

ASTEROID LIGHTCURVE ANALYSIS AT CS3-PALMER DIVIDE STATION: 2016 DECEMBER THRU 2017 MARCH

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Lightcurves for 18 main-belt asteroids were obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2016 December thru 2017 March. Many of the asteroids were “strays” in the field of planned targets, demonstrating a good reason for data mining images. Analysis shows that the Hungaria asteroid (45878) 2000 WX29 may be binary.

CCD photometric observations of 18 main-belt asteroids were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2016 December thru 2017 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 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 usually taken from the CMC-15 (<http://svo2.cab.inta-csic.es/vocats/cmc15/>) or APASS (Henden et al., 2009) catalogs. The MPOSC3 catalog was used as a last resort. This catalog is based on the 2MASS catalog (<http://www.ipac.caltech.edu/2mass>) with magnitudes converted from J-K to BVRI (Warner, 2007). The nightly zero points for the catalogs are generally consistent to about ± 0.05 mag or better, but on occasion reach 0.1 mag and more. There is a systematic offset among the catalogs so, whenever possible, the same catalog is used throughout the observations for a given asteroid. Period analysis is also done with *MPO Canopus*, which implements the FALC algorithm developed by Harris (Harris et al., 1989).

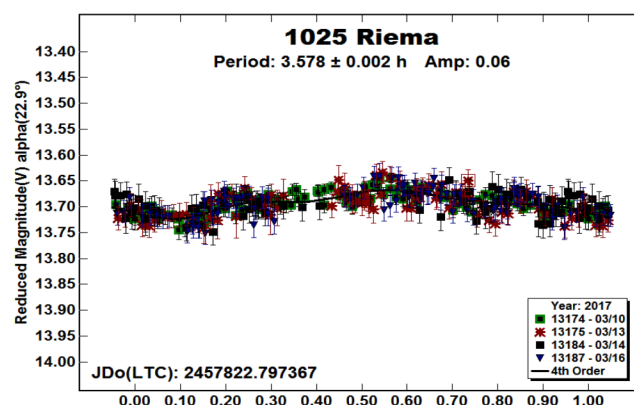
In the plots below, the “Reduced Magnitude” is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying $-5 \cdot \log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid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

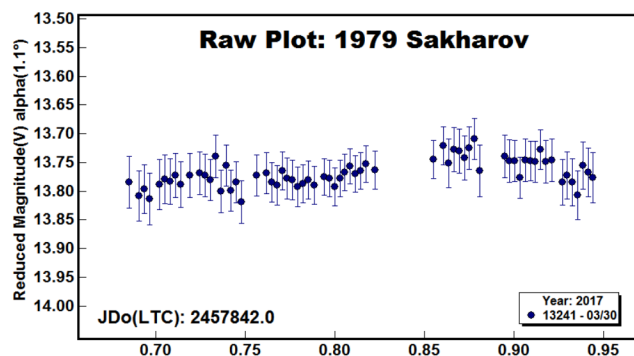
If the plot includes an amplitude, e.g., “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

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 bibcodes, is also available for download. Readers are strongly encouraged to obtain, when possible, the original references listed in the LCDB for their work.

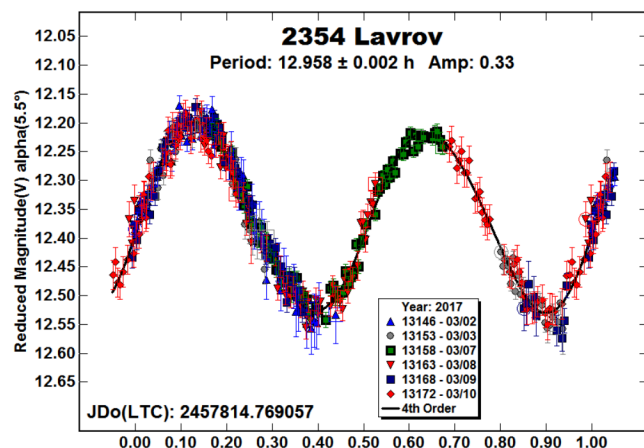
1025 Riema. The period of 3.578 h found from the PDS data agrees with earlier results, e.g., Stephens (2003; 3.580 h).



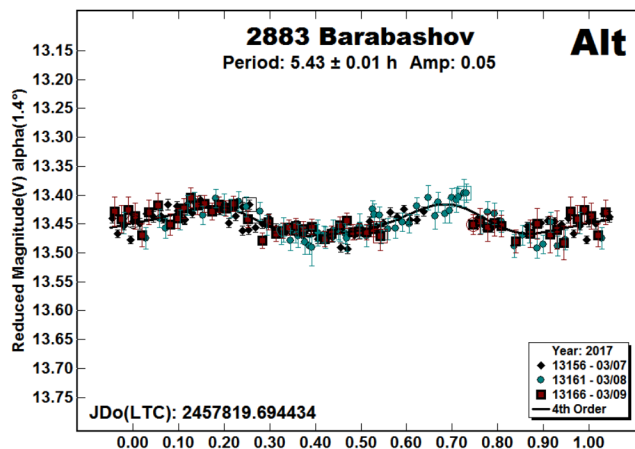
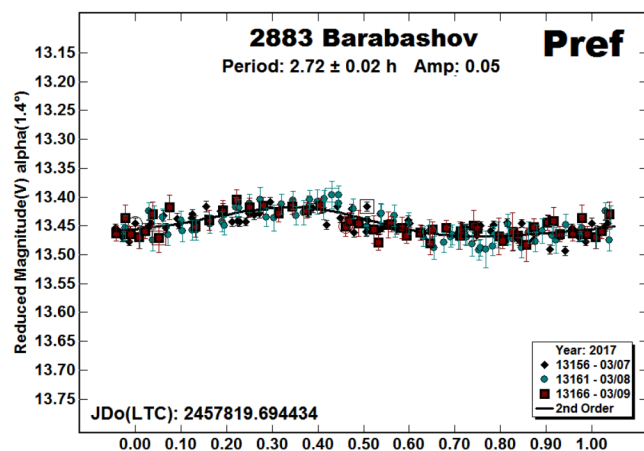
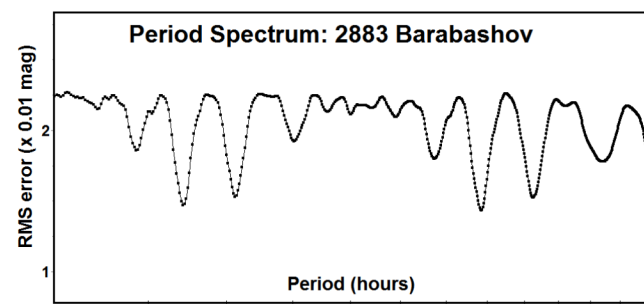
1979 Sakharov was in the same field as a planned target for one night. No period could be found. Earlier results include Pravec et al. (2011 web, 7.5209 h) and Oey (2014; 7.589 h);



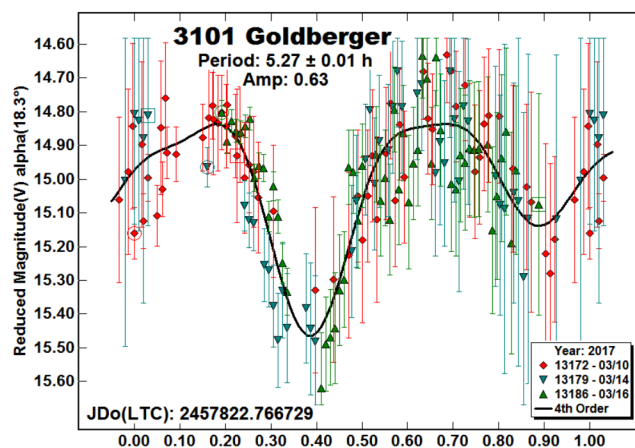
2354 Lavrov. Waszczak et al. (2015) found a period of 12.961 h from a limited data set. The denser data set from PDS confirms that earlier result.



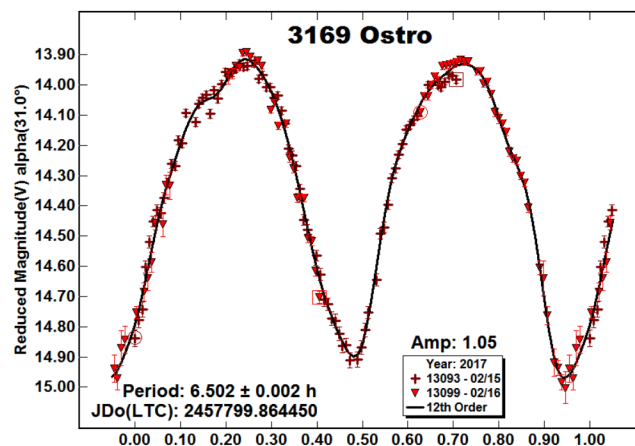
2883 Barabashov. The low amplitude (0.06 mag) and low phase angle in 2017 meant that a bimodal solution could not be assumed (Harris et al., 2014). The period spectrum showed nearly equal solutions at 2.7 and 5.4 hours. The preferred solution is 2.72 h since it provides complete coverage of the curve and has a slightly lower RMS fit to the Fourier model. Pravec et al. (2017web) also found an ambiguous solution. Their shorter period was 2.6840 h and the alternate period was 5.3680 h. Both of their solutions had an amplitude of 0.04 mag.



3101 Goldberger. This Hungaria member was worked by the author twice before: Warner (2014, 5.268 h; 2016, 5.270 h). The asteroid was considerably fainter than in previous years and there was a nearly full moon in the sky. This meant lower SNR values and so this solution is not as highly rated in the LCDB (Warner et al., 2009a).

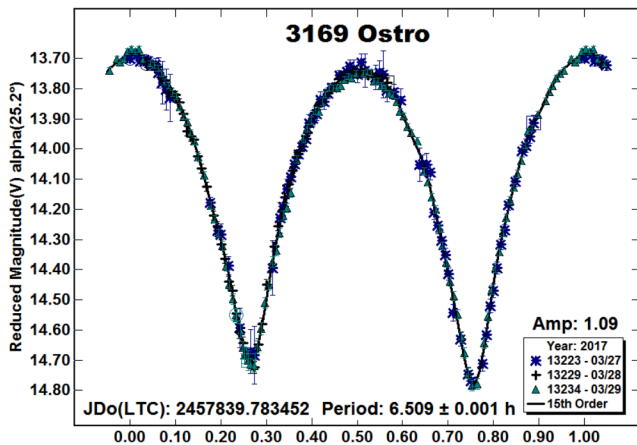


3169 Ostro. This Hungaria asteroid is a suspected “contact binary”, or at least a single body that is highly bifurcated (Descamps et al., 2005). This would be more likely if the lightcurve featured “shoulders” on the descending and ascending branches. The 2017 apparition was the fourth that was observed by the author. All previous results in the LCDB are statistically the same as the average period of 6.505 h reported here.

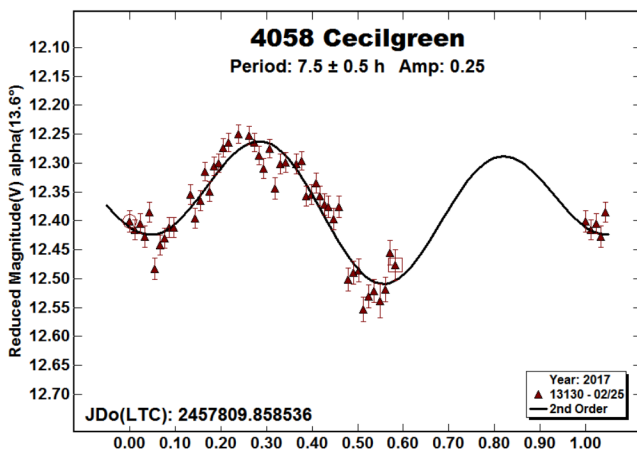


Number	Name	2017 mm/dd	Pts	Phase	L_{PAB}	B_{PAB}	Period	P.E.	Amp	A.E.	Group
1025	Riema	03/10–03/16	315	23.0, 21.3	203	20	3.578	0.002	0.06	0.01	H
1979	Sakharov	03/30–03/30	66	1.2	188	-2	7.79	0.01	0.07	0.01	V
2354	Lavrov	03/02–03/10	401	5.5, 2.3	176	0	12.958	0.002	0.33	0.01	MB-O
2883	Barabashov	03/07–03/09	130	1.2, 1.4	168	2	2.74	0.01	0.06	0.01	MB-I
3101	Goldberger	03/10–03/16	162	18.3, 17.0	194	23	5.27	0.01	0.63	0.05	H
3169	Ostro	02/15–02/16	149	31.0, 30.9	194	33	6.502	0.002	1.05	0.02	H
3169	Ostro	03/27–03/29	251	25.2, 24.9	202	36	6.509	0.001	1.09	0.02	H
4058	Cecilgreen	02/25–02/25	48	13.6	197	10	7.5	0.5	0.25	0.02	EOS
5745	1991 AN	01/29–01/29	278	5.0	124	7	4.087	0.005	0.92	0.02	FLOR
26703	2001 FB144	03/19–03/19	54	2.6	172	2	8.4	0.5	0.37	0.04	MB-I
26934	Jordancotler	01/29–01/29	174	4.3	125	8	28	5	0.35	0.1	FLOR
43662	2002 FP8	02/25–02/25	46	15.3	186	-5	4.5	0.3	0.67	0.04	V
45566	2000 CK58	03/10–03/26	174	12.8, 9.8	198	21	4.704	0.005	0.47	0.03	MB-O
45878	2000 WX29	16/12/12–01/06	197	22.4, 7.0	115	4	3.9207	0.0003	0.1	0.01	H
47170	1999 TE33	03/29–03/29	59	14.2	165	0	>16.		>0.4		FLOR
53595	2000 CK62	03/01–03/02	76	9.8, 10.3	179	-1	4.10	0.02	0.14	0.02	FLOR
59636	1999 JJ81	01/30–01/30	48	6.6	142	-7	3.7	0.2	0.2	0.03	MB-I
67525	2000 RW83	03/30–03/30	60	1.2	188	-2	16	4	>0.3		FLOR
68435	2001 RF81	02/16–02/16	49	4.1	141	0	6.5	0.2	0.82	0.04	FLOR

Table II. Observing circumstances. The phase angle (α) is given at the start and end of each date range. 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 (see Harris *et al.*, 1984). The Group column gives the orbital group to which the asteroid belongs. The definitions and values are those used in the LCDB (Warner *et al.*, 2009a). FLOR = Flora; H = Hungaria; MB-I/M/O = main-belt inner/middle/outer; V = Vestoid.

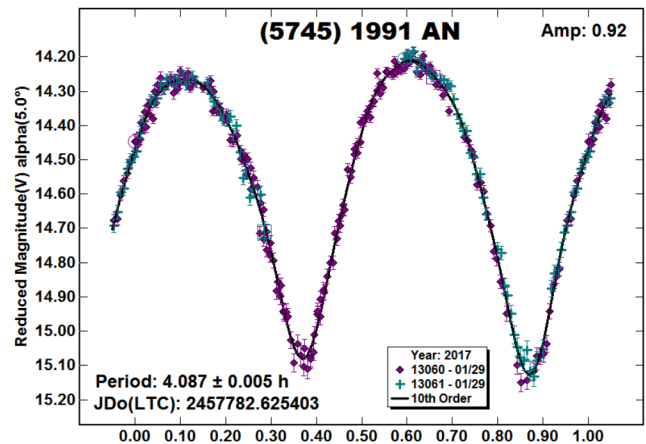


4058 Cecilgreen is a member of the Eos group. It was in the same field as a planned target for one night. Even with the limited data set, a reasonable estimate of the period was possible.

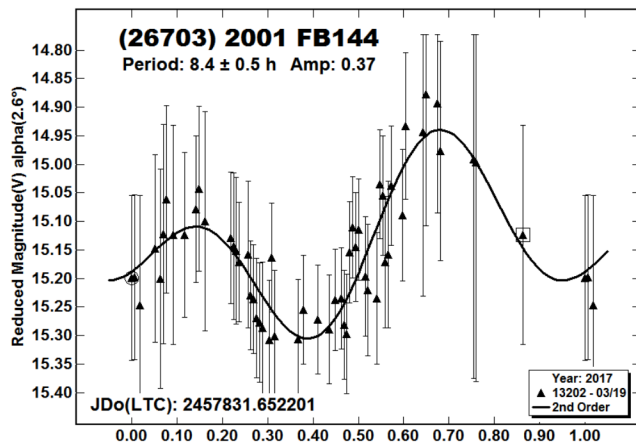


(5745) 1991 AN. This was another asteroid in the same field as the planned target for one night. However, the length of the run and

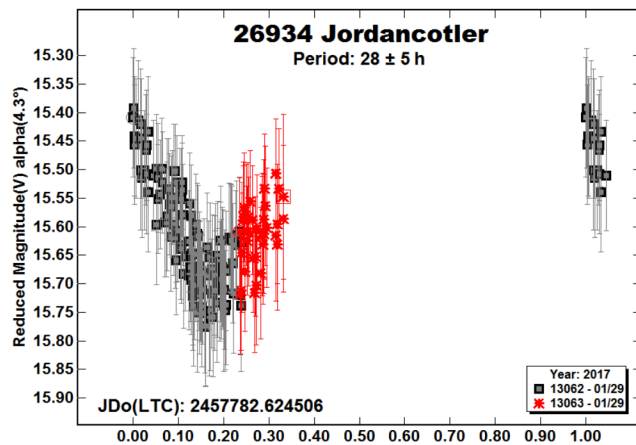
the relatively short period allowed finding an accurate synodic period for the Flora group member.



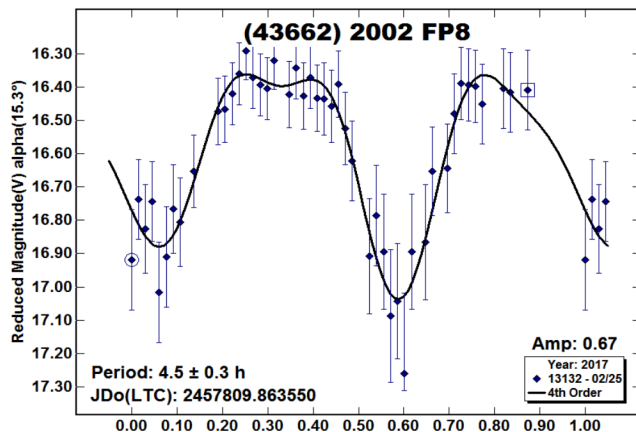
(26703) 2001 FB144 is an inner main-belt asteroid with an estimated diameter of about 3.5 km (LCDB; Warner *et al.*, 2009a). That any data were obtained was the result of making something good out of something bad. The telescope was misaimed for its planned target, which was out of the field entirely. A check was made for any asteroids that might be in the field; 2001 FB144 was the only one that had a sufficient SNR. The presumed period is hardly definitive but will serve as a guide for any future observations.



26934 Jordancotler. Here is another example of data mining images taken of a planned target. Not only was this Flora member in the field, but several possible variable stars were found as well. Given the amplitude of at least 0.3 mag, the final result should almost certainly be a bimodal lightcurve. The period reported here is based on looking at possible half-periods (monomodal) around 14 hours. The 28 h period adopted here was the most likely result but should be taken with a great deal of skepticism.

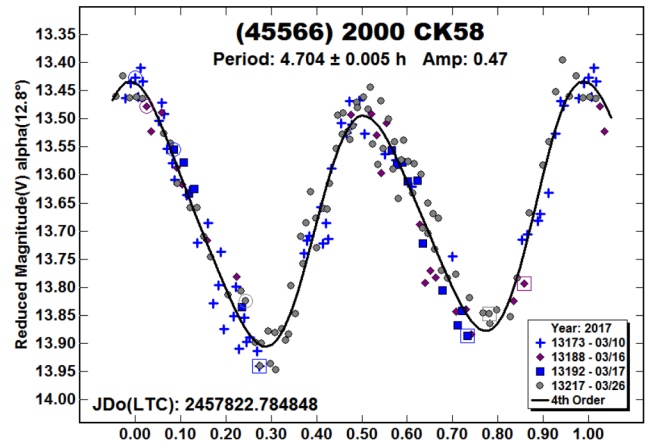


(43662) 2002 FP8. There were no previously reported periods for this Vestoid, yet another stray asteroid around for only one night.



(45566) 2000 CK58. Much of the data were taken with a nearly full moon in the sky, and so the error bars were large (very low SNR), so much so that they are not included here to make the

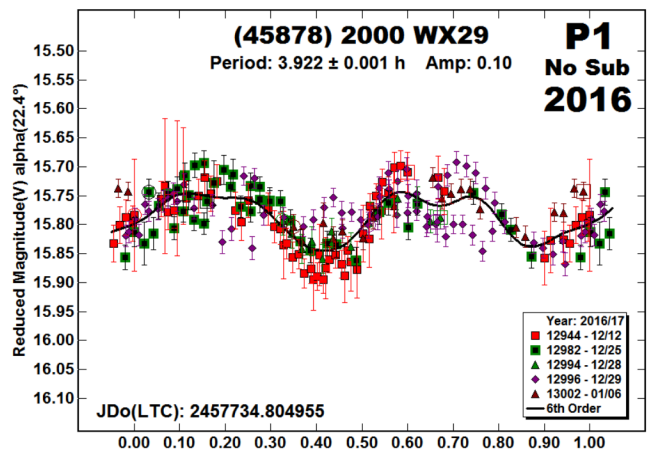
lightcurve readable. Even under these circumstances, it was possible to find an acceptable rotation period, mostly because of the large amplitude.

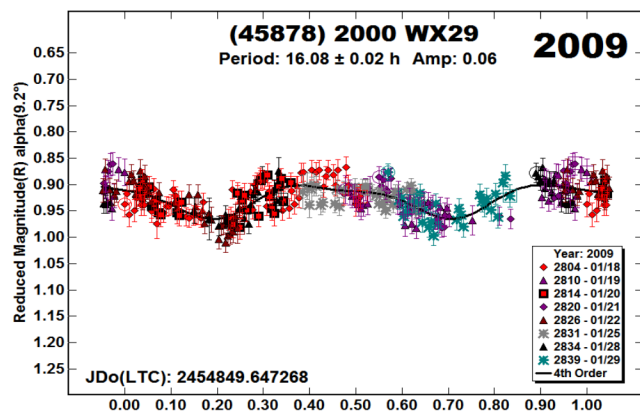
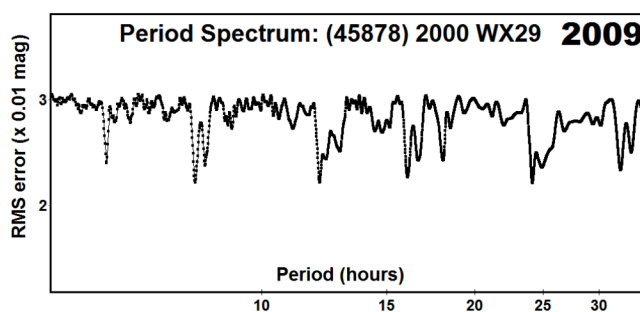
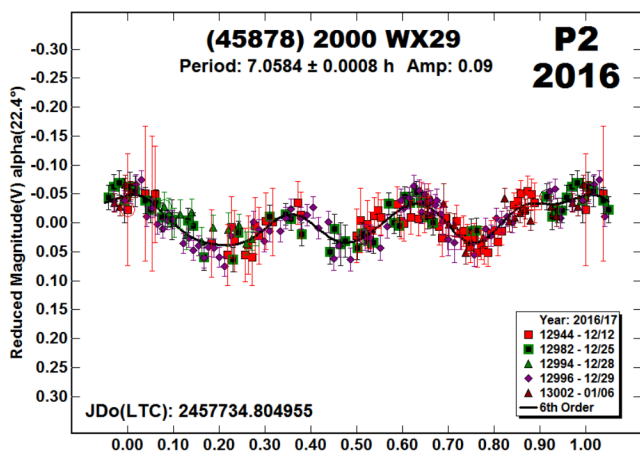
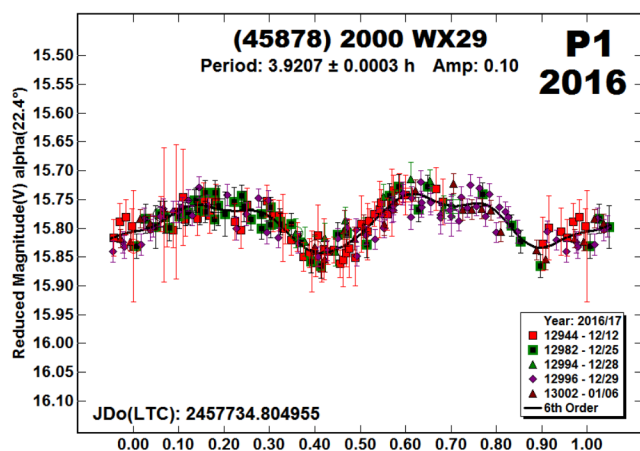
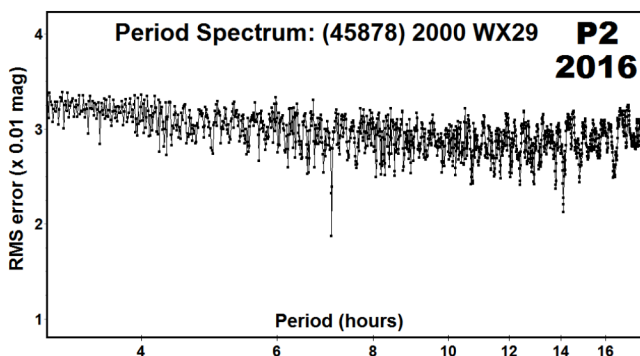
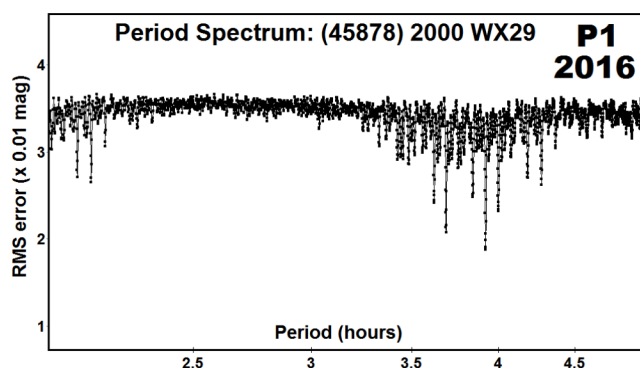


(45878) 2000 WX29. Analysis of the 2016 data indicates that this Hungaria might be a binary. The single period analysis shows what appeared to be deviations that could not be attributed to systematic causes. The dual-period search feature in *MPO Canopus* was used to find two distinctive periods: $P_1 = 3.9207$ h and $P_2 = 7.0584$ h. The two are related by a 9:5 integer ratio, so it is possible that the Fourier analysis was simply finding a second period that was harmonically related to the first.

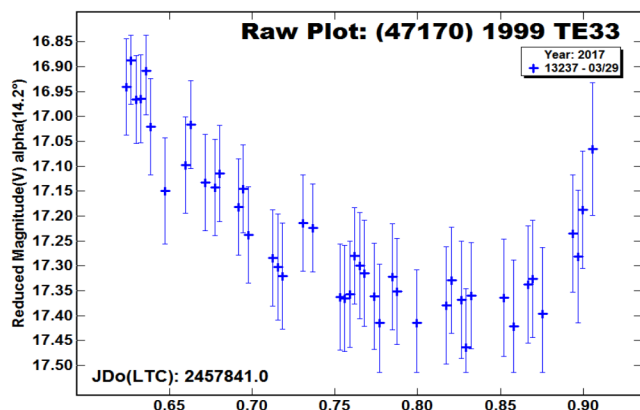
The shape of the P_2 lightcurve is unusual, which adds additional doubt as to its veracity. However, on the assumption that the second period is not an analysis or systematic artifact, then a possible explanation is a binary system with each body rotating independently of the orbital period of the satellite. No mutual events (occultations and/or eclipses) were detected, which would have confirmed the binary nature of the asteroid.

This analysis prompted another look at the data obtained in 2009 (Warner, 2009b). At that time, an ambiguous, but single, period of 16.07 h was found, the alternate being the half-period of 8.03 h. A dual-period search on the 2009 data failed to find reasonable solutions, especially any near the periods found from the 2016 data. Observations at future apparitions are strongly encouraged.

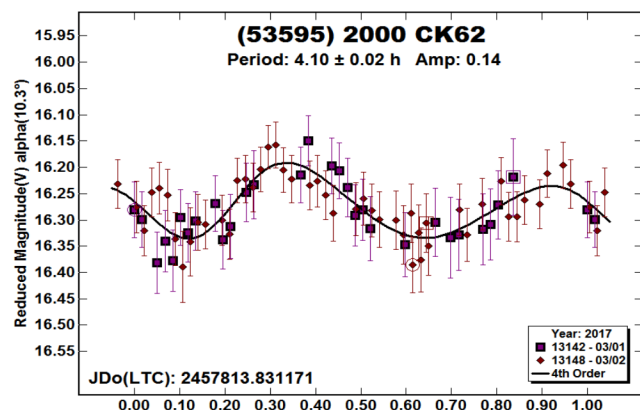




(47170) 1999 TE33. This Flora member was in the field for only one night. A best estimate for a period is $P > 16$ h with an amplitude $A > 0.4$ mag.

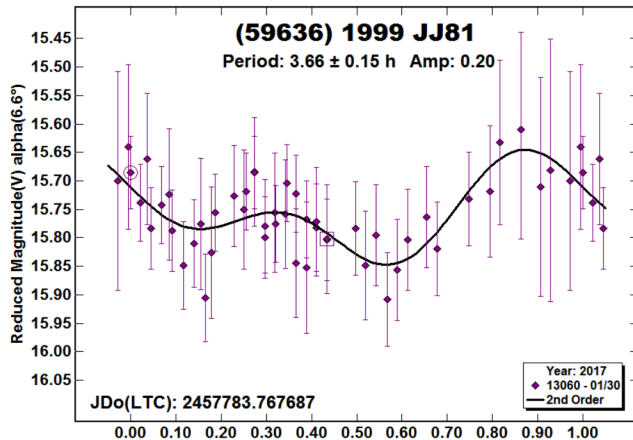


(53595) 2000 CK62. There were no reports of a period in the LCDB for this Flora member.

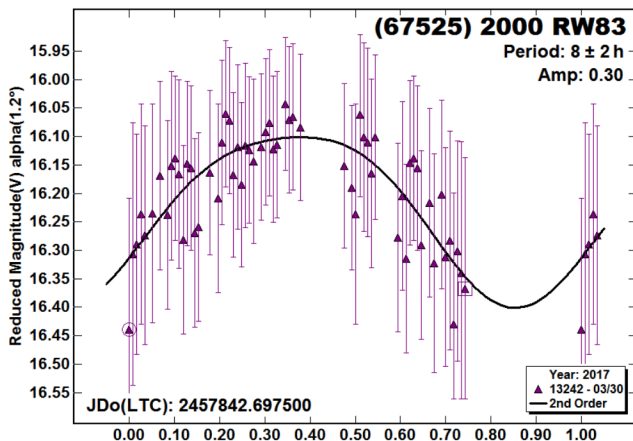


Like many of the other asteroids, this was a target of opportunity but for two nights instead of just one. This and the length of the runs allowed finding a reasonably secure period of 4.10 ± 0.02 h. While the amplitude does not assure a bimodal solution (Harris et al., 2014), the asymmetry of the lightcurve makes it likely that the correct period was found.

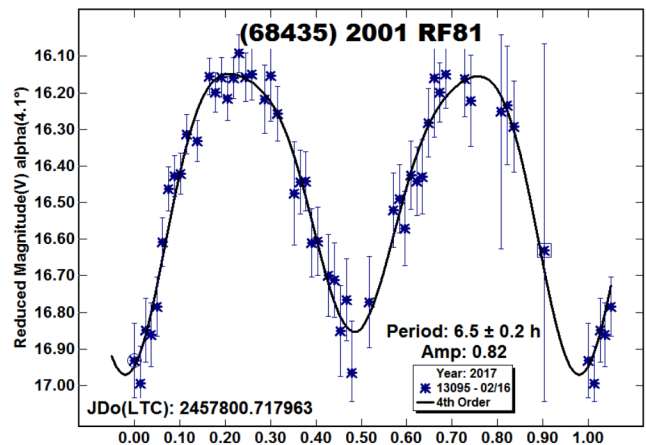
(59636) 1999 JJ81. There were no previously reported periods in the LCDB for this 3 km inner main-belt asteroid that was another single night target of opportunity.



(67525) 2000 RW83. The lightcurve plot shows one of several half-period solutions. Based on this, the true period may be on the order of 16 hours. However, without having at least one minimum, that is not certain. At the very least, the period is greater than 12 hours. This 2 km Flora member was another single-night only stray in a planned target field.



(68435) 2001 RF81. Also a single-night opportunity, the 1.9 km Flora member had no previously reported period in the LCDB. The amplitude and low phase angle assure that the lightcurve should be bimodal (Harris et al., 2014). Fortunately, there were enough data to cover almost a complete cycle of the purported period. While the period uncertainty is several tenths of an hour, the period is secure in the sense that it was the only one that fit the requirements for a bimodal lightcurve that was approximately symmetrical (Harris et al., 2014).



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LIGHTCURVE ANALYSIS OF 1773 RUMPELSTILZ AND 2040 CHALONGE

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Photometric observations of asteroids 2040 Chalonge and 1773 Rumpelstilz were made at the Philips Academy Observatory from 2016 December 2016 through 2017 February. 1773 Rumpelstilz was found to have rotational period 106.075 ± 0.001 h with amplitude 0.78 mag. 2040 Chalonge was found to have rotational period 10.383 ± 0.001 h with amplitude 0.22 mag;

CCD photometric observations of 1773 Rumpelstilz and 2040 Chalonge were made at the Phillips Academy Observatory as part of a high school astronomy research course between 2016 December and 2017 February. The CALL website (<http://minorplanet.info/call.html>) was used to select the targets, which were chosen for their favorable declinations, appealing names, and relatively bright magnitudes. A search of the asteroid lightcurve database (LCDB; Warner *et al.*, 2009) did not reveal previously reported lightcurve results for the asteroids. All observations were made with a 0.40-m f/8 Ritchey-Chrétien telescope by DFM Engineering. Images were taken with an Andor Tech iKon DW436 camera with a 2048x2048 array of 13.5-micron pixels. The resulting image scale was 0.86 arcseconds per pixel. All images were dark and flat-field corrected, 1x1 binning mode, and guided.

MPO Canopus was used to make photometric measurements of

the asteroid as well as to generate the final lightcurve and period spectrum. Comparison stars were chosen to have near solar color using the Comp Star Selector tool in *MPO Canopus*. In addition, brighter comparison stars were favored. Data merging and period analysis were also done with *MPO Canopus* using an implementation of the Fourier analysis algorithm of Harris (FALC; Harris *et al.*, 1989). The combined data sets were analyzed by the authors.

1773 Rumpelstilz was discovered on 1968 April 17 by P. Wild at Zimmerwald. We observed the asteroid for fifteen nights from 2017 January to February; the composite lightcurve includes 580 data points. This asteroid has a rather long period of 106.075 ± 0.001 h with amplitude of 0.78 mag. Although full coverage was not achieved, the large amplitude of the lightcurve requires the bimodal solution (Harris *et al.*, 2014) that was favored by the period spectrum.

