ASTEROID LIGHTCURVE ANALYSIS AT CS3-PALMER DIVIDE STATION: 2014 MARCH-JUNE

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Lightcurves for 19 main-belt asteroids were obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2014 March through June. Some of the objects were members of the Hungaria group/family, observed as follow-up to previous apparitions to check for the possibility of undiscovered satellites or to provide additional data for spin axis and shape modeling.

CCD photometric observations of 19 asteroids were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) in 2014 January through March. Table I gives a listing of the telescope/CCD camera combinations used for the observations. All the cameras use CCD chips from the KAF blue-enhanced family and so have essentially the same response. The pixel scales for the combinations range from 1.24-1.60 arcsec/pixel.

Desig	Telescope	Camera
PDS-1-12N	0.30-m f/6.3 Schmidt-Cass	ML-1001E
PDS-1-14S	0.35-m f/9.1 Schmidt-Cass	FLI-1001E
PDS-2-14N	0.35-m f/9.1 Schmidt-Cass	STL-1001E
PDS-2-14S	0.35-m f/9.1 Schmidt-Cass	STL-1001E
PDS-20	0.50-m f/8.1 Ritchey-Chretien	FLI-1001E

Table I. List of CS3-PDS telescope/CCD camera combinations.

All lightcurve observations were unfiltered since a clear filter can result in a 0.1-0.3 magnitude loss. The exposure duration varied depending on the asteroid's brightness and sky motion. Guiding on a field star sometimes resulted in a trailed image for the asteroid.

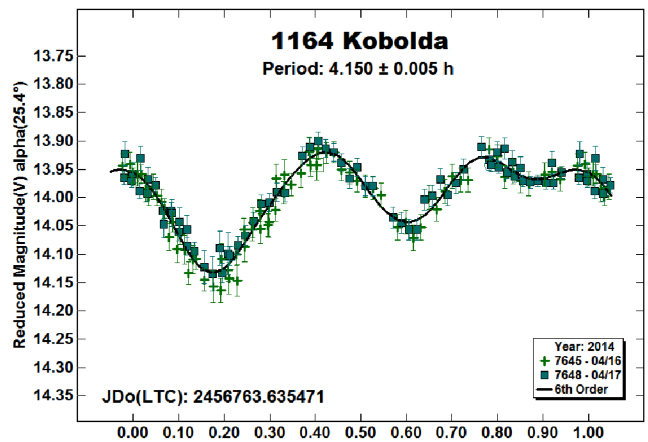
Measurements were done using *MPO Canopus*. If necessary, an elliptical aperture with the long axis parallel to the asteroid's path was used. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. Catalog magnitudes were usually taken from the MPOSC3 catalog, which is based on the 2MASS catalog (*http://www.ipac.caltech.edu/2mass*) but with magnitudes converted from J-K to BVRI using formulae developed by Warner (2007). When possible, magnitudes are taken from the APASS catalog (Henden *et al.,* 2009) since these are derived directly from reductions based on Landolt standard fields. Using either catalog, the nightly zero points have been found to be consistent to about ± 0.05 mag or better, but on occasion are as large as 0.1 mag. This consistency is critical to analysis of long period and/or tumbling asteroids. Period analysis is also done using *MPO Canopus*, which implements the FALC algorithm developed by Harris (Harris *et al.,* 1989).

In the plots below, the "Reduced Magnitude" is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying –5*log (rΔ) to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid distances in AU. The magnitudes were normalized to the phase angle given in parentheses, e.g., alpha(6.5°), using G = 0.15, unless otherwise stated. The horizontal axis is the rotational phase, ranging from –0.05 to 1.05.

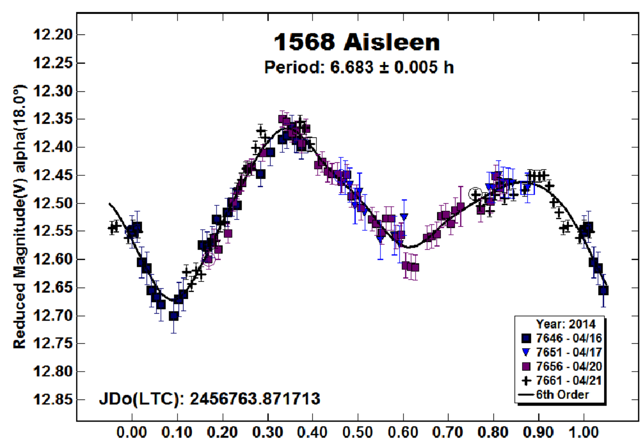
For the sake of brevity, only some of the previously reported results may be referenced in the discussions on specific asteroids. For a more complete listing, the reader is directed to the asteroid lightcurve database (LCDB; Warner *et al.,* 2009). The on-line version at *http://www.minorplanet.info/lightcurvedatabase.html* allows direct queries that can be filtered a number of ways and the results saved to a text file. A set of text files of the main LCDB tables, including the references with bibcodes, is also available for download. Readers are strongly encouraged to obtain, when possible, the original references listed in the LCDB for their work.

Individual Results

1164 Kobolda (Phocaea). Previously reported periods include Higgins and Oey (2007; 4.141 h), Sauppe *et al.* (2007; 4.154 h), and Higgins (2011; 4.142 h). The CS3-PDS period of 4.150 h is in good agreement.



1568 Aisleen (Phocaea). Malcolm (2001) reported a period of 6.68 h for this asteroid. Hanus *et al.* (2011) found a sidereal period of 6.67597 h as part of determining a spin axis and shape model. They reported a pole in ecliptic coordinates of (109°, –68°).

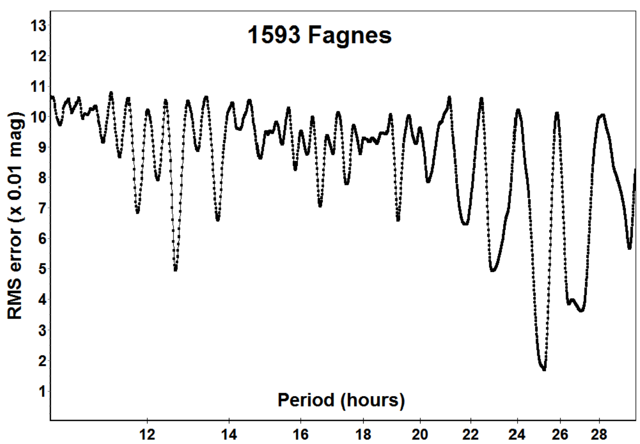


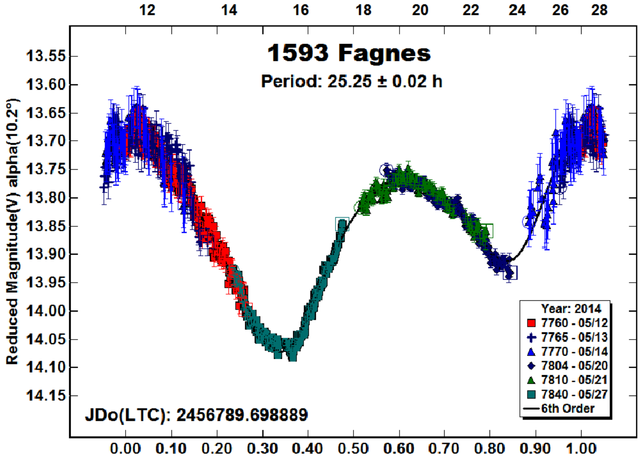
1593 Fagnes (Mars-crosser). Harris *et al.* (1992) reported a period of 16.45 h while Lagerkivst *et al.* (1992) reported 25.1 h. The period spectrum from the 2014 PDS data shows a weak solution near 16.5 h, but – by far – the preferred period is 25.25 hours.

Number	Name	2014 mm/dd	Pts	Phase	L_{PAB}	B_{PAB}	Period	P.E.	Amp	A.E.
1164	Kobolda	04/16-04/17	140	25.4,25.7	165	13	4.150	0.005	0.21	0.02
1568	Aisleen	04/16-04/21	130	18.0,17.4	245	30	6.683	0.005	0.31	0.02
1593	Fagnes	05/12-05/27	801	10.2,13.8	232	14	25.25	0.02	0.38	0.02
2048	Dwornik	06/05-06/08	112	31.6,31.3	313	20	3.730	0.005	0.05	0.01
3022	Dobermann	04/20-04/23	230	10.3,11.0	207	17	10.336	0.005	0.75	0.02
3893	DeLaeter	05/15-05/21	165	16.3,18.8	205	9	5.633	0.003	0.13	0.02
4132	Bartok	04/14-04/15	107	21.1,21.3	158	-2	3.297	0.005	0.41	0.03
5692	Shirao	06/10-06/11	181	10.9,11.2	249	16	2.8878	0.0004	0.16	0.02
6384	Kervin	04/02-04/07	220	19.4,18.8	204	31	3.619	0.002	0.10	0.01
7247	1991 TD1	[12]09/14-09/22	274	18.7,21.1	336	17	3.176	0.002	0.15	0.01
7247	1991 TD1	04/23-04/25	225	8.5,9.6	201	8	3.176	0.002	0.11	0.01
9356	Elineke	05/15-05/18	102	13.3,14.0	209	17	2.750	0.005	0.21	0.02
11279	1989 TC	04/16-04/21	165	17.3,19.8	179	-4	4.003	0.002	0.15	0.02
13186	1996 UM	05/02-05/04	100	22.3,23.0	181	1	4.293	0.003	0.37	0.02
13245	1998 MM19	05/01-05/04	140	12.8,12.6	228	17	4.667	0.002	0.47	0.02
17633	1996 JU	05/14-05/19	175	17.8,0.0,17.7	190	26	6.20[A]	0.02	0.21	0.02
26227	1998 HJ7	05/10-05/21	330	16.6,21.1	211	19	22.07[A]	0.05	0.15	0.03
48470	1991 TC2	04/12-04/17	186	6.5,8.8	195	6	10.19	0.05	0.19	0.02
52314	1991 XD	04/01-04/03	189	16.7,16.5	194	26	7.683	0.005	0.61	0.03
96155	1973 HA	04/12-04/15	271	16.9,16.9	196	21	15.59	0.02	0.59	0.03

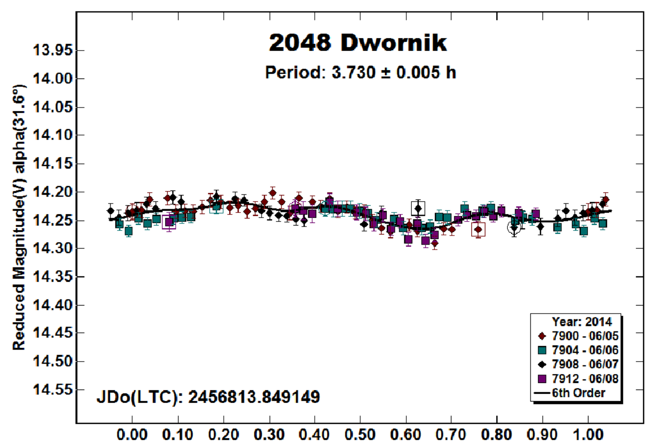
Table II. Observing circumstances. [12] Dates in 2012. [A] preferred period of ambiguous solution.

The phase angle (α) is given at the start and end of each date range, unless it reached a minimum, which is then the second of three values. If a single value is given, the phase angle did not change significantly and the average value is given. L_{PAB} and B_{PAB} are each the average phase angle bisector longitude and latitude, unless two values are given (first/last date in range).

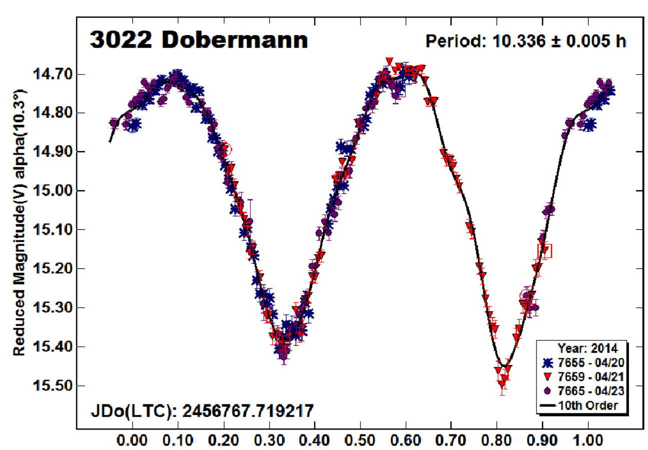




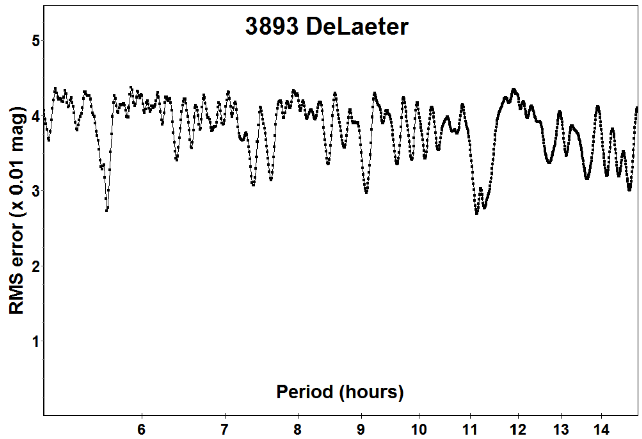
2048 Dwornik (Hungaria). Dwornik was observed in 2014 as part of an on-going program to obtain sufficient data for spin axis modeling for members of the Hungaria group/family. The 2014 apparition was the fourth one observed by the author (see the references in the LCDB).

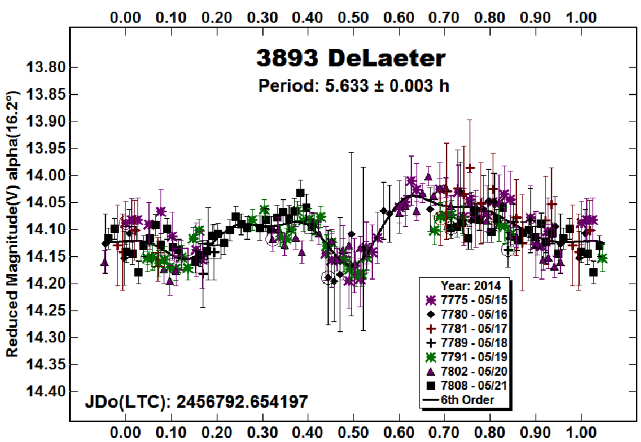


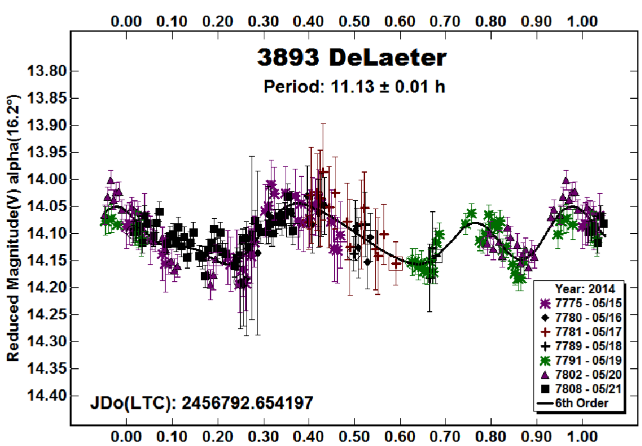
3022 Dobermann (Hungaria). This is also the fourth apparition that the author observed this particular Hungaria member. Initial modeling using those four data sets indicates a reliable pole solution and retrograde rotation. Details will be in a future paper.



3893 DeLaeter (Phocaea). The period spectrum using the 2014 PDS data indicates two possible solutions at around 5.5 and 11 hours. The lightcurve plots show the data phased to these solutions. Given the shape of the two, the shorter period is preferred, although the more complex shape of the longer period cannot be formally excluded (see Harris *et al.*, 2014).

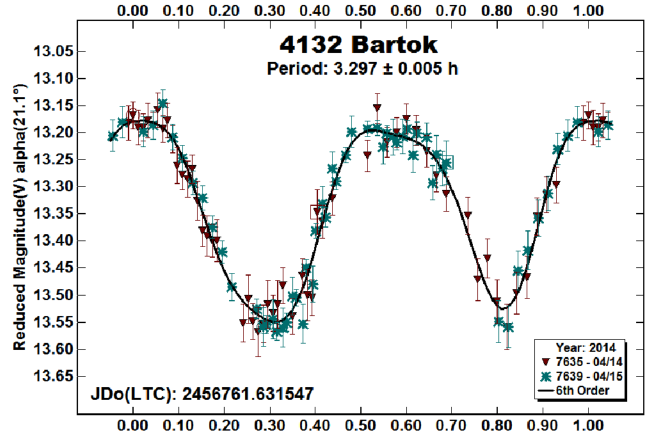




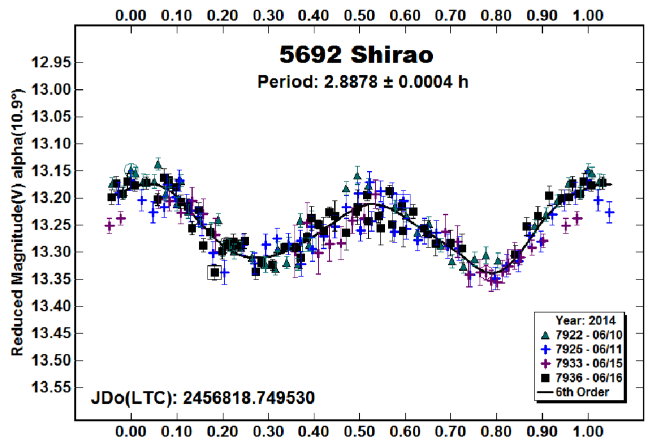


Stephens (2004) reported a period of 13.83 hours, which was not one of the likely solutions in the period spectrum above. His data were available on the MPC lightcurve database site (*www.minorplanetcenter.net/light_curve*). Even after adjusting zero points in his data, the period did not change substantially and could not be made to fit the periods reported here.

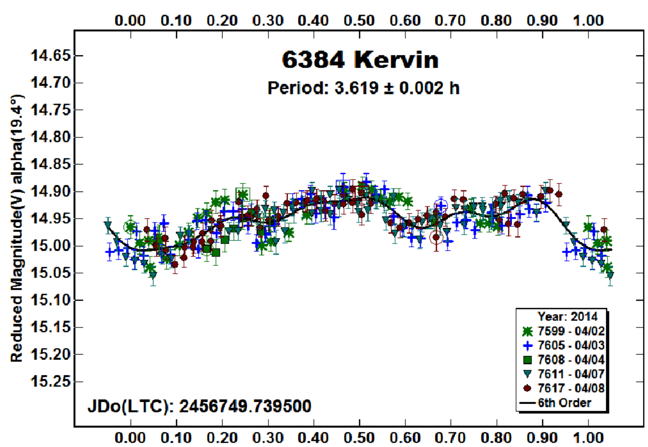
4132 Bartok (Phocaea). Skiff (2011) and Behrend (2014) both reported periods of about 3.297 h. The PDS period of 3.297 h matches those results.



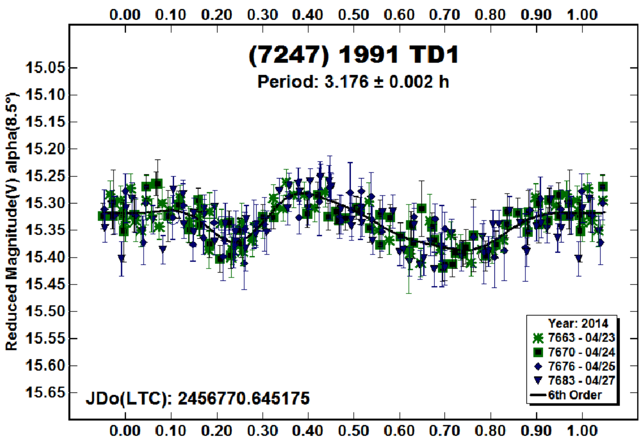
5692 Shirao (Main-belt, middle). Previous results include Behrend (2001; 2.90 h), Pray (2005; 2.886 h), and Behrend (2006; 2.90 h). The PDS result of 2.8878 h is in good agreement.

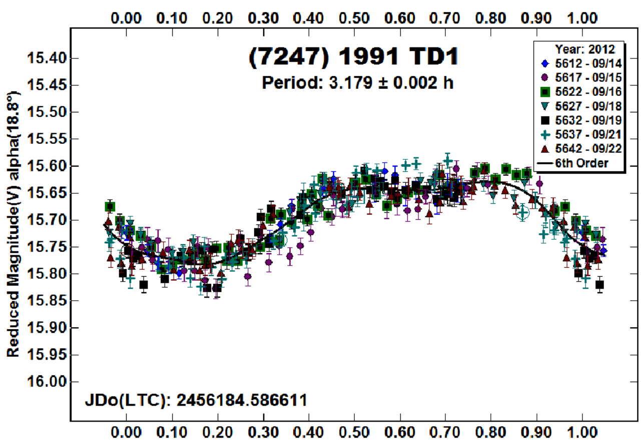


6384 Kervin (Hungaria). In addition to the 2014 apparition, the author worked this asteroid at three previous apparitions: Warner *et al.* (2006, 3.6203 h), Warner (2008, 3.647 h) and Warner (2011, 3.617 h). Analysis of the 2014 data set found P = 3.619 h.

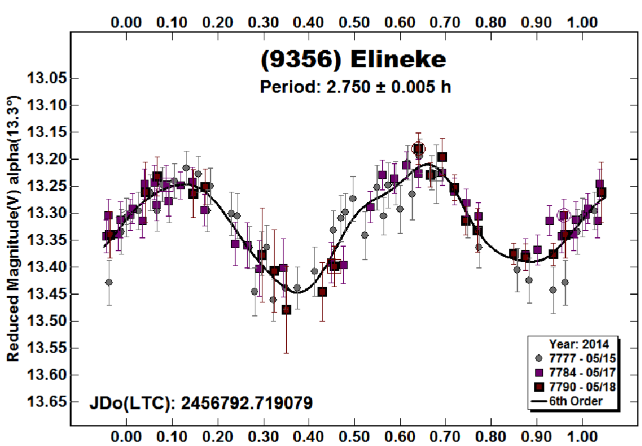


(7247) 1991 TD1 (Hungaria). The author first worked this asteroid in 2012, reporting a period of 6.3515 h (Warner, 2013b) based on a bimodal lightcurve. Analysis of the data obtained in 2014 found a period of 3.176 h. Forcing the data to the long period resulted in an unlikely quadramodal lightcurve, i.e., one with four minimum/maximum pairs per rotation. The 2012 data were re-examined and found to fit a period of 3.179 hours with a monomodal lightcurve. Given the low amplitude and relatively small phase angle, such a shape is not improbable (see Harris *et al.*, 2014).

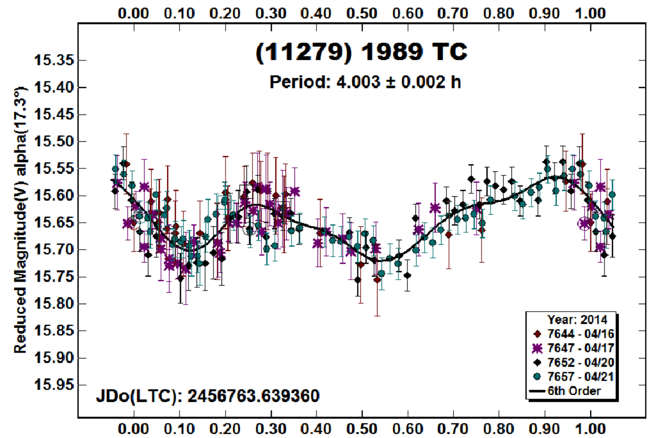




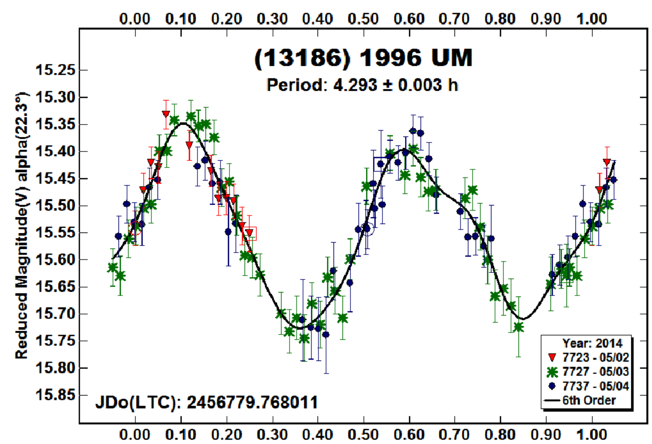
9356 Elineke (Main-belt, middle). This appears to be the first reported lightcurve for this asteroid.



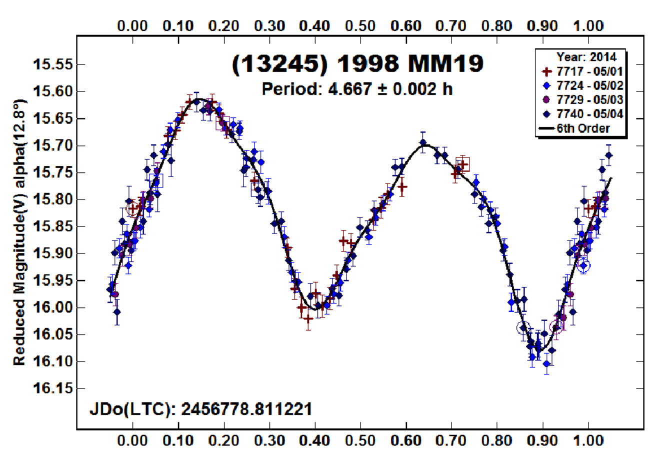
(11279) 1989 TC (Hungaria). The author first worked 1989 TC in 2010 (Warner, 2011) and reported a period of 4.020 h and amplitude A = 0.13 mag. Analysis of the data from 2014 produced a period of 4.003 h and amplitude of A = 0.15 mag. The two periods are statistically the same despite being more than 3-sigma apart. The phase angle bisector longitudes were about 90° apart so, given that the amplitude was about the same both times, it's probable that the spin axis pole favors one of the ecliptic poles.



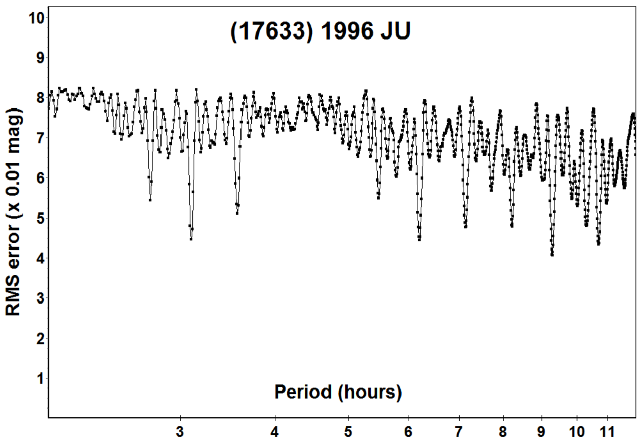
(13186) 1996 UM (Hungaria). A period of 4.304 h was reported by the author based on data obtained in 2013 (Warner, 2013a). The amplitude was 0.69 mag at L_{PAB} ~ 310°. The 2014 data, at L_{PAB} ~ 180°, produced P = 4.293 h and A = 0.37 mag. The diameters going through these two points are at an angle of 50°. Assuming that the viewing aspect in 2013 was nearly equatorial, it is likely that the amplitude would be even lower if L_{PAB} (and north pole of the spin axis) were in the vicinity of 40 ± 20° (or 220 ± 20°).

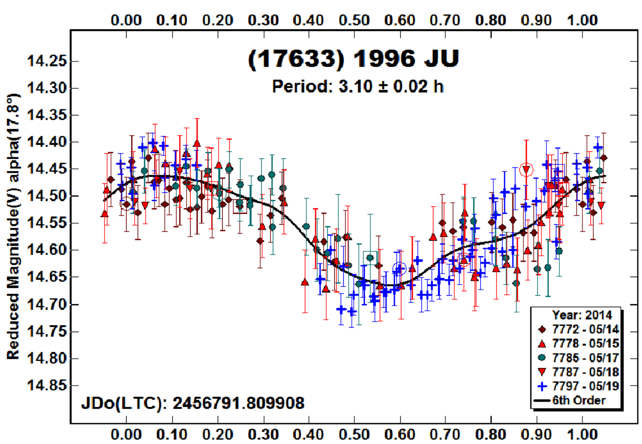


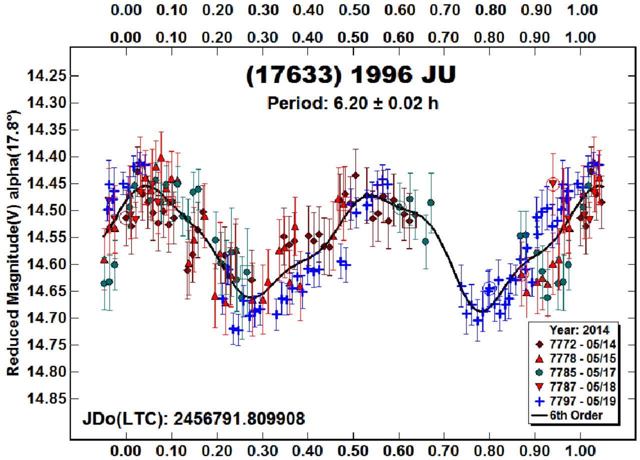
(13245) 1998 MM19 (Hungaria). Warner (2013c) found a period of 4.664 h. The period derived from the 2014 data is in close agreement. The amplitude at the two apparitions differed by nearly 0.2 mag, indicating that the spin axis is tilted somewhat away from the north or south ecliptic pole.



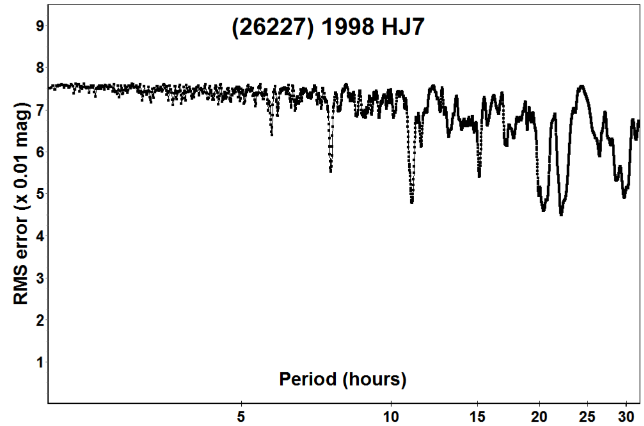
(17633) 1996 JU (Phocaea). Albers *et al.* (2010) first reported a period of 6.2098 h. The data from PDS in 2014 produced two periods, one close to Albers (6.20 h) with a bimodal lightcurve and one at the half-period (3.10 h) and a monomodal lightcurve. The amplitude in both cases is on the border for assuming a bimodal lightcurve (see Harris *et al.*, 2014). There is a significant asymmetry in the Albers lightcurve that supports the 6.20 h solution. The same cannot be said for the PDS data. However, since the period spectrum favors the longer period and it supported by earlier work, the 6.20 h solution is adopted for this work.

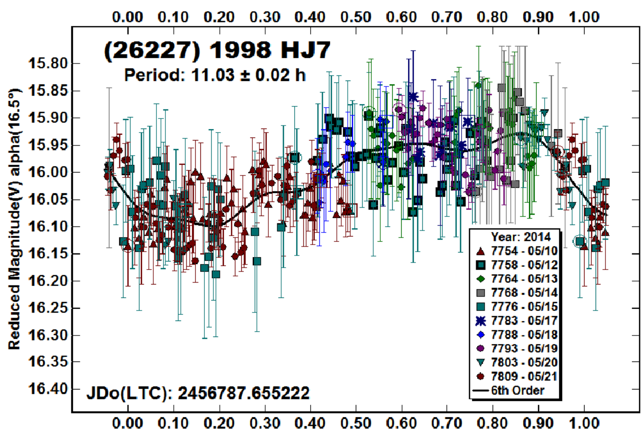


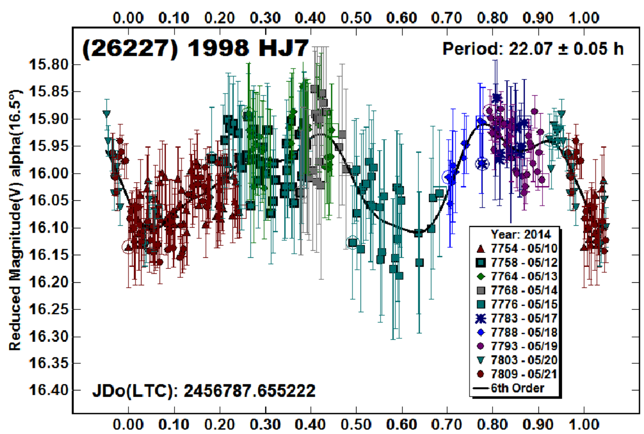




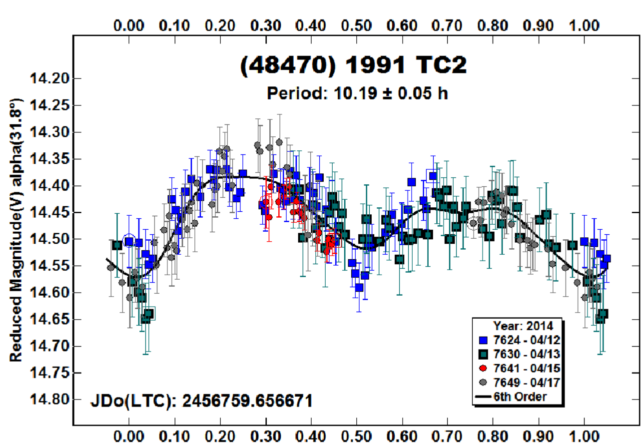
(26227) 1998 HJ7 (Hungaria). The period spectrum using the PDS 2014 data favors a period of 22 h. There is sufficient asymmetry in the two halves to support this, but the noisy data may be a contributing factor. The shorter period cannot be formally excluded. There were no other results found in the literature.





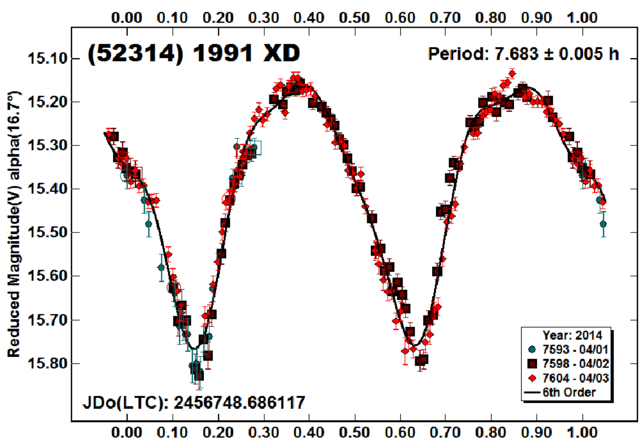


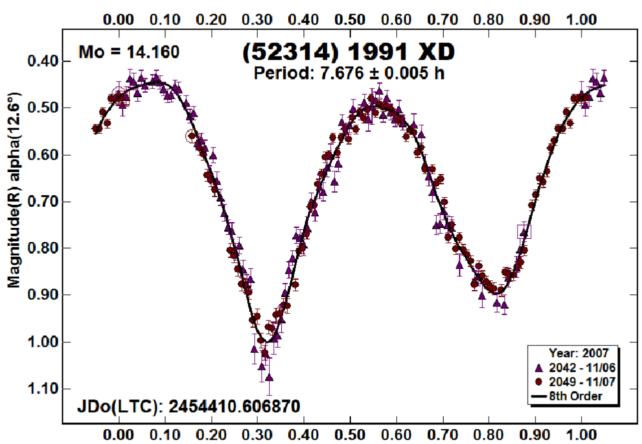
(48470) 1991 TC2 (Hungaria).



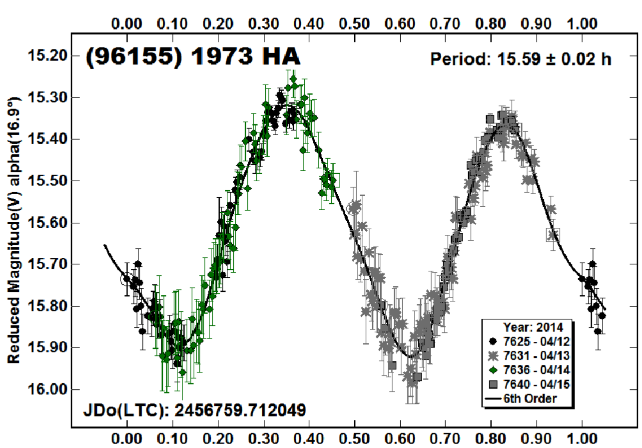
The author first worked 1991 TC2 in 2011 (Warner, 2011). The period was found to be 10.48 h. The data from the 2014 observations produced a period of 10.19 h. Neither data set could be manipulated so that it would fit the period of the other. The amplitude in both cases was 0.19 mag.

<u>(52314) 1991 XD (Hungaria)</u>. The 2014 apparition was the second time the author had observed 1991 XD. The first time (Warner, 2008) a period of 7.663 h was found. Analysis of the 2014 data set found *P* = 7.683 h. A second look at the 2007 results found the data (consisting of two consecutive nights in November) better fit a period of 7.676 ± 0.005 h. This is more in line with the 2014 result.





<u>(96155) 1973 HA (Mars-crosser)</u>. This appears to be the first reported lightcurve for 1973 HA.



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ASTEROID LIGHTCURVES FROM ALTIMIRA OBSERVATORY

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The following asteroid lightcurve synodic periods are reported: 502 Sigune (*P* = 10.929 ± 0.02 h); 781 Kartvelia (*P* = 19.04 ± 0.02 h); 828 Lindemannia (*P* = 20.52 ± 0.02 h); and 3322 Lidiya (*P* = 710 ± 10 h).

CCD differential photometry was performed on four asteroids at Altimira Observatory in southern California using a 28-cm *f*/6.3 Schmidt-Cassegrain telescope (SCT) and ST-8XE non-anti blooming gate (NABG) imager. Comparison stars were selected using the “solar-color” criterion in *MPO Canopus*, and their V-band magnitudes were extracted from the APASS DR7 catalog. No color transforms were applied to any of these targets; this is reasonable given that the comp stars were selected to have colors similar to a typical asteroid. All of the observations used for this report have been uploaded to the Minor Planet Center’s ALCDEF web site (*http://www.minorplanetcenter.net/light_curve*).

502 Sigune. This object has a well-determined lightcurve period (*P* = 10.922 h) in the Lightcurve Database (LCDB; Warner *et al.*, 2009), and according to Warner *et al*. (2014) it is a candidate for shape/spin modeling if a few more lightcurves can be gathered. Three nights of differential photometry using a clear filter during the 2014 April apparition yielded the phased lightcurve shown in Figure 1. This figure is wrapped to the best-fit period, *P* = 10.929 ± 0.02 h, which is consistent with previous reports.

781 Kartvelia. A lightcurve period of *P* = 19.06 h has been reported by Behrend (2003) for this asteroid and Melton *et al*. (2012) reported *P* = 19.02 ± 0.02 h. This asteroid was observed on 7 nights during the 2014 April apparition using unfiltered differential photometry. The resulting lightcurve, phased to the best-fit period *P* = 19.04 h, is shown in Figure 2. Considering the formal accuracy of the period solutions (± 0.02 h), this is consistent with the previously-reported periods.

828 Lindemannia. No lightcurve period has been previously reported for this asteroid. Ditteon *et al.* (2012) observed a 0.08-mag variation but did not determine a period. Masiero *et al*. (2012) reported the diameter and albedo from WISE observations, but no lightcurve parameters. This asteroid was observed through 10 nights during its 2013 Oct–Nov apparition. The phased lightcurve is shown in Figure 3, wrapped to the best-fit period of *P* = 20.52 ± 0.02 h. The amplitude appears to be ≈ 0.15 mag (peak-to-peak) although this may be an underestimate since the maximum near phase ≈ 0.8 was not observed.

3322 Lidiya. There is no report in the lightcurve data base (Warner *et al.*, 2009), and no observations in ALCDEF for this asteroid. It was selected for study because it had a favorable apparition in late 2012, i.e., relatively bright and at a convenient northern declination. Observations were made in a mixture of V- and R-band as well as clear filter on nineteen nights. Each individual lightcurve was basically a flat line (within measurement noise), which suggested a long rotation period. The asteroid’s V-magnitude was estimated from the R-band and unfiltered