

ASTEROID LIGHTCURVE ANALYSIS AT CS3-PALMER DIVIDE STATION: 2018 APRIL-JUNE

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Lightcurves for 24 main-belt asteroids were obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2018 April-June.

CCD photometric observations of 24 main-belt asteroids were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2018 April-June. The main focus at CS3-PDS is on near-Earth asteroids. However, a nearly full moon and most NEAs being in rich star fields during the quarter meant finding other targets to keep the telescopes working. Hungaria members were observed to provide additional data for spin axis modeling. Most of the other objects were chosen because they had no previous period reported and were bright enough to work when the moon was full or they were in more sparse areas of the sky.

Table I lists the telescope/CCD camera combinations that were used. All the cameras use the KAF-1001E blue-enhanced CCD chip 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 cause a 0.1-0.3 mag 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 made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. Catalog magnitudes were taken from the APASS (Henden et al., 2009) or CMC-15 (Munos, 2017) catalogs.

The nightly zero points for the APASS and CMC-15 catalogs are generally consistent to about ± 0.05 mag or better, but occasionally reach >0.1 mag. There is a systematic offset between the two catalogs and so, whenever possible, the same catalog was used for all observations of a given asteroid. Period analysis was done with *MPO Canopus*, which implements the FALC algorithm by Harris (Harris et al., 1989).

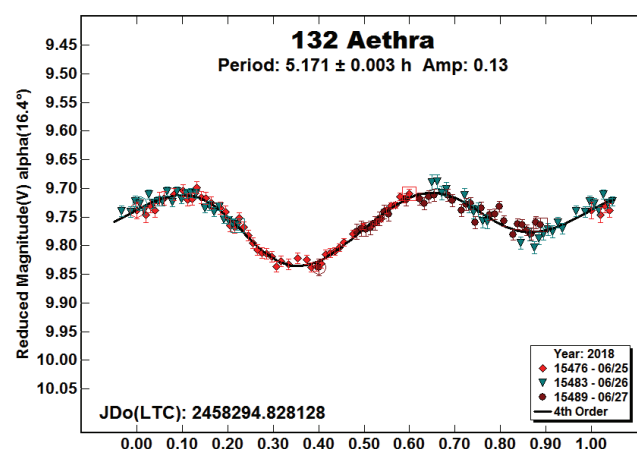
In the lightcurves below, the “Reduced Magnitude” is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying $-5 \cdot \log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid distances in AU. The magnitudes were normalized to the phase angle in the

parentheses using $G = 0.15$, unless otherwise stated. The X-axis is the rotational phase ranging from -0.05 to 1.05 .

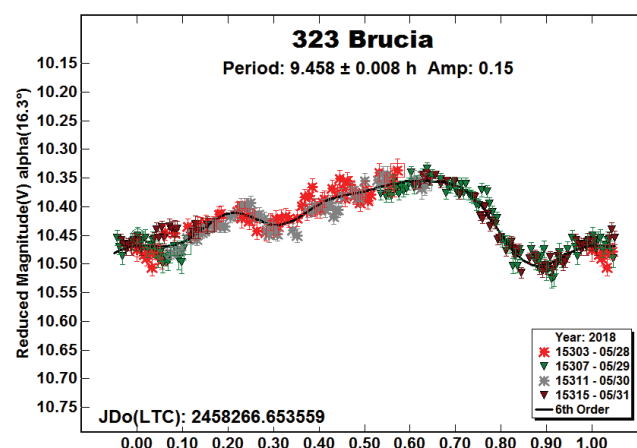
If the plot includes an amplitude, e.g., “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

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., 2009a). 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 Bibcode, is also available for download. Readers are strongly encouraged, when possible, to cross-check with the original references listed in the LCDB.

132 Aethra. Previous results include Galad (2010; 5.181 h) and Pilcher (2017; 5.1802 h). The results here are close to but not statistically the same. This could be the result of not having data for more than three consecutive nights.

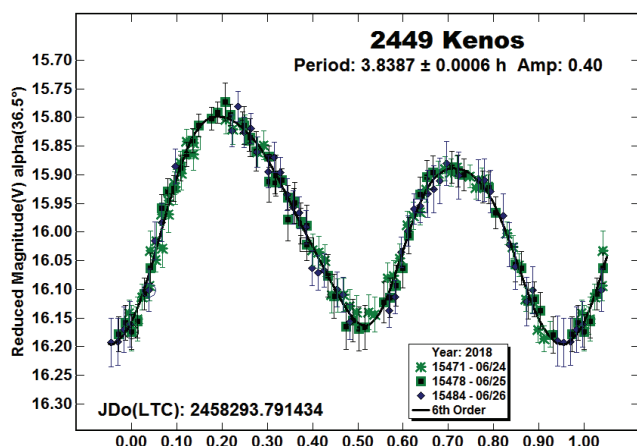


323 Brucia. The period of 9.458 h is in good agreement with Warner (2014; 9.463 h) and Behrend (2006).

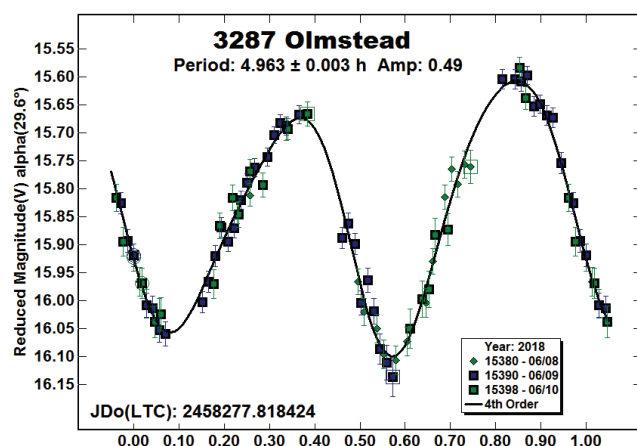


2449 Kenos. This was the fourth apparition the asteroid was observed at Palmer Divide. The earlier results include 3.8492 h (Warner, 2007), 3.846 h (Warner, 2010), and 3.8481 h (Warner, 2015b). The 2015 data indicated two periods, the second being 15.85 h. This was attributed to a non-spheroidal satellite that was tidally locked to its orbital period. No mutual events (occultations

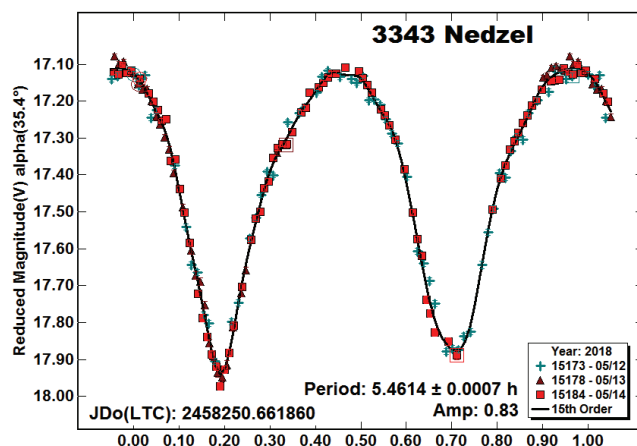
and/or eclipses) were seen at that time and so the asteroid was only a suspected binary. The 2018 data showed no indications of a secondary period. Coverage at future apparitions is suggested.



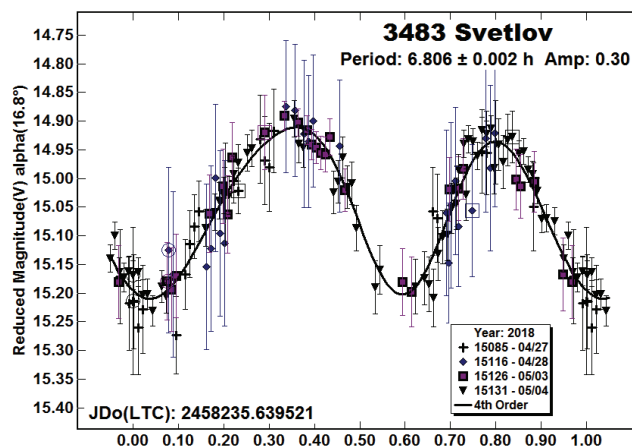
3287 Olmstead. The only previous result is from Wisniewski et al. (1997), who found a period of 4.80 h. That was based on a single night of data. The lightcurve appeared to show a full cycle but there was no overlapping data from a second cycle. Many times, even with some data from a second cycle, additional nights will change the result by a significant amount. Here, there were three consecutive nights, leading to a more secure solution.



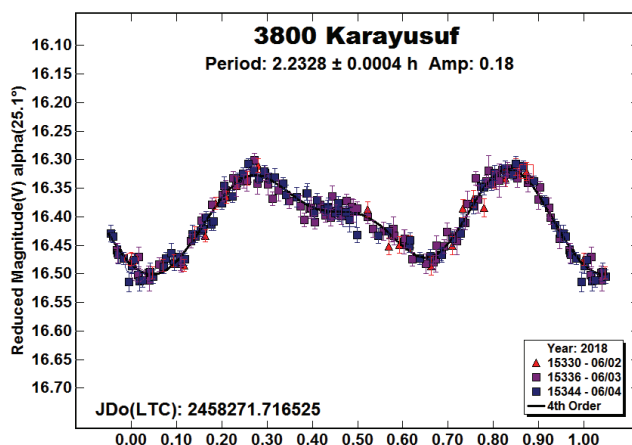
3343 Nedzel. Previous results are from Folberth (2012; 5.4620 h) and Stephens (2018; 5.467 h).



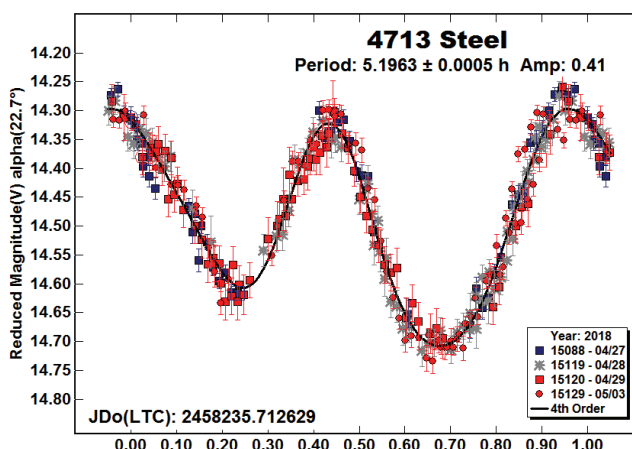
3483 Svetlov. This was the fifth time this Hungaria was observed by the author (Warner, 2010; 2012; 2015a; 2015d). The previous period results average to 6.80 ± 0.02 h.



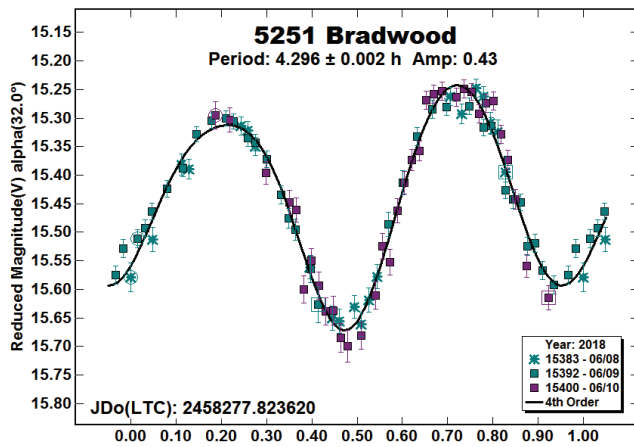
3800 Karayusuf. Three previous results are Warner (2008, 2.2319h – suspected binary; 2010, 2.232 h; 2014, 2.221 h). There were no indications of a satellite in the 2018 data.



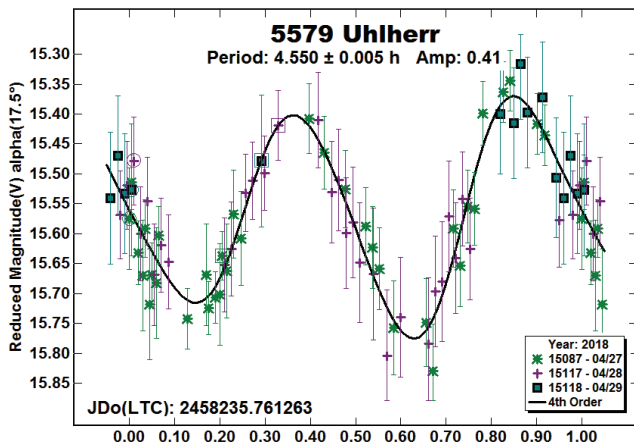
4713 Steel. Previous results from Palmer Divide observations of this Hungaria are from Warner (2010, 5.199 h; 2012c, 5.193 h; 2015a, 5.203 h).



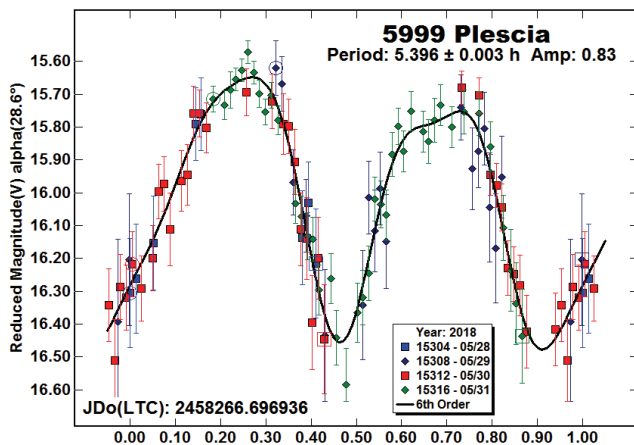
5251 Bradwood. Waszczak et al. (2015) found a period of 4.301 h using a sparse data set. Even so, their result is close to the one found here using a dense lightcurve.



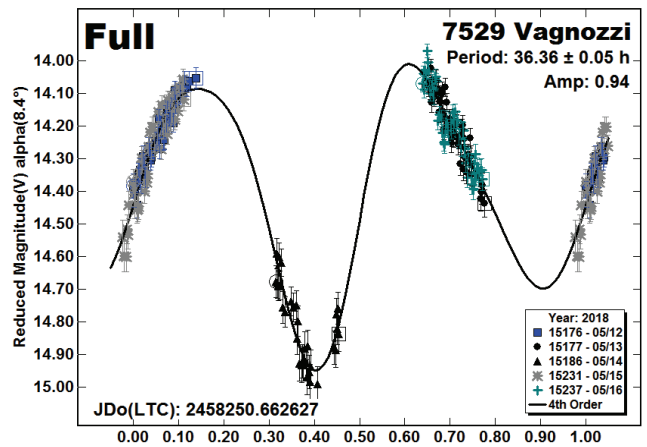
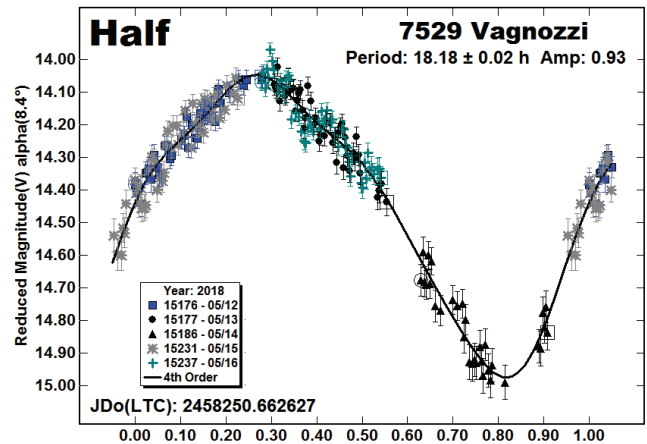
5579 Uhlherr. Being another Hungaria, Uhlherr has been observed by the author numerous times before: Warner (2009b, 4.754 h; 2012, 4.777 h; 2015c, 4.52 h), and by Stephens (2017, 4.48 h).



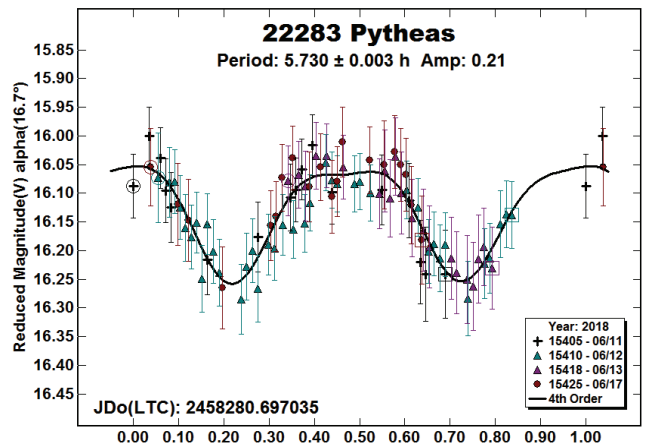
5999 Plescia. Pravec et al. (2011) found a period of 5.392 h. At about the same time, Skiff (2011) found the same result. The lightcurve from his 2010 December observations ($\alpha = 29.5^\circ$) had an amplitude of 0.95 mag. A month later ($\alpha = 25.7^\circ$) the amplitude dropped to 0.72 mag, which is expected (Zappala et al., 1990).



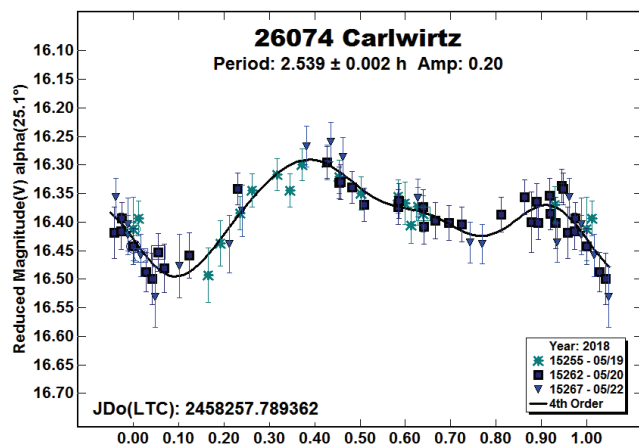
7529 Vagnozzi. There were no previous lightcurve results in the LCDB for this inner main-belt object. The period of 36.36 h is based on finding the best fit to a half period.



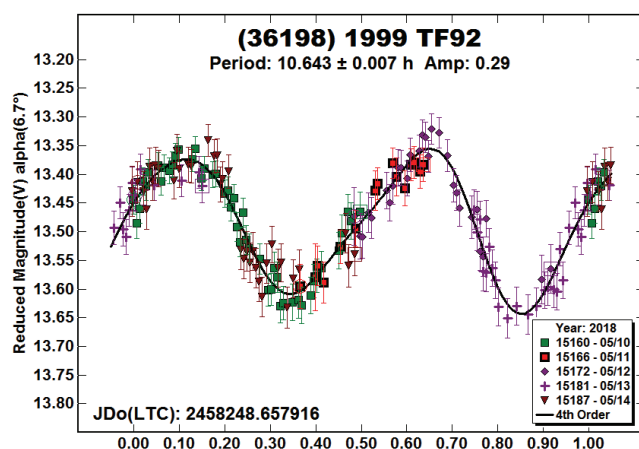
22283 Pytheas. This also appears to be a first-time lightcurve result. The solution is considered reasonably secure, although due to its symmetry and amplitude, a monomodal lightcurve with a period of 2.865 h, noticeably favored in the period spectrum, cannot be formally excluded (Harris et al., 2014).



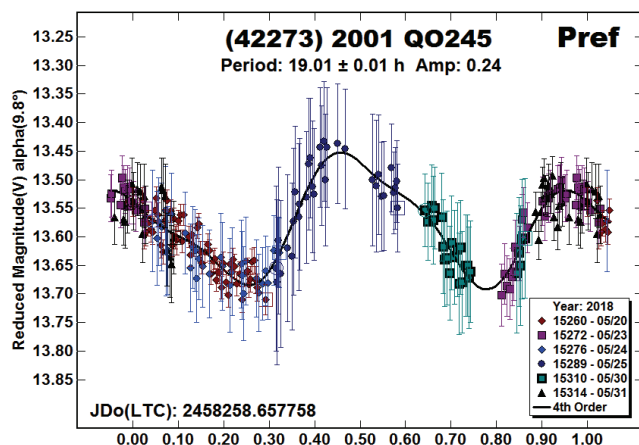
26074 Carlwartz. This is a suspected binary (Warner, 2013). No mutual events were seen but a strong secondary period of 16.11 h was found, suggesting a tidally-locked satellite with a somewhat elongated shape. There were no indications of a satellite in the 2018 data.



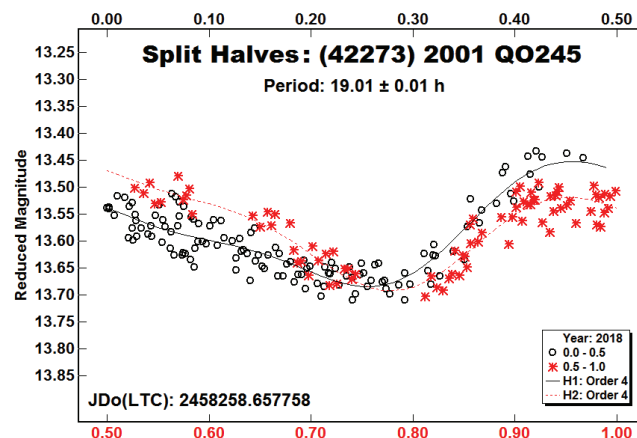
(36198) 1999 TF92. There were no lightcurve entries in the LCDB for this Eos group member. The solution is considered secure.



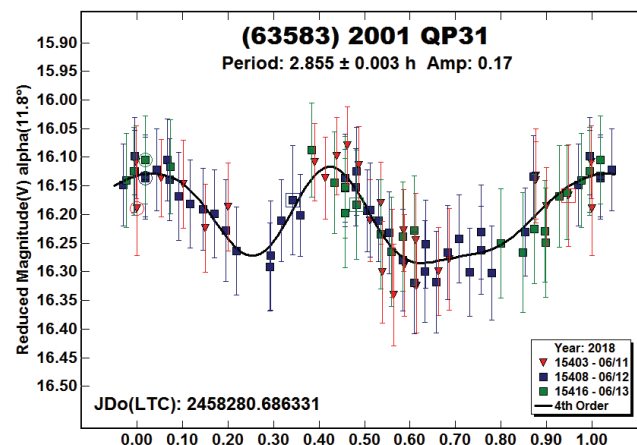
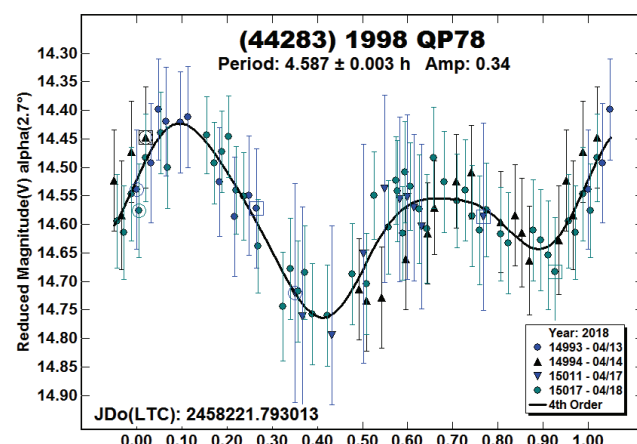
(42273) 2001 QO245. This looks to be the first reported lightcurve period for 2001 QO245, a 15-km outer main-belt asteroid. The period spectrum shows a strong preference for a solution of about 19 h. However, there was a somewhat remote possibility that the half-period was correct. A “split-halves” plot helps resolve the ambiguity at relatively low phase angles.



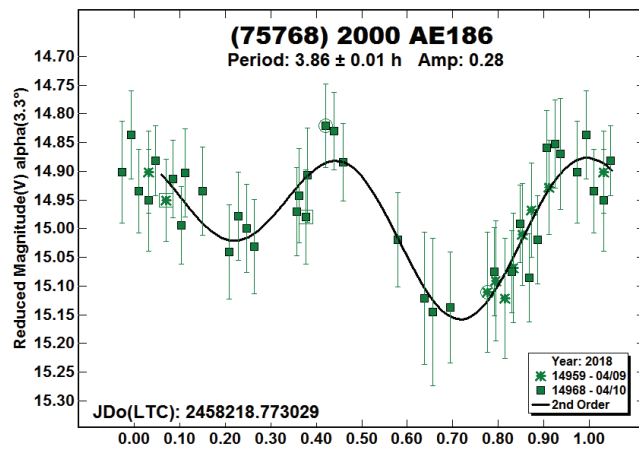
This plot splits the lightcurve for a given period into halves, superimposing the second half over the first. If the two halves are the same within the noise level, the half-period should be given consideration. In this case, however, the two halves were significantly different and so the longer period was adopted.



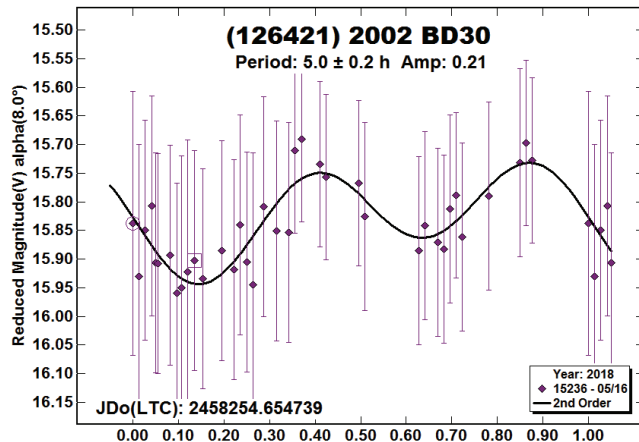
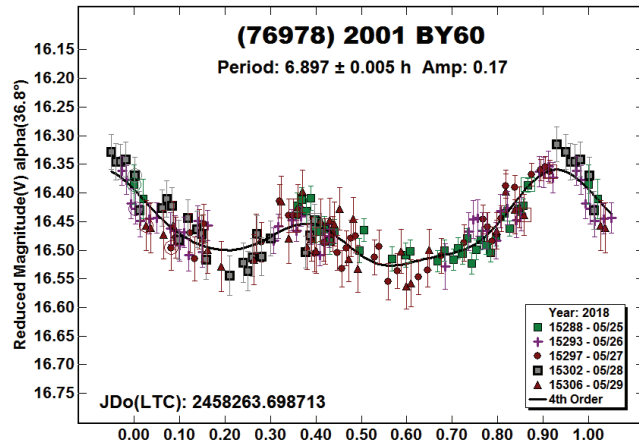
(44283) 1998 QP78, (63583) 2001 QP31. There were no previous lightcurve period entries in the LCDB for either of these asteroids. Mainzer et al. (2016) reported a diameter of $D = 4.67$ km and albedo $p_V \sim 0.27$ for 1998 QP78, a member of Eunomia group. For 2001 QP31, Nugent et al. (2016) found $D = 2.11$ km and $p_V = 0.31$.



(75768) 2000 AE186 is a 3.6 km member of the Eunomia group. It was in the field of view of a planned target for a single night. There was no previous lightcurve entry in the LCDB.

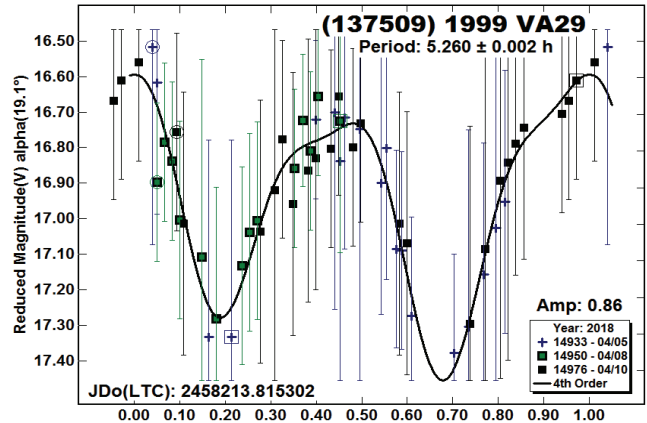
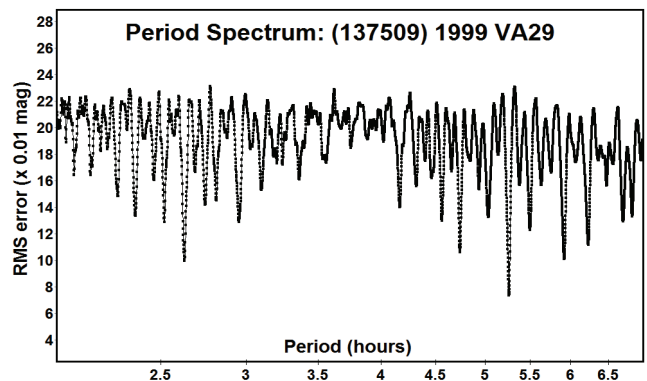


(76978) 2001 BY60, (126421) 2002 BD30. This is another pair of asteroids that didn't have LCDB lightcurve entries. The low amplitude and high phase angle for 2001 BY60 make the solution less than secure but it's probably correct. On the other hand, 2002 BD30 was in the field of view on one night, very faint, and had only a hint of a period.

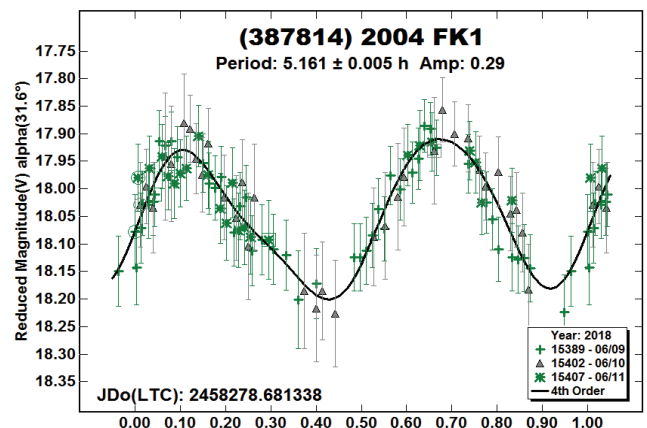
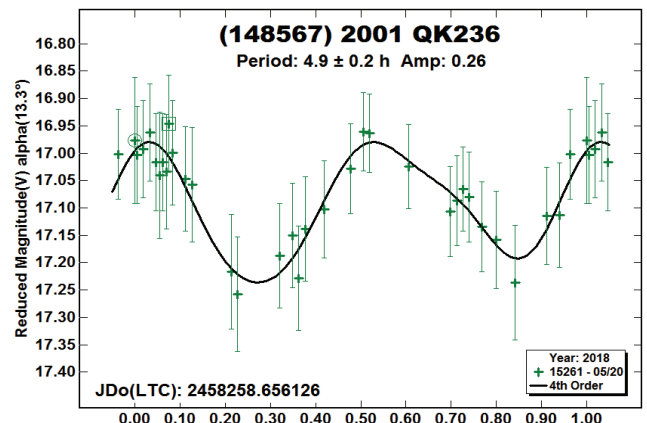


(137509) 1999 VA29. The large error bars in the data for 1999 VA29, a 1.6 km member of the Flora group, would have made finding a period nearly impossible were it not for the large amplitude of 0.86 mag and having data from more than one night. Still, the result should be viewed with some skepticism.

The asteroid is never brighter than $V \sim 18.1$. The next opportunity is 2020 Nov at $+21^\circ$ Declination and galactic latitude -25° .



(148567) 2001 QK236, (387814) 2004 FK1. These are two more newcomers to the LCDB.



Number	Name	2018 mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Group
132	Aethra	06/25-06/27	125	16.4, 16.4	352	26	5.171	0.003	0.13	0.01	MC
323	Brucia	05/28-05/31	276	16.3, 16.7	201	26	9.458	0.008	0.15	0.01	MC
2449	Kenos	06/24-06/26	165	36.5, 36.2	313	34	3.8387	0.0006	0.40	0.02	MC
3287	Olmstead	06/08-06/10	79	29.6, 29.2	296	17	4.963	0.003	0.49	0.02	MC
3343	Nedzel	05/12-05/14	171	12.2, 13.5	216	1	5.4614	0.0007	0.83	0.02	MC
3483	Svetlov	04/27-05/04	137	16.8, 17.8	206	27	6.806	0.002	0.30	0.02	H
3800	Karayusuf	06/02-06/04	178	25.2, 25.8	232	16	2.2328	0.0004	0.18	0.01	MC
4713	Steel	04/27-05/03	277	22.7, 23.2	211	32	5.1963	0.0005	0.41	0.02	H
5251	Bradwood	06/08-06/10	89	32.1, 31.9	305	20	4.296	0.002	0.43	0.02	MC
5579	Uhlherr	04/27-04/29	78	17.5, 16.7	237	18	4.550	0.005	0.41	0.03	H
5999	Plescica	05/28-05/31	103	28.7, 29.0	202	18	5.396	0.003	0.83	0.04	MC
7529	Vagnozzi	05/12-05/16	218	8.4, 10.1	214	1	36.38	0.05	0.94	0.04	MB-I
22283	Pytheas	06/11-06/17	97	16.7, 19.2	233	11	5.730	0.003	0.21	0.02	MC
26074	Carlwirtz	05/19-05/22	65	25.1, 24.0	258	29	2.539	0.002	0.20	0.02	H
36198	1999 TF92	05/10-05/14	160	6.7, 8.2	213	2	10.643	0.007	0.29	0.02	EOS
42273	2001 QO245	05/24-05/31	213	11.3, 13.8	219	8	19.01	0.01	0.24	0.02	MB-O
44283	1998 QP78	04/13-04/18	81	2.7, 3.8	202	6	4.587	0.003	0.34	0.03	EUN
63583	2001 QP31	06/11-06/12	86	11.8, 12.1	247	15	2.855	0.003	0.17	0.02	MC
75768	2000 AE186	04/09-04/09	41	3.3, 3.3	202	6	3.86	0.01	0.28	0.03	EUN
76978	2001 BY60	05/25-05/29	168	36.8, 36.6	262	43	6.897	0.005	0.17	0.02	MC
126421	2002 BD30	05/16-05/16	37	8.0, 8.0	219	9	5.0	0.2	0.21	0.03	MB-O
137509	1999 VA29	04/05-04/08	57	19.1, 20.1	161	5	5.260	0.002	0.86	0.05	FLOR
148567	2001 QK236	05/20-05/20	33	13.4, 13.4	221	7	4.9	0.2	0.28	0.03	MB-I
387814	2004 FK1	06/09-06/11	104	31.6, 32.0	238	35	5.161	0.005	0.29	0.03	MC

Table II. Observing circumstances and results. The phase angle (α) is given at the start and end of each date range. L_{PAB} and B_{PAB} are, respectively, the average phase angle bisector longitude and latitude (see Harris *et al.*, 1984). The Group column gives the orbital group to which the asteroid belongs. The definitions are those used in the LCDB (Warner *et al.*, 2009a). EUN: Eunomia, FLOR: Flora, H: Hungaria, MB-I/O: Main-belt inner/outer, MC: Mars-crosser.

Acknowledgements

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LIGHTCURVE AND ROTATION PERIOD DETERMINATIONS FOR SEVEN ASTEROIDS

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CCD photometric observations of seven asteroids were conducted from 2018 January through June. A review of the results obtained for synodic rotation periods as well as the lightcurves established is presented here.

Photometric observations of seven asteroids were conducted at Sopot Astronomical Observatory (SAO) between 2018 January-June in order to determine the asteroids' synodic rotation periods. For this purpose, two 0.35-m *f*/6.3 Meade LX200GPS Schmidt-Cassegrain telescopes were employed. The telescopes are equipped with a SBIG ST-8 XME and a SBIG ST-10 XME CCD cameras. The exposures were unfiltered and unguided for all targets. Both cameras were operated in 2x2 binning mode, which produces image scales of 1.66 arcsec/pixel and 1.25 arcsec/pixel for ST-8 XME and ST-10 XME cameras, respectively. Prior to measurements, all images were corrected using dark and flat field frames.

Photometric reduction, lightcurve construction, and period analysis were conducted using *MPO Canopus* (Warner, 2018a). Differential photometry with up to five comparison stars of near solar color ($0.5 \leq B-V \leq 0.9$) was performed using the Comparison Star Selector (CSS) utility. This helped ensure a satisfactory quality level of night-to-night zero point calibrations and correlation of the measurements within the standard magnitude framework. Depending on a case-by-case basis, primarily on the coverage quality of a certain sky zone by a particular catalog, field comparison stars were calibrated using standard magnitudes from three different catalogs: 1. Johnson V magnitudes from the AAVSO Photometric All-Sky Survey catalog (APASS; Henden *et al.*, 2009) Data Release 9; 2. Johnson V magnitudes from MPOSC3 hybrid catalog, where BVRI magnitudes were derived from J and K 2MASS catalog magnitudes by applying formulae developed by Warner (2007); 3. Cousins R magnitudes derived from the Carlsberg Meridian Catalog 15 (VizieR, 2018) Sloan *r'* magnitudes using the formula: $R = r' - 0.22$. All data sets pertaining to a single target were consistently calibrated using a single catalog. In some instances, small zero point adjustments were necessary in order to achieve the best match between individual data sets in terms of minimum RMS residual of a Fourier fit.

Some of the targets presented in this paper were observed within the Photometric Survey for Asynchronous Binary Asteroids (BinAstPhot Survey) under the leadership of Dr Petr Pravec from Ondřejov Observatory, Czech Republic.

Table I gives the observing circumstances and results.