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LIGHTCURVE ANALYSIS OF NEA (361071) 2006 AO4

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ROTAT and SATINO Observatories (C95)

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CCD photometric observations of Amor-type asteroid (361071) 2006 AO4 were made on 2013 September 23. From the lightcurve we obtained a synodic period of 4.09 ± 0.17 h with an amplitude of 0.13 mag.

Remote Observatory Theoretical Astrophysics Tübingen (ROTAT) is a 60-cm remotely operated telescope located on the Observatoire de Haute-Provence (OHP) site at Haute-Provence, France, about 100 km north-east of Marseille. ROTAT was formerly located and operated in Tübing by the Dept. for Theoretical Astrophysics, University of Tübingen.

Image acquisition was made with an SBIG STL-1100M CCD camera attached to the $f/3.2$ Newtonian focus of the ROTAT telescope, resulting in a pixel scale of 1.94 arcsec/pixel with 2x2 binning. No filters were used. All images were measured using *Astrometrica*, i.e. PSF-based all-sky photometry. Dark and flat images were applied.

Magnitudes were reduced to unity distance and times were corrected for light-time. The observations show a fair amount of scatter. Hence the period search was done with two different methods. First, a period scan using the Phase Dispersion Minimization algorithm (PDM; Stellingwerf, 1978) was done. Second, the period was determined by performing fourth-order Fourier fits to a range of possible periods. Both approaches showed a most likely period around 4 h.

The final period $P = 4.09 \pm 0.17$ h with an amplitude $A = 0.13$ mag was obtained from a fourth-order Fourier fit, similar to the FALC method developed by Harris (Harris *et al.*, 1989). The computations were done with a Python/SciPy script developed by the authors. The PDM algorithm is provided by the Python PyAstronomy package (<https://github.com/sczesla/PyAstronomy>). Our results are consistent with those of Warner (2014) who

reported another lightcurve, observed in 2013 August, from which he obtained a period $P = 4.093 \pm 0.001$ h.

Acknowledgements

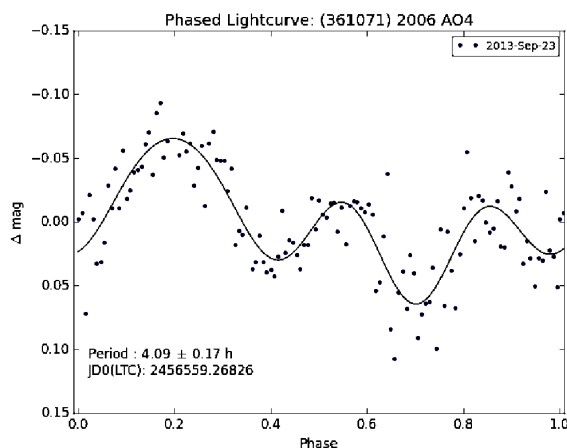
We would like to thank Dr. Dieter Husar (Hamburg) and Prof. Dr. Hanns Ruder (Tübingen), chairmen of "Stiftung Interaktive Astronomie und Astrophysik", for granting us access to the ROTAT facilities and their friendly support.

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Warner, B.D. (2014). "Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2013 June-September." *Minor Planet Bul.* **41**, 41.



NEAR-EARTH ASTEROID LIGHTCURVE ANALYSIS AT CS3-PALMER DIVIDE STATION: 2015 JANUARY – MARCH

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(Received: 27 March)

Lightcurves for 35 near-Earth asteroids (NEAs) were obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2014 December through 2015 March. One object, (159454) 2000 DJ8, may be a highly bifurcated body, or a close binary.

CCD photometric observations of 35 near-Earth asteroids (NEAs) were made at the Center for Solar System Studies-Palmer Divide

Station (CS3-PDS) from 2015 January – March. Table I lists 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
Squirt	0.30-m f/6.3 Schmidt-Cass	ML-1001E
Borealis	0.35-m f/9.1 Schmidt-Cass	FLI-1001E
Eclipticalis	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Australis	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Zephyr	0.50-m f/8.1 R-C	FLI-1001E

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

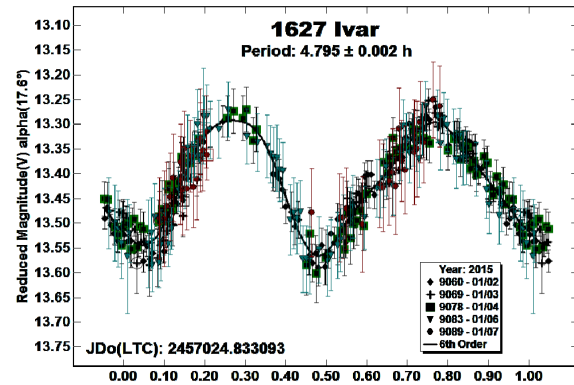
All lightcurve observations were unfiltered since a clear filter can result in a 0.1–0.3 magnitude loss. The exposure duration varied depending on the asteroid’s brightness and sky motion. Guiding on a field star sometimes resulted in a trailed image for the asteroid.

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).

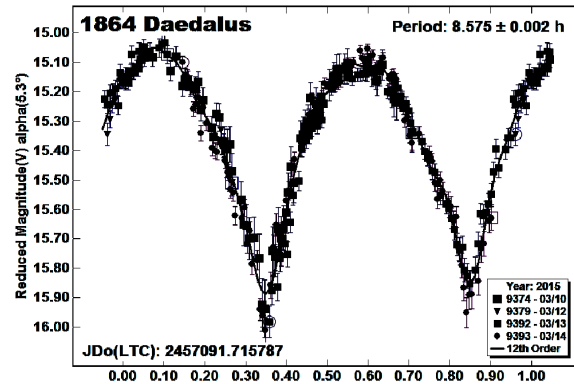
In the plots below, the “Reduced Magnitude” is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying $-5 \log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid distances in AU. The magnitudes were normalized to the given phase angle, e.g., $\alpha(6.5^\circ)$, using $G = 0.15$, unless otherwise stated. The X-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.

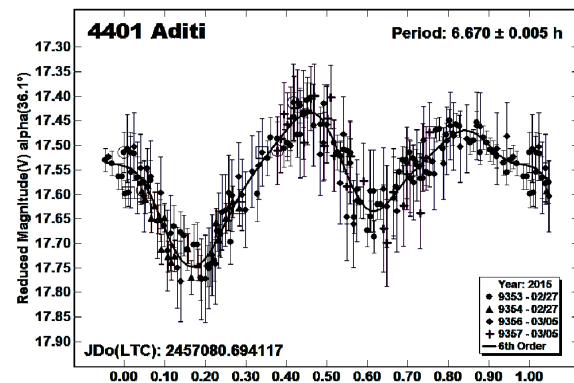
1627 Ivar. There are numerous entries in the LCDB for this near-Earth asteroid, all close to 4.8 hours, including Warner (2014a) who found $P = 4.8003$ h, $A = 0.28$ mag in early 2015 June and then $P = 4.7961$ h, $A = 0.73$ mag in mid-August. A shape model (Kassalain *et al.*, 2004) already exists. The main benefit of additional lightcurves now is to improve on the model and see if the YORP (Yakovsky-O’Keefe-Radzievskii-Paddack) effect is slowly changing the sidereal period of the asteroid, as seen in other asteroids, e.g., 1862 Apollo (Kassalain *et al.*, 2007).



1864 Daedalus. The period for this NEA was first determined more than 50 years ago (Gehrels *et al.*, 1971; 8.57 h). Subsequent results include Pravec *et al.* (1991, 8.572 h). Thomas *et al.* (2014) determined that Daedalus is taxonomic type Sq on the SMASS system (Small Main-Belt Asteroid Spectroscopic Survey; see Bus *et al.*, 2002a/b). The period of 8.575 h derived from the 2015 CS3-PDS observations is in good agreement with the earlier results.



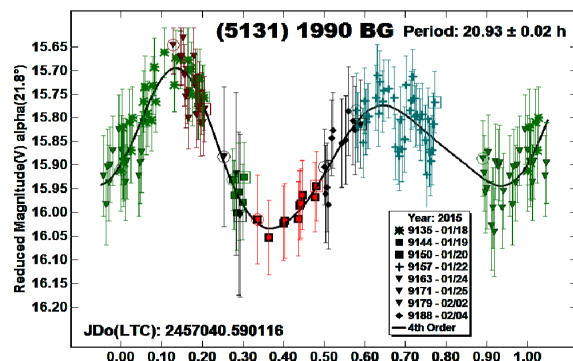
4401 Aditi. The observations in 2015 March at CS3-PDS were follow-up to those made in 2014 August–September.



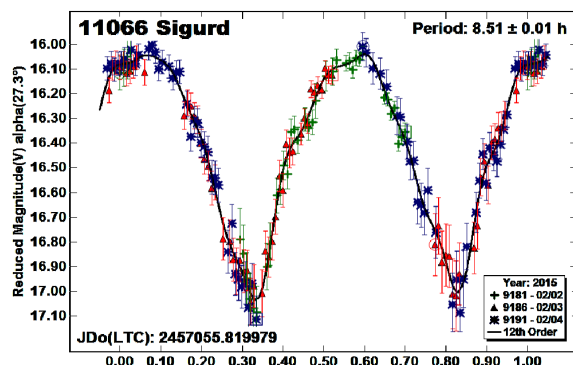
The amplitude at the earlier observations was $A = 0.64$ mag ($\alpha = 33^\circ$) and only $A = 0.29$ mag for the latter despite a similar phase angle of $\alpha = 35^\circ$. In this case, there was a significant difference in the viewing aspect as judged by the phase angle bisector longitude and latitude (L_{PAB} and B_{PAB} ; see Harris *et al.*,

1984). For comparison the PAB values were: 2014 (23° , -11°) and 2015 (156° , 36°). The significant difference in amplitude and lightcurve shapes between the two data sets will be helpful when trying to model the asteroid when even more data are available.

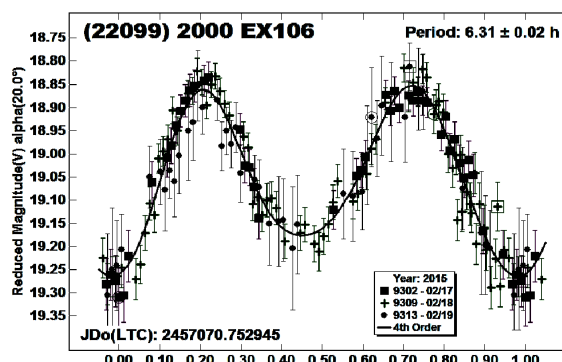
(5131) 1990 BG. No previous results were found in the LCDB for 1990 BG. The period given is the best bimodal solution in a search from 10 to 60 hours in that the slopes of the individual nights follow the Fourier model curve. A solution at about 18.5 hours produced an unlikely monomodal solution and its double period of about 37 hours an even more unlikely solution based on a highly asymmetric lightcurve with large gaps.



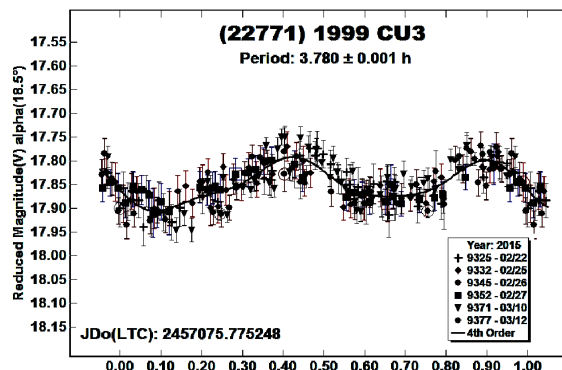
11066 Sigurd. Pravec *et al.* (1998) reported a period of 8.4958 h and Krugly *et al.* (2002) found a period of 8.496 h. The result here is in good agreement with those results. In addition, the 2015 lightcurve shows the lowest amplitude of the three, the greater difference being 0.18 mag when comparing 2015 to 2002.



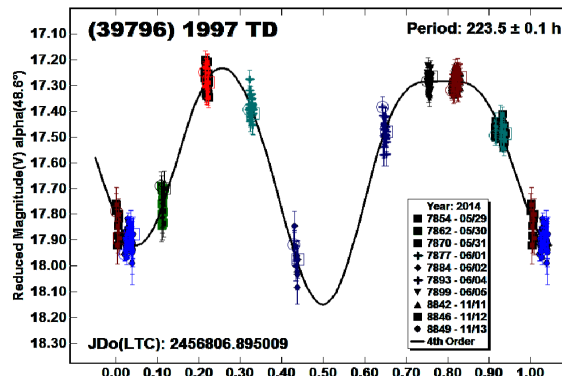
(22099) 2000 EX106. The period found from the 2015 CS3-PDS observations is in good agreement with the one of 6.334 h found by Pravec *et al.* (2002).



(22771) 1999 CU3. Based on observations in 2003 September-November, Pravec *et al.* (2003) found an average synodic period of 3.7822 h. The amplitude varied from 0.81-1.25 mag. The period of 3.780 h reported here is in good agreement. The lower amplitude of 0.12 mag suggests a nearly pole-on viewing aspect. If so, then the spin axis ecliptic longitude would be near the phase angle bisector longitude (L_{PAB}) of 175° (or 355°).

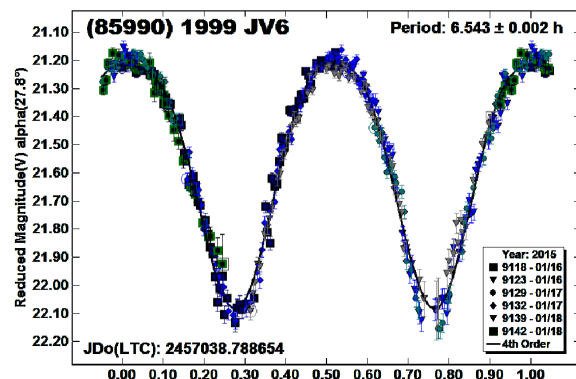


(39796) 1997 TD. Given that the slopes of individual sessions do not follow the slope of the Fourier model curve and the expected damping time for tumbling exceeds the age of the Solar System (see Pravec *et al.*, 2005; 2014), it's likely that this slow rotator is a tumbler, i.e., in non-principal axis rotation (NPAR).

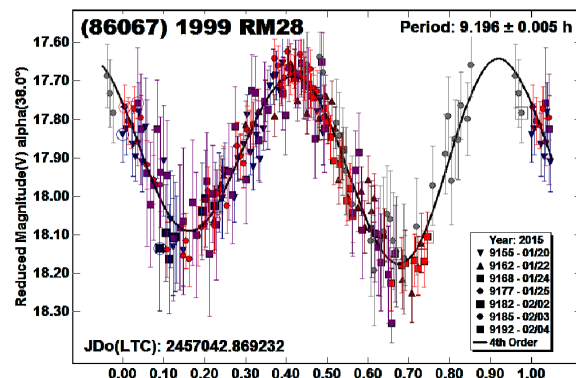
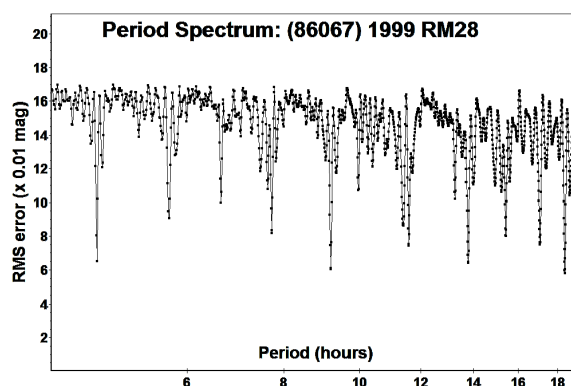


(85990) 1999 JV6. Warner (2014b) found $P = 6.538$ h, $A = 0.87$ mag ($\alpha = 12^\circ$) based on observations in 2014 January. The 2015 January observations, $A = 0.93$ mag ($\alpha = 26^\circ$), were at almost the

same phase angle bisector longitude and latitude. The difference in amplitude is probably due to the difference in phase angles.

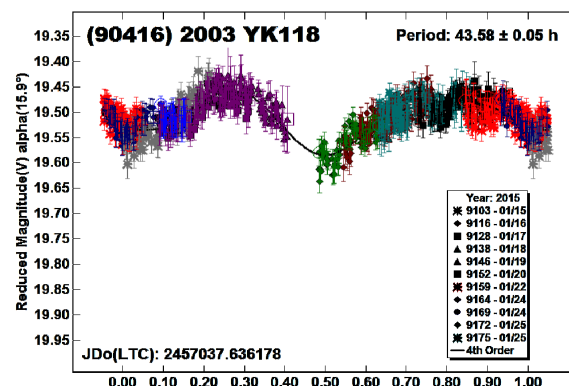
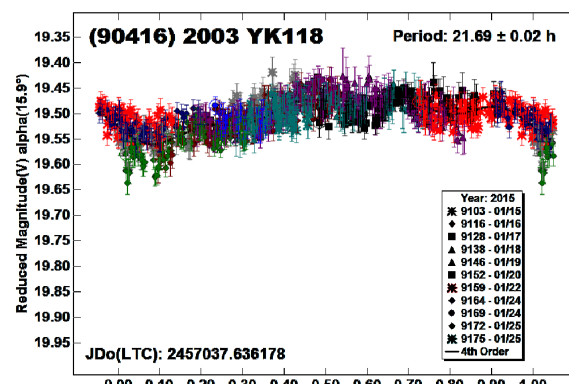


(86067) 1999 RM28. The LCDB did not have any lightcurve entries for 1999 RM28. However, it did note that Thomas *et al.* (2014) determined that this is a type Q object, which is an intermediate class between the S and V types. The period spectrum for 1999 RM28 is highly ambiguous. After reviewing half-period, double period, and double period *split halves* solutions, a period of 9.196 h is adopted for this paper. See Harris *et al.* (2014) for a discussion of a *split halves* plot and its value for eliminating ambiguous periods.

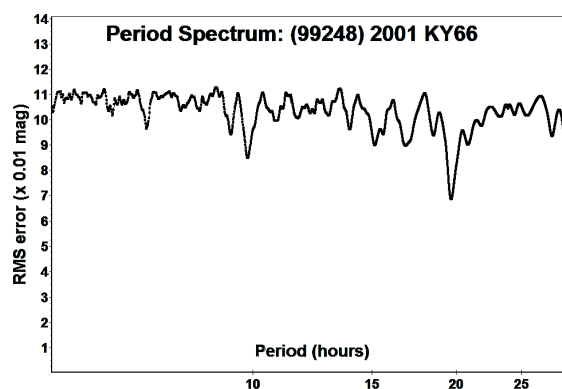


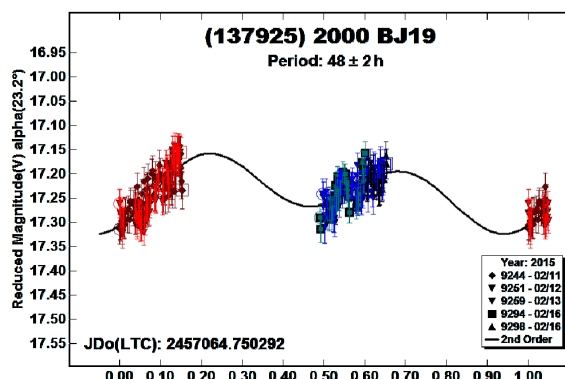
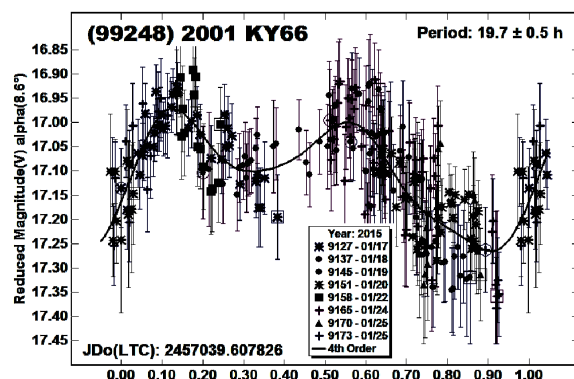
(90416) 2003 YK118. The period spectrum for 2003 YK118 shows two likely periods. Even though the amplitude is only 0.13 mag and, therefore, a bimodal solution cannot be assumed (Harris *et al.*, 2014), the longer period of 43.58 h with a bimodal lightcurve is

adopted for this paper. This is based mostly on the slightly better fit to the Fourier model curve. There were no previous entries in the LCDB for this NEA.

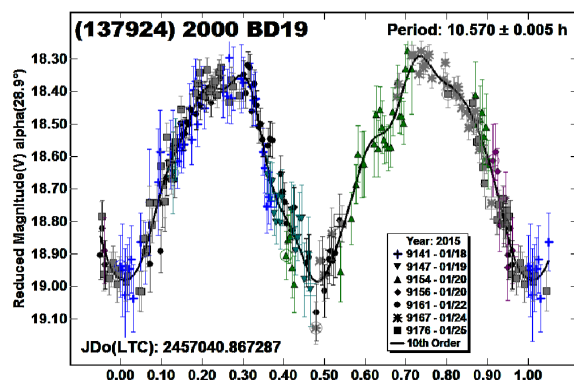


(99248) 2001 KY66. This asteroid faded from $V = 18.2$ to 18.6 over the course of the observations. The only telescope available was the smallest one at CS3, the 0.30-m SCT, which resulted in a noisier than preferred data set. The period spectrum shows a strong solution at 19.7 hours. However, the lightcurve for that period is far from convincing due to the irregular shape. The period reported here should not be considered definitive. In 2019, 2001 KY66 returns, reaching $V \sim 15.5$ at $+54^\circ$ declination. Perhaps a better solution will be found then.

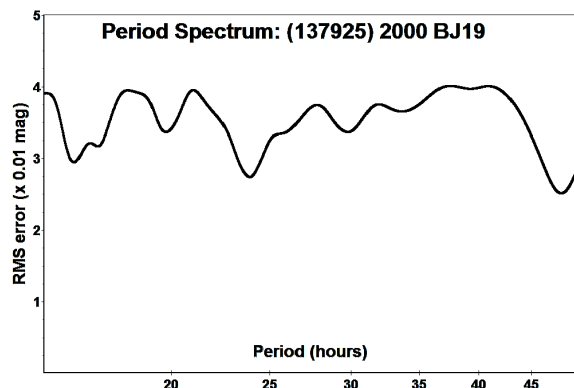




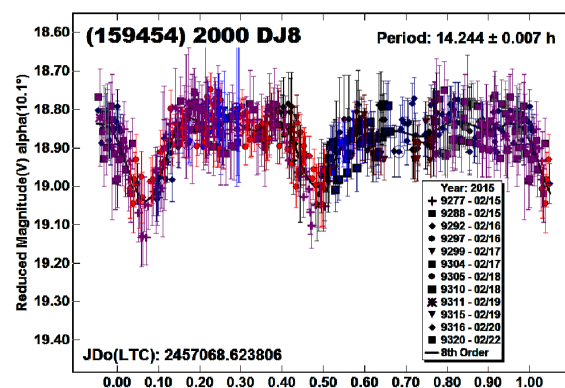
(137924) 2000 BD19. Thomas *et al.* (2014) report this to be a type V asteroid, making it similar spectroscopically to Vesta and raising the possibility that it might be a splinter created from the collisions that formed the impact features on Vesta. There were no other entries in the LCDB for 2000 BD19.



(137925) 2000 BJ19. The period spectrum for 2000 BJ 19 shows two solutions, both nearly commensurate with an Earth day. The longer period, 48 ± 2 h, is adopted for this paper, although the shorter period of about 24 hours cannot be excluded, nor can one of about 12 hours. The moon and weather intervened in early March. By then, the asteroid had moved too far north for the telescopes at CS3.

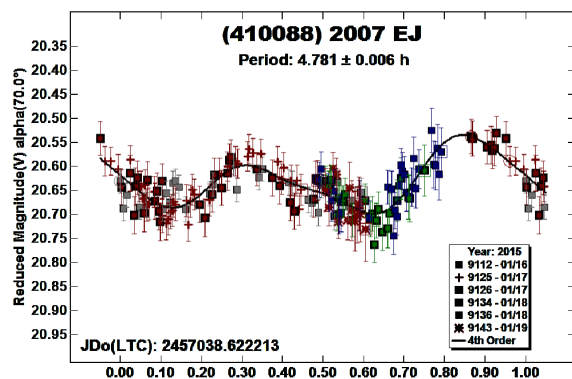


(159454) 2000 DJ8. The exact nature of 2000 DJ8 is a mystery. The lightcurve is similar to other objects, e.g., (69230) Hermes, which are thought to be two very close objects (sometimes misnamed *contact binaries*) that are fully synchronized, i.e., their rotation and orbital periods are the same. If true in this case, the smaller body is about half the effective size of the larger. The problem for 2008 DJ is that the two events are not evenly spaced and so imply an eccentric orbit. This is not likely given the orbital period (Alan Harris, private communications).

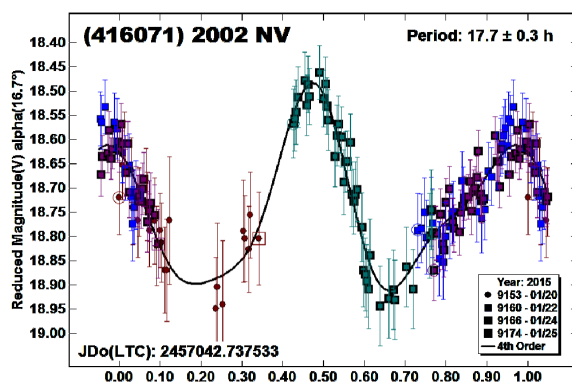


Harris suggested an alternative solution of the half-period, i.e., about 7 hours, and some large feature not viewed equatorially. This idea cannot be formally excluded. The next reasonable chance to observe this NEA is not until 2020 January-February ($V \sim 17.2$, Dec -4°).

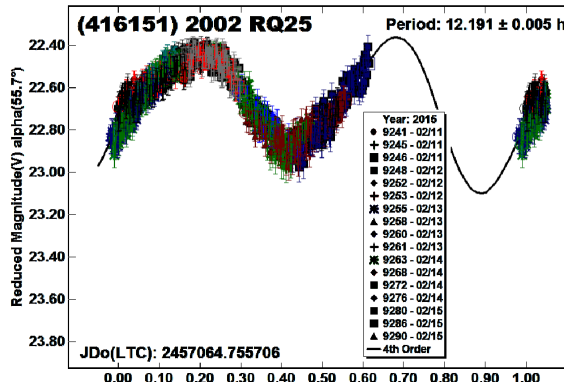
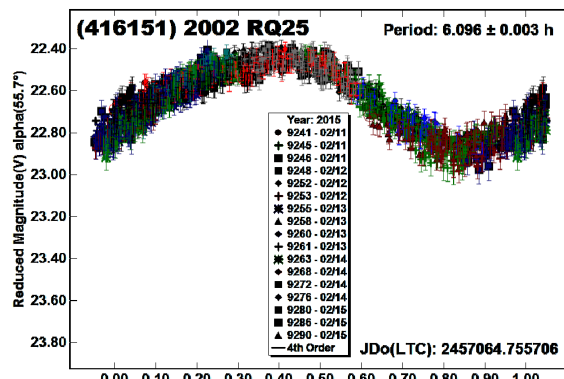
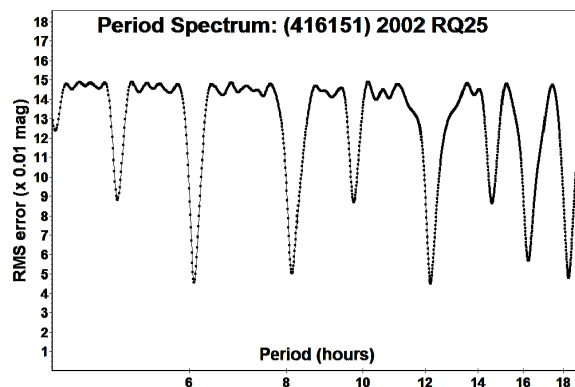
(410088) 2007 EJ. There were no previous entries in the LCDB for 2007 EJ. The next good opportunity for 2007 EJ is 2018 November ($V \sim 16.9$, Dec -49°).



(416071) 2002 NV. Given the unusual shape of the lightcurve, this solution should not be considered too reliable, although it is probably correct to within about 1-2 hours and so is good enough for use in rotational statistics studies.

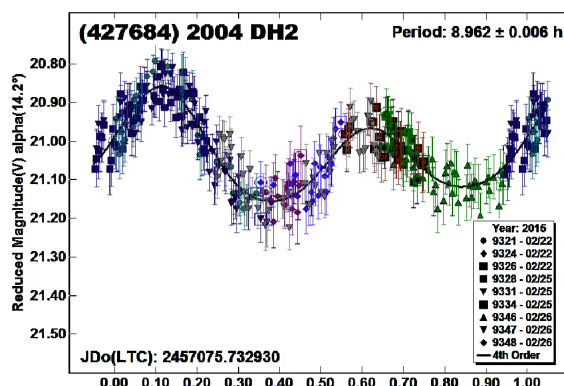


(416151) 2002 RQ25. The period spectrum for 2002 RQ25 shows a number of possibilities, the two most likely being a monomodal solution at about 6 hours and a bimodal solution at 12 hours.



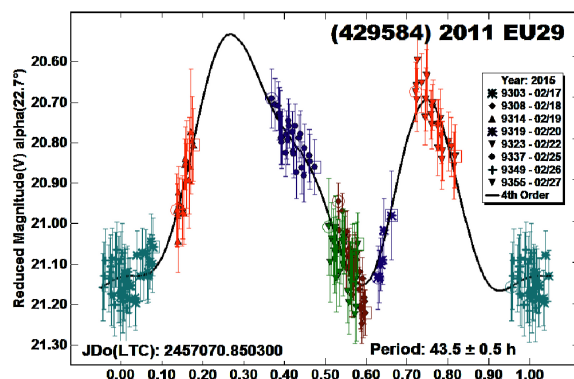
Usually, an amplitude of 0.42 mag dictates a bimodal lightcurve (Harris *et al.*, 2014). However this is mitigated by the large phase angle where, due to deep shadowing effects, even a nearly spheroidal body can have a large amplitude. The longer period is adopted for this paper, but the shorter period cannot be formally excluded.

(427684) 2004 DH2. There were no previous entries in the LCDB for 2004 DH2. The rounded minimums are somewhat unusual. Most elongated bodies show sharper minimums than maximums.

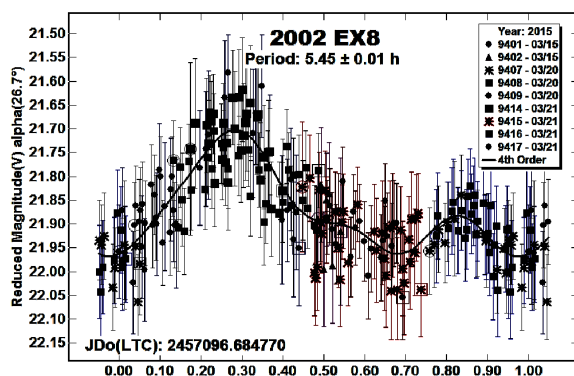


(429584) 2011 EU29. The large amplitude and relatively low phase angle favor a bimodal solution (Harris *et al.*, 2014). However, the large gaps in the coverage make for an uncertain period. The tumbling damping time (Pravec *et al.*, 2005; 2014) is longer than the age of the Solar System, so signs of tumbling, e.g., the slopes of individual sessions not matching the model

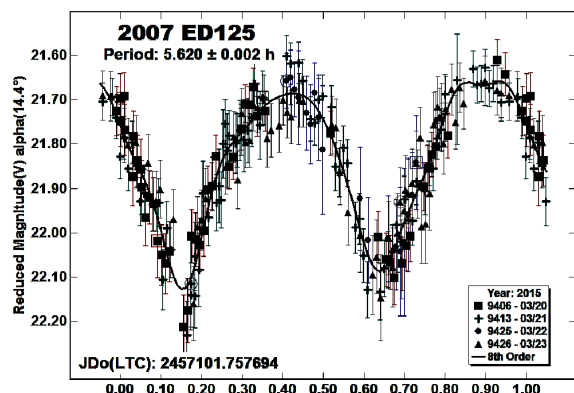
lightcurve, would not be unexpected. No such signs are obvious in this data set.



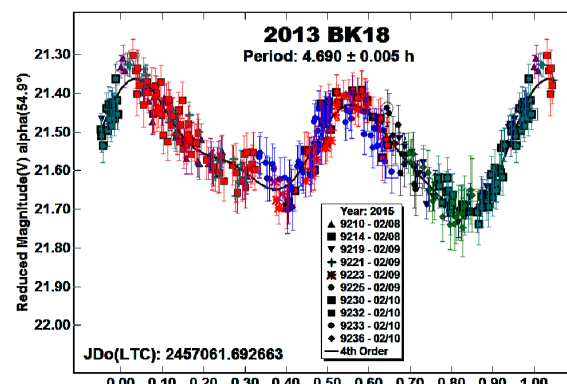
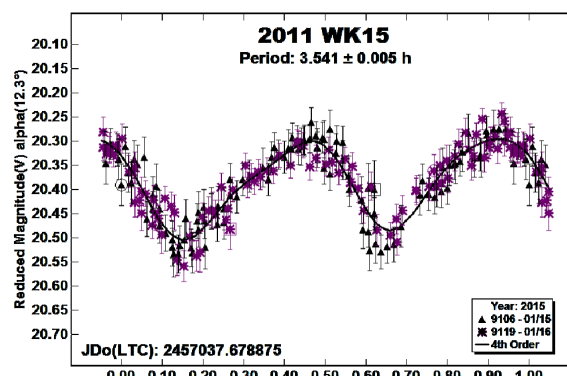
2002 EX8. The period spectrum may have a strong preference for the period of 5.45 h, but the amplitude of the lightcurve barely exceeds the error bars, meaning that the variation is likely real but the period solution is suspect. In this lightcurve, the two maximums, at 0.3 and 0.8 rotation phase, are significantly different, which might prompt a search for a period twice long, i.e., that this is a monomodal solution. A search along those lines produced very unsatisfactory results with the slopes of the data unable to follow the resulting Fourier model curve.



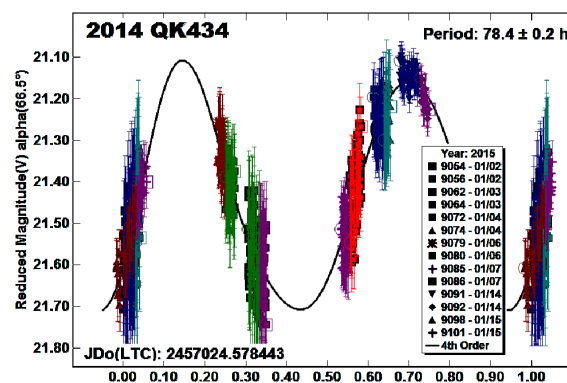
2007 ED125. This appears to be the first period reported in the literature for this NEA. The large amplitude and relatively short period make the solution secure.



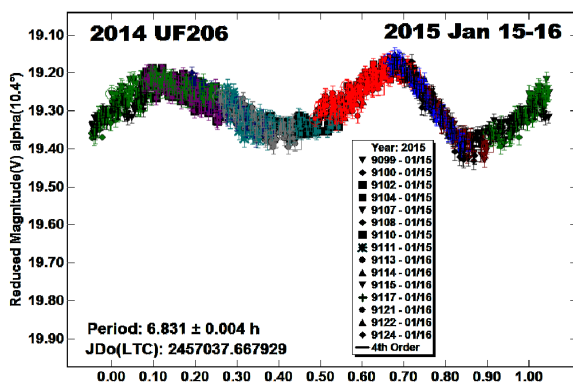
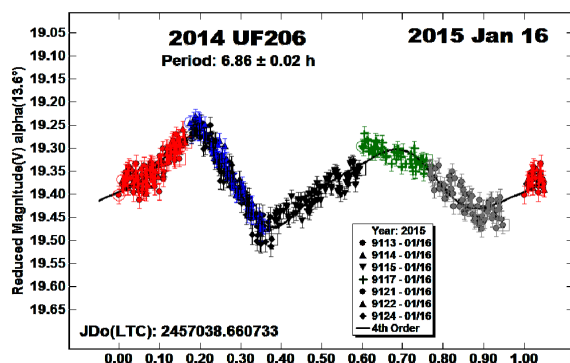
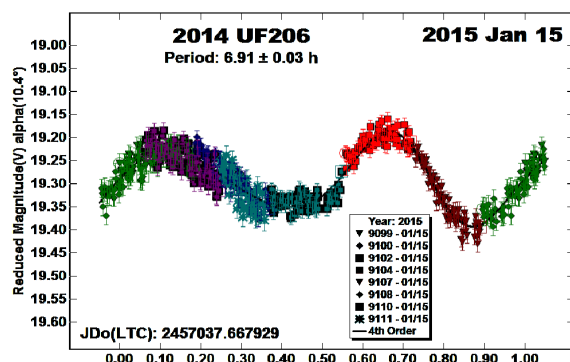
2011 WK15, 2013 BK18. There were no previous entries in the LCDB for 2011 WK15 or 2013 BK18. Both periods are considered secure.



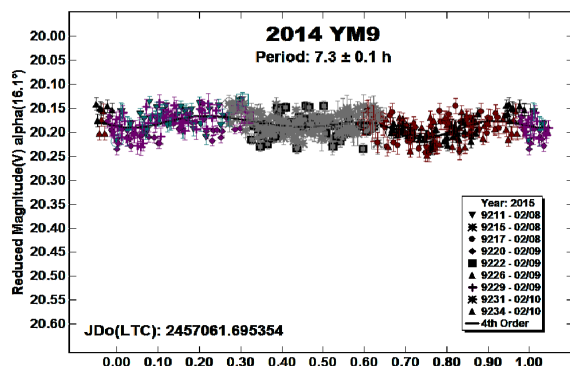
2014 QK434. This NEA is similar to 2011 EU29 in that the period and size make it a good candidate for being in non-principal axis rotation (NPAR, *tumbling*) but there are no overt signs of that being the case. 2014 QK434 won't be brighter than V = 18 again until 2033 September. Follow-up is left to the next generation of observers.



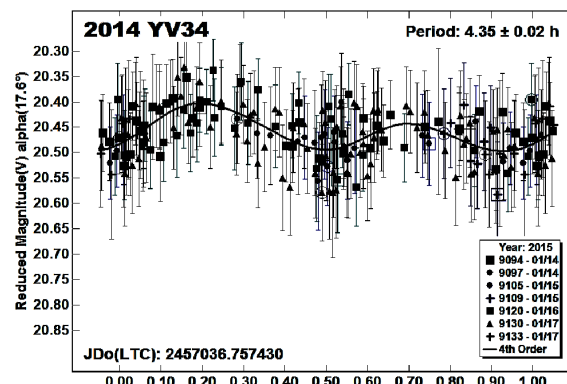
2014 UF206. From 1995 through 2050, the 2015 apparition is the only one at which the asteroid is brighter than V = 20, so it was a unique opportunity for photometry observations. The lightcurves are for 2015 Jan 15, Jan 16, and the combined data set. The result from the combined set is considered secure.



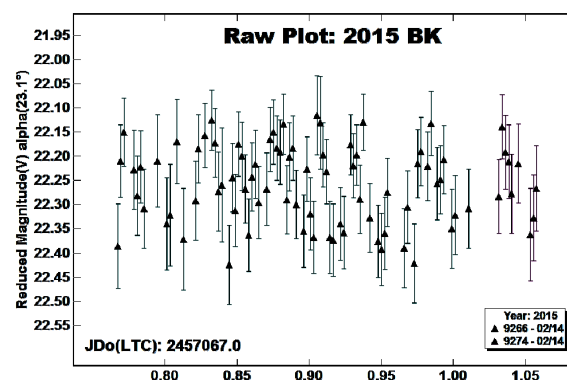
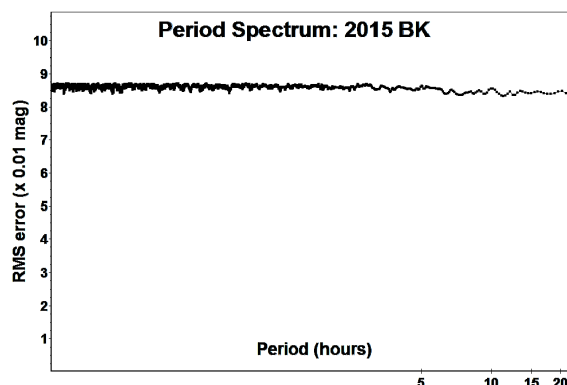
2014 YM9. Despite three nights of observations, the data set showed no discernable trend and only small variations over each night. The lightcurve shows the best fit, but unreliable, solution.



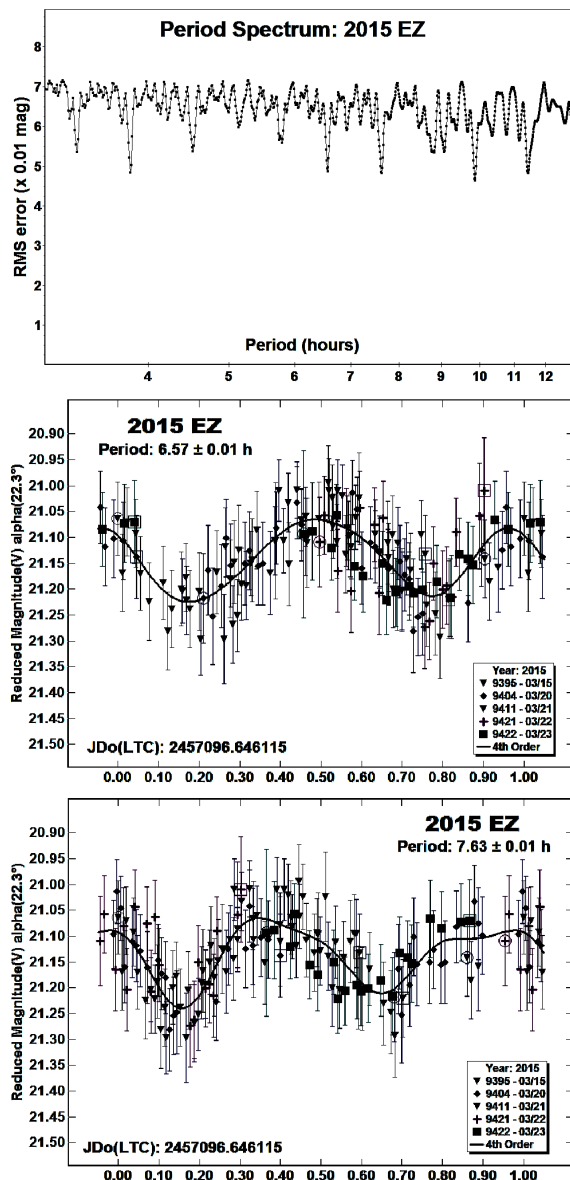
2014 YV34. Since the error bars are about equal to the lightcurve amplitude, the result of 4.35 h is not very reliable. There were no previous entries in the LCDB. The 2015 apparition is the only one from 1995-2050 when the asteroid reaches $V < 20$.



2015 BK. No solution could be found for 2015 BK, as shown by the flat line of the period spectrum. The lightcurve shows the raw data for one night. This appears to be the first reported attempt to determine the period for 2015 BK and probably the last for many years. The next time the asteroid is $V < 20$ is not until 2047.



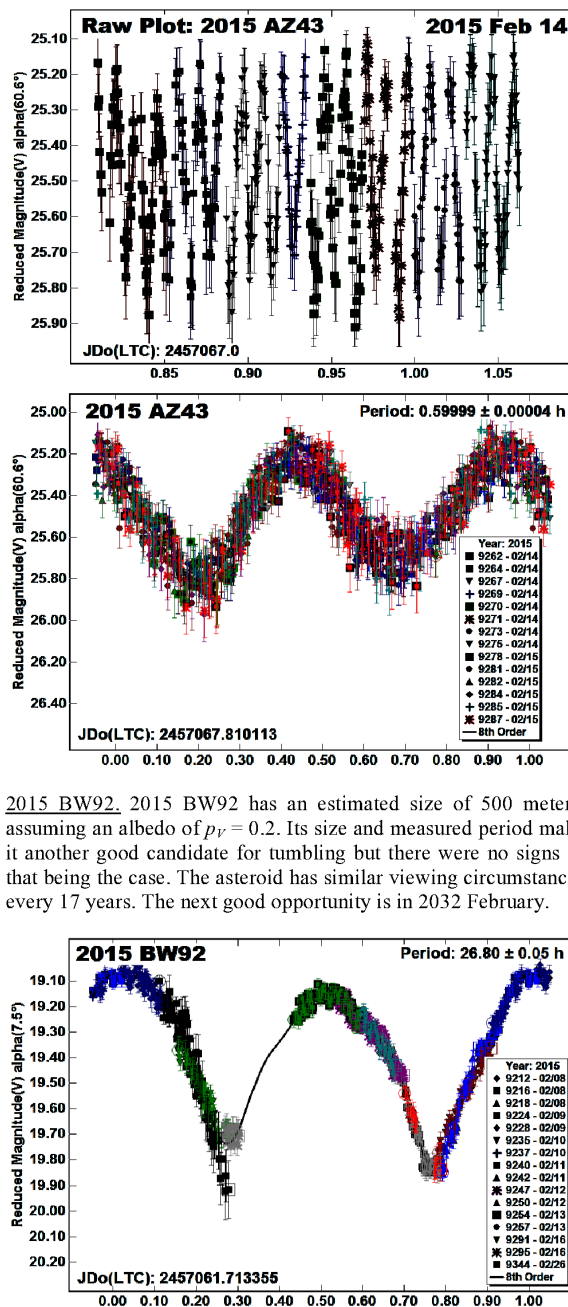
2015 EZ. The period spectrum shows several possible solutions for 2015 EZ. The lightcurves show the data phased to the two more likely periods. For this paper, the period of 6.57 h is adopted because of its more symmetrical shape. The next good opportunity ($V < 19$) to observe this NEA comes in 2023 April.



2015 AZ43. This was another “one-shot” chance to determine the rotation period of an NEA. 2015 AZ43 won’t be brighter than 23.9 again through 2050. It peaked at $V \sim 17.2$ in 2015 mid-February but was within reach of the CS3 telescopes for only two days because of its sky position and rapid fading.

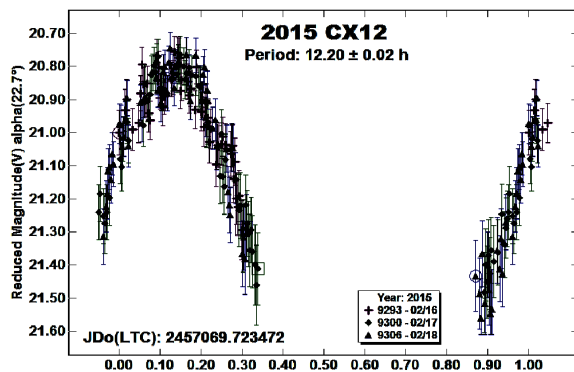
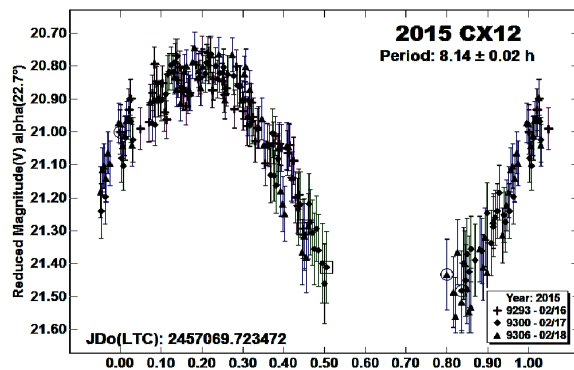
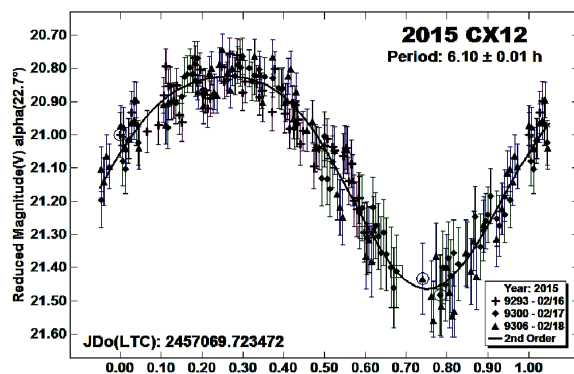
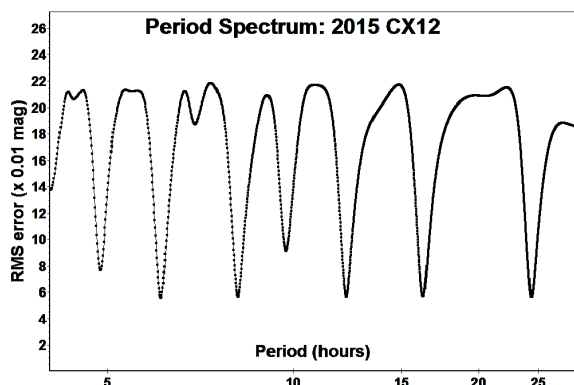
The raw plot for each night showed immediate indications that the asteroid was a super-fast rotator, i.e., $P < 1$ h. When working asteroids with estimated diameters of about $D < 200$ meters, the possibility of such short periods must be kept in mind. Most important, the exposures are not so long as to cover more than

about 20% of the rotation period. In this case, the exposures were only 20 seconds, well under the limit of 6.7 minutes for a period of 36 min (see the discussion in Pravec *et al.*, 2000).



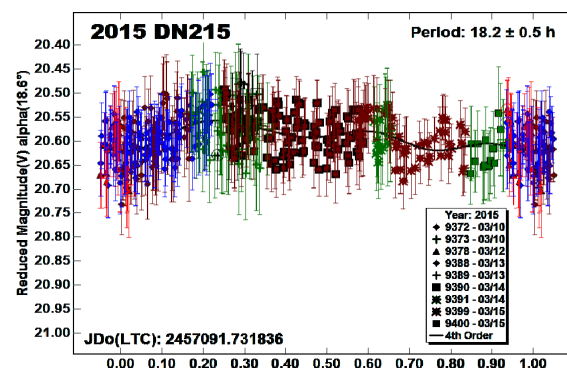
2015 BW92. 2015 BW92 has an estimated size of 500 meters, assuming an albedo of $p_V = 0.2$. Its size and measured period make it another good candidate for tumbling but there were no signs of that being the case. The asteroid has similar viewing circumstances every 17 years. The next good opportunity is in 2032 February.

2015 CX12. The period spectrum shows several strong solutions, each commensurate with an Earth day. That makes it difficult for a single station to find a reliable period. The monomodal solution at 6.1 h leads to the bimodal solution of 12.20 h, but with a large gap. The solution for 8.14 h would require a very large amplitude to complete the curve smoothly. The shorter solution at 6.1 h doesn’t make that likely. Given this and phase angle, a period of 12.20 h is adopted for this paper.

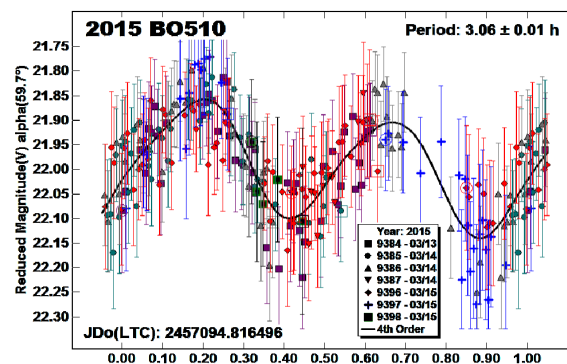
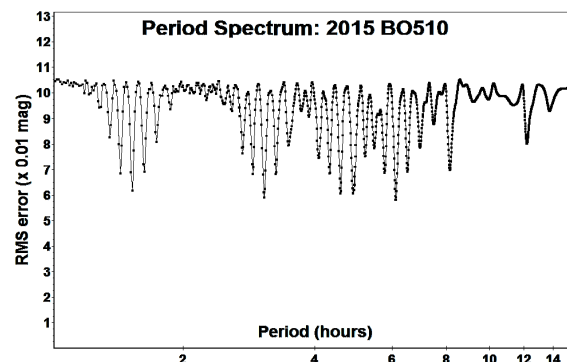


2015 DN215. A period of 18.2 h is adopted for this paper, but a solution 36.3 h cannot be formally excluded. In fact, a number of other solutions is possible and so neither of these results is more

likely than any other. The next, and last time through 2050, that this asteroid is $V < 20$ is in 2024 March.



2015 BO510. The period spectrum for 2015 BO510 shows several strong possible solutions. Within the groups are the favored solution and then “sideband” periods that differ by one-half or one rotation over 24 hours.



A monomodal solution was rejected because it would have a period of about 1.5 h. Given the estimated size of 340 meters, this would be highly unlikely. The bimodal solution at 3.06 h seemed most likely (and is adopted for this paper). A check was also made for the double period at 6.12 hours (a trimodal solution at about 4.5 hours being rejected). A quadramodal lightcurve is not impossible at high phase angles, even with an amplitude of nearly 0.3 mag.

Despite the quadramodal lightcurve not showing a high degree of symmetry, a clue that the half-period might be valid, it was rejected because of gaps in coverage. The Fourier analysis

Number	Name	2015 mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period	P.E.	Amp	A.E.	Grp
1627	Ivar	01/02-01/07	350	17.7,16.3	145	0	4.795	0.002	0.27	0.03	NEA
1864	Daedalus	03/10-03/14	280	5.3,5.0,5.1	172	8	8.575	0.002	0.95	0.03	NEA
4401	Aditi	02/27-03/05	203	36.1,33.0	156	36	6.670	0.005	0.29	0.03	NEA
5131	1990 BG	01/18-02/04	153	21.8,25.5	75	-20	37.2	0.5	0.33	0.05	NEA
11066	Sigurd	02/02-02/04	174	27.4,26.2	169	15	8.51	0.01	0.97	0.03	NEA
22099	2000 EX106	02/17-02/19	165	20.0,18.4	166	7	6.31	0.02	0.41	0.03	NEA
22771	1999 CU3	02/22-03/12	229	18.5,7.6	174	-4	3.780	0.001	0.12	0.02	NEA
39796	1997 TD	05/29-11/13	284	48.6,17.8	280	11	223	5	0.92	0.05	NEA
85990	1999 JV6	01/16-01/18	360	27.7,21.5	131	-3	6.543	0.002	0.93	0.03	NEA
86067	1999 RM28	01/20-02/04	218	38.0,32.2	171	16	9.196	0.005	0.51	0.03	NEA
90416	2003 YK118	01/15-01/25	651	15.9,23.7	112	12	43.58 ^A	0.05	0.13	0.01	NEA
99248	2001 KY66	01/17-01/25	260	8.6,13.4	104	-1	19.7	0.5	0.3	0.04	NEA
137924	2000 BD19	01/18-01/25	251	28.9,25.4	141	20	10.570	0.005	0.69	0.04	NEA
137925	2000 BJ19	02/11-02/16	271	23.2,23.0	161	22	48 ^A	2	0.17	0.02	NEA
159454	2000 DJ8	02/15-02/22	515	10.2,19.1	138	7	14.244	0.007	0.25	0.03	NEA
410088	2007 EJ	01/16-01/19	170	69.8,64.6	81	25	4.781	0.006	0.16	0.02	NEA
416071	2002 NV	01/20-01/25	161	16.7,16.4	134	-11	17.7	0.3	0.41	0.05	NEA
416151	2002 RQ25	02/11-02/15	1067	55.8,71.4	153	34	12.191 ^A	0.005	0.72	0.05	NEA
427684	2004 DH2	02/19-02/26	206	23.0,3.9	162	-3	8.962	0.006	0.3	0.03	NEA
429584	2011 EU29	02/17-02/27	178	22.9,7.2	164	-3	43.5	0.5	0.65	0.1	NEA
	2002 EX8	03/15-03/21	228	26.8,35.4	160	-8	5.45	0.03	0.27	0.05	NEA
	2007 ED125	03/20-03/23	216	14.4,10.1	188	3	5.620	0.002	0.55	0.05	NEA
	2011 WK15	01/15-01/16	204	12.3,12.5	122	5	3.541	0.005	0.21	0.02	NEA
	2013 BK18	02/08-02/10	330	55.3,63.2	107	-8	4.690	0.005	0.34	0.03	NEA
	2014 YM9	02/08-02/10	494	16.3,20.9	130	5	7.3	0.1	0.04	0.01	NEA
	2014 YV34	01/14-01/17	196	17.6,15.4	128	2	4.35	0.02	0.09	0.02	NEA
	2014 UF206	01/15-01/16	1000	10.7,13.9	119	7	6.831	0.004	0.20	0.02	NEA
	2014 QK434	01/02-01/15	640	66.3,46.8	73	-13	78.4	0.2	0.60	0.05	NEA
	2015 BK	02/14-02/15	334	23.1,23.4	158	9	-	-	-	-	NEA
	2015 EZ	03/15-03/23	151	22.4,29.8	163	-9	6.57	0.02	0.16	0.03	NEA
	2015 CX12	02/16-02/18	192	22.7,20.8	145	-15	12.2	0.02	0.67	0.03	NEA
	2015 AZ43	02/14-02/15	767	60.5,65.1	163	28	0.59992	0.00004	0.58	0.05	NEA
	2015 BW92	02/08-02/26	716	7.5,7.2,21.2	137	-1	26.80	0.05	0.75	0.03	NEA
	2015 DN215	03/10-03/15	431	18.5,8.6	179	5	18.2	0.5	0.06	0.01	NEA
	2015 BO510	03/13-03/15	241	59.7,65.2	199	29	3.06	0.03	0.28	0.03	NEA

Table II. Observing circumstances. ^A preferred period for an ambiguous solution. Pts is the number of data points used in the analysis. 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, respectively the average phase angle bisector longitude and latitude, unless two values are given (first/last date in range). Grp is the orbital group of the asteroid. See Warner *et al.* (LCDB; 2009).

algorithm in *MPO Canopus* can find a “best” solution, one with the lowest RMS fit, by also minimizing the number of overlapping data points in the phased lightcurve. This is called a *fit by exclusion*, and can lead to accepting an incorrect solution that is longer than the correct period.

The next good photometry opportunity for this NEA is in 2031 March and again 16 years later in 2047 March.

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THREE UNUSUAL HUNGARIA ASTEROIDS

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Three Hungaria asteroids observed at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) in 2015 January-March showed unusual characteristics. 2449 Kenos, a probable member of the Hungaria *collisional family*, is likely to be a binary object with period $P_1 = 3.8481$ h and $P_2 = 15.85$ h. The 2015 observations of 6901 Roybishop, a member of the Hungaria *orbital group*, showed signs of a weak secondary period, $P_2 = 10.58$ h. The secondary period is in contradiction with previous results. (23615) 1996 FK12 may be another example of so-called *wide binaries*, showing a strong short period, $P_2 = 3.6456$ h, presumably due to a widely-separated satellite that is not tidally locked to a very long orbital period. The primary in such a system has a very long period, $P_1 = 368$ h in this instance. The main question for 1996 FK12 is the validity of the long period.

CCD photometric observations of three Hungaria asteroids were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2015 January-March: 2449 Kenos, 6901 Roybishop, and (23615) 1996 FK12. Analysis of the data indicated that each might be a binary object.

Table I lists 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
Squirt	0.30-m f/6.3 Schmidt-Cass	ML-1001E
Borealis	0.35-m f/9.1 Schmidt-Cass	FLI-1001E
Eclipticalis	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Australius	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Zephyr	0.50-m f/8.1 R-C	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 (2007b). 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