreover, single station observations could not cover the whole rotation, as the phases drift by only 2 minutes per one sidereal Earth's revolution. The composite lightcurve shown in Fig. 2 contains also the data gathered by Pilcher (2015) in the same apparition to show the goodness of the fit and to complete the phase coverage. Data from previous apparitions, where available, also fit the 23.894 hours period resulting in irregular lightcurve with significant gaps. In such small amplitude range, lightcurves can actually be very irregular, because at the weak overall elongation of the shape, various small topographic features strongly influence brightness variations. The previously accepted period of 15.962 hours was

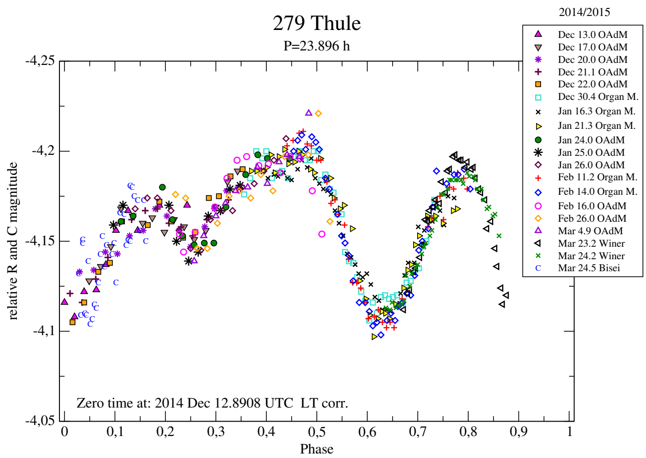

Fig. 2: Composite lightcurve of asteroid (279) Thule in 2014/2015. The only period fitting this data is 23.896 ± 0.005 h. Previously accepted period in LCDB was 15.962 h.

apparently an alias (2/3)P of the period presented here. It should be noted that in 2015 apparition this shorter period gives substantial misfits of various fragments relative to each other due to the asymmetric lightcurve, and resolves the long standing uncertainty for the the rotation period of Thule.

2.2 (673) Edda

First remarks on its lightcurve character come from the work of Addleman et al. (2005), where it was mentioned among a few asteroids with too small amplitude or too noisy data for a lightcurve to be distinguished. In the years 2005 and 2007 the group led by Behrend et al. (2015) gathered data for (673) Edda that displayed amplitudes around 0.12 mag and provided good fit to 14.92 hours period in 2005, but a substantial misfit to it in 2007. This period has been assigned code 2 in LCDB, which implied that it might have been wrong by 30% or an integer multiple.

Our extensive campaign, conducted in the year 2015, unambiguously revealed the period of 22.340 ± 0.004 hours and an unusually asymmetric lightcurve with a very wide minimum and the other one sharp and narrow (Fig. 3). This new period is almost exactly at 3/2 of the previously accepted one. The amplitude of this lightcurve is at the level of 0.21 ± 0.01 mag, the largest noted for Edda so far. Interestingly the period of 22.340 hours implies 3 maxima lightcurve in the previous apparition in 2013/2014, with much smaller, 0.13 mag amplitude, though. We conclude that the shape of this asteroid must be very asymmetric.

2.3 (737) Arequipa

Photometric data of this target were gathered by Harris & Young (1980) in the year 1978, and the group of Behrend et al. (2015) in 2005 and 2007. The amplitudes ranged from over 0.1 to 0.27 mag, and all the period determinations were close to 14.13 hours, but the character of the lightcurves was complicated and changed from apparition to apparition. The quality code for this period determination was 3, that is, the period

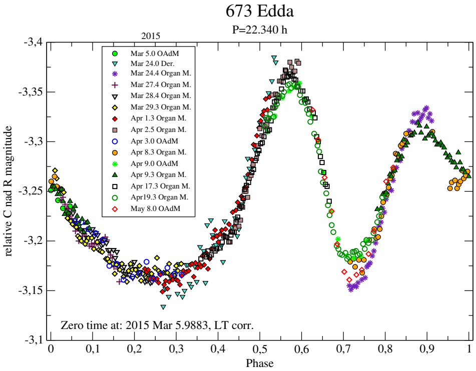

Fig. 3: Composite lightcurve of asteroid (673) Edda in 2015. The only period fitting this data is 22.340 ± 0.004 h. Previously accepted period was 14.92 h.

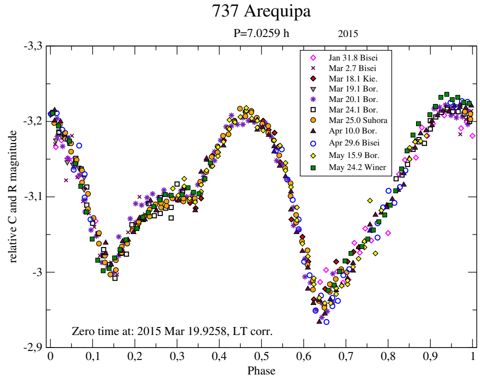

Fig. 4: Composite lightcurve of asteroid (737) Arequipa in 2015. The only period giving physically plausible lightcurve is 7.0259 ± 0.0004 h, while 14.13 h was accepted before.

was considered secure. We note that some of the previously observed apparitions, including the one in 2014 observed by us, were unluckily distributed, probably close to polar aspects, which would result in a kind of monomodal lightcurve over 7-hour period, thus bimodal, 14-hours period composite seemed more plausible.

However, in the 2015 apparition, this target was probably close to the equatorial aspect, because typical, bimodal behaviour is clearly visible over shorter 7.0259 ± 0.0003 hours period (Fig. 4). The 14-hour period composite would in 2015 produce nonphysical quadrimodal lightcurve of rather high, 0.26 ± 0.01 mag amplitude, and repeating brightness variations over 0.5 phase.

This case is a good example of a "difficult" asteroid where years of photometric studies failed to reveal its true period of rotation. The difficulty stemmed from probably complex shape of this body and low inclination of spin axis, a combination of which strongly changed the character of the lightcurve from one apparition to another, and produced very small amplitudes in some of them.

2.4 (70) Panopaea - corrigendum

In Marciniak et al. (2015) we presented data for (70) Panopaea from the apparition in late 2014, where certain asymmetries of some fragments suggested that, instead of previously accepted 15.797 hours, the rotational period is twice as long, i.e. 31.619 hours. However, new good quality data gathered by us in the next apparition in late 2015 clearly rule out the longer period (see Fig. 5 and 6). Lightcurve fragments folded with 31-hour period show almost exactly the same irregularities over 180 degrees of the rotational phase, suggesting the same topographic features present on both sides of an asteroid shape. As this is highly improbable, we come back to the original value of 15.797 hours (with the best fitting synodic period in 2015 of 15.808 ± 0.003 hours and the amplitude at the level of 0.11 ± 0.01 mag), and now consider this shorter period secure. This way we confirm periods found in previous works by Schroll & Schober (1983), Harris & Young (1989), and Behrend et al. (2015).

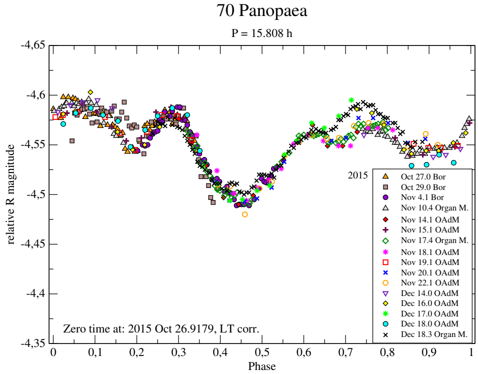

Fig. 5: Composite lightcurve of asteroid (70) Panopaea in the year 2015 with adopted period P=15.808 ± 0.003 h.

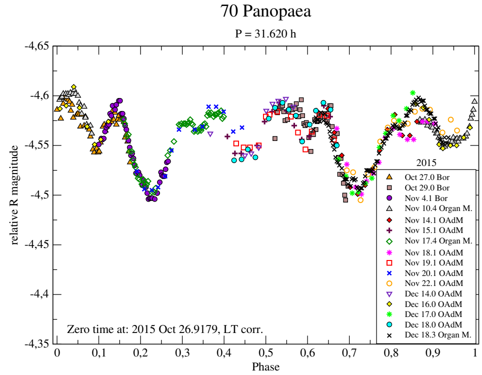

Fig. 6: Double period composite of (70) Panopaea in 2015, with unusually symmetric behaviour.

3 Conclusions

In the course of our study started in late 2012, we have gathered new data for around a half of our sample of 'difficult' asteroids, that resulted in 50 secure period determinations based on full lightcurve coverage, often confirmed in subsequent apparitions. From that number at least 13 targets have different values of the period to those accepted in LCDB before (7 published in Marciniak et al. 2015, and confirmed in subsequent apparition, 3 from the present work, and at least another 3 where new data do not fit the previously accepted period, but the new period is not constrained well enough). This confirms our finding that around 25% of bright long-period low-amplitude population asteroids had incorrectly determined periods. These wrong values have influenced asteroid size-frequency relation and other studies for many years. Moreover, there are probably many more such wrong determinations, especially in the smaller size range. This stresses the importance to focus photometric studies on such more demanding targets to correct and debias the sample of asteroids with known lightcurve parameters, but also those with determined spin states and shape models.

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