

MAIN-BELT ASTEROIDS OBSERVED FROM CS3: 2020 JANUARY TO MARCH

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(Received: 2020 April 10)

CCD photometric observations of 13 main-belt asteroids were obtained at the Center for Solar System Studies (CS3) from 2020 January to March. An additional 4 main-belt asteroids from prior years are also reported upon or revisited.

The Center for Solar System Studies (CS3) has seven telescopes which are normally used in program asteroid family studies. The focus is on near-Earth asteroids, but when suitable targets are not available, Jovian Trojans and Hildas are observed. When a nearly full moon is too close to the family targets being studied, targets of opportunity amongst the main-belt families were selected.

Table I lists the telescopes and CCD cameras that were used to make the observations. Images were unbinned with no filter and had master flats and darks applied. The exposures depended upon various factors including magnitude of the target, sky motion, and Moon illumination.

Telescope	Camera
0.30-m f/6.3 Schmidt-Cass	FLI Microline 1001E
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0.35-m f/11 Schmidt-Cass	FLI Microline 1001E
0.40-m f/10 Schmidt-Cass	FLI Proline 1001E
0.50-m F8.1 R-C	FLI Proline 1001E

Table I: List of CS3 telescope/CCD camera combinations.

Image processing, measurement, and period analysis were done using *MPO Canopus* (Bdw Publishing), which incorporates the Fourier analysis algorithm (FALC) developed by Harris (Harris et al., 1989). The Comp Star Selector feature in *MPO Canopus* was used to limit the comparison stars to near solar color. Night-to-night calibration was done using field stars from the ATLAS catalog (Tonry et al., 2018), which has Sloan *griz* magnitudes that were derived from the GAIA and Pan-STARR catalogs, among others and are “native” magnitudes of the catalog.

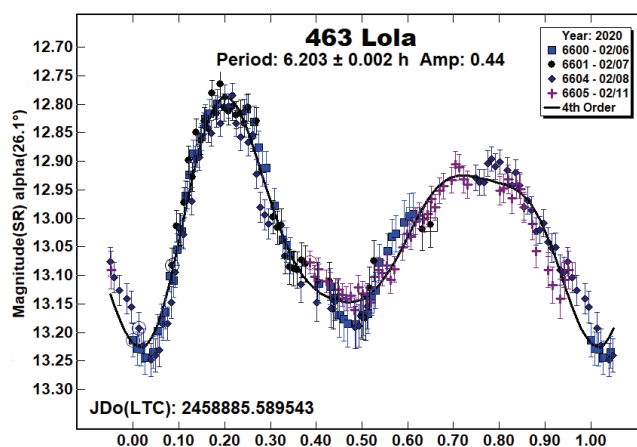
We used the ATLAS R or *r'* (SR) magnitudes. Those adjustments are mostly ≤ 0.03 mag. The occasions where larger corrections were required may have been related in part to using unfiltered observations, poor centroiding of the reference stars, and not correcting for second-order extinction terms.

The magnitudes were normalized to the comparison stars used in the earliest session and to the phase angle given in parentheses using $G = 0.15$. In other words, the data were made to seem that they were all obtained at the same time using the same comparison stars. The X-axis rotational phase ranges from -0.05 to 1.05 .

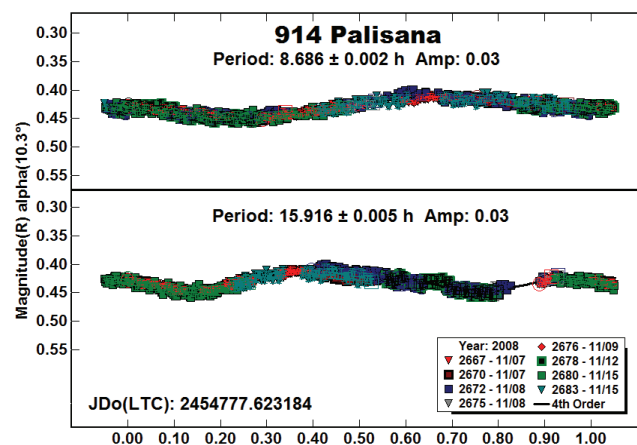
The amplitude indicated in the plots (e.g. Amp. 0.23) is the amplitude of the Fourier model curve and not necessarily the adopted amplitude of the lightcurve.

For brevity, only some of the previously reported rotational periods may be referenced. A complete list is available at the lightcurve database (LCDB; Warner et al., 2009).

463 *Lola*. For a low numbered asteroid, it is interesting that this inner main-belt asteroid has only three reported rotational periods from the past. Bembrick (2012, 2.206 h), Lecrone et al. (2005, 6.20 h), and Menke (2005, 2.621 h) all found periods similar to our result.



914 *Palisana*. We originally observed this Phocaea family member in 2008 reporting a period of 15.922 h (Warner, 2009b). Behrend et al. (2019web) observed it in 2019 August reporting a period of 8.681 h; this caused us to reevaluate our 2008 data. The comparison star magnitudes were changed from APASS V magnitudes (Henden et al., 2009) to ATLAS SR magnitudes (Tonry et al., 2018). The quality of each comparison star was reviewed. Our new analysis of the 2008 data showed several aliases including our original period of 15.92 h and a period of 8.686 h, near that found by Behrend et al. (2019web). After this analysis and taking into account the larger amplitude for the Behrend et al. lightcurve, we now slightly favor the 8.686 h period.



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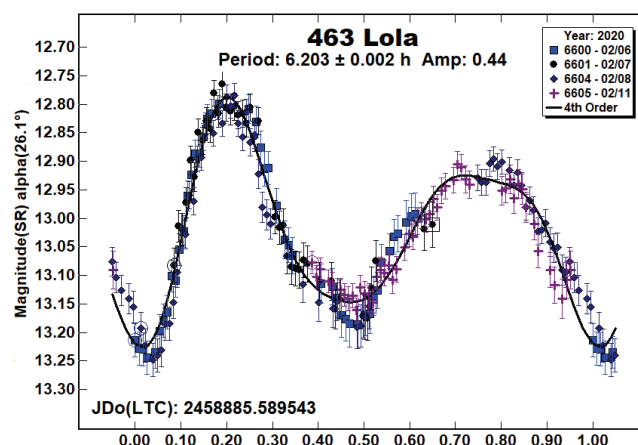
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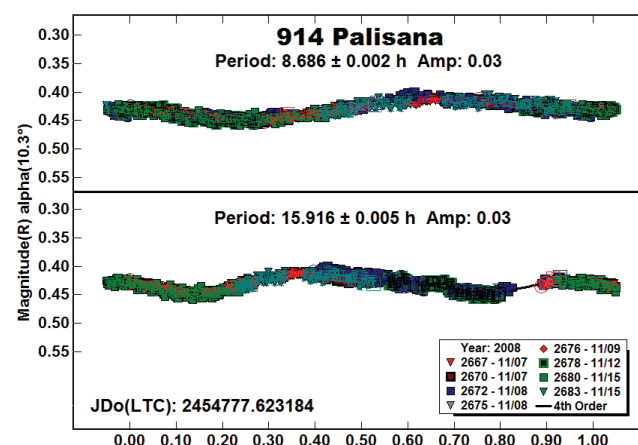
The amplitude indicated in the plots (e.g. Amp. 0.23) is the amplitude of the Fourier model curve and not necessarily the adopted amplitude of the lightcurve.

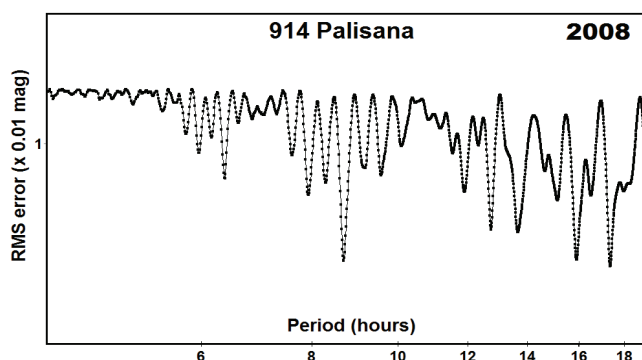
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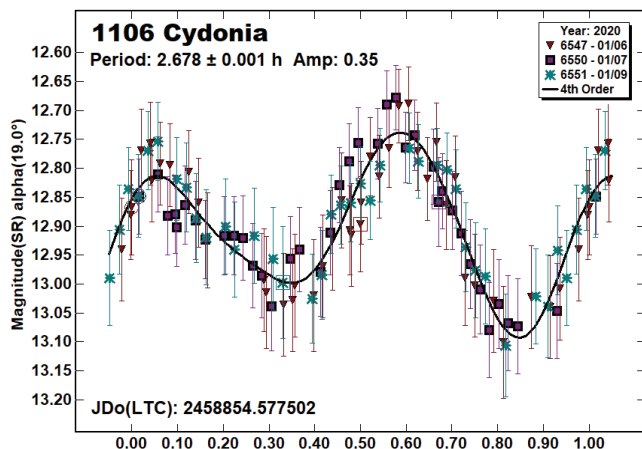


914 *Palisana*. We originally observed this Phocaea family member in 2008 reporting a period of 15.922 h (Warner, 2009b). Behrend et al. (2019web) observed it in 2019 August reporting a period of 8.681 h; this caused us to reevaluate our 2008 data. The comparison star magnitudes were changed from APASS V magnitudes (Henden et al., 2009) to ATLAS SR magnitudes (Tonry et al., 2018). The quality of each comparison star was reviewed. Our new analysis of the 2008 data showed several aliases including our original period of 15.92 h and a period of 8.686 h, near that found by Behrend et al. (2019web). After this analysis and taking into account the larger amplitude for the Behrend et al. lightcurve, we now slightly favor the 8.686 h period.



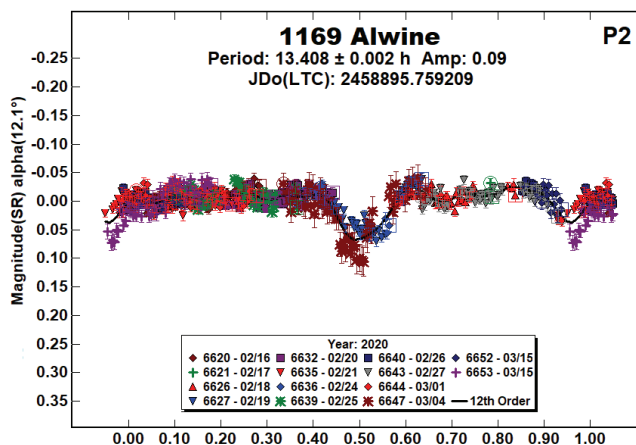
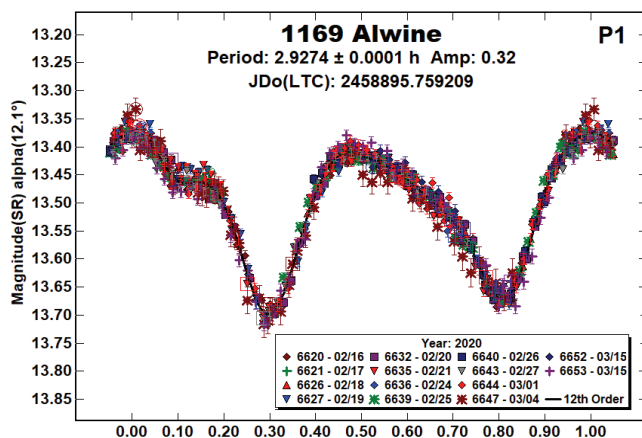


1106 Cydonia. This member of the Eunomia family has been observed twice before. KlingleSmith et al. (2016, 2.679 h) and Aznar (2017, 2.67 h) each found periods similar to our result.

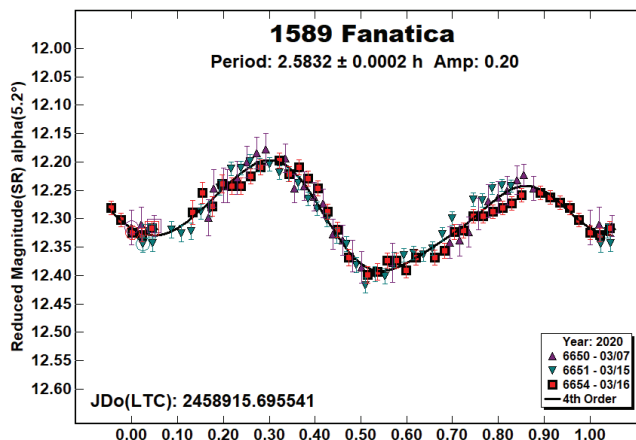


1169 Alwine. This member of the Eunomia family was observed between 2019 December and 2020 March by the Photometric Survey for Asynchronous Binary Asteroids (Pravec, 2020web) as a 'Prime Suspect' of being a binary asteroid. They found a primary period of $P_1 = 2.9274$ h and several attenuations that only roughly fit an orbital period of $P_2 = 54.45$ h.

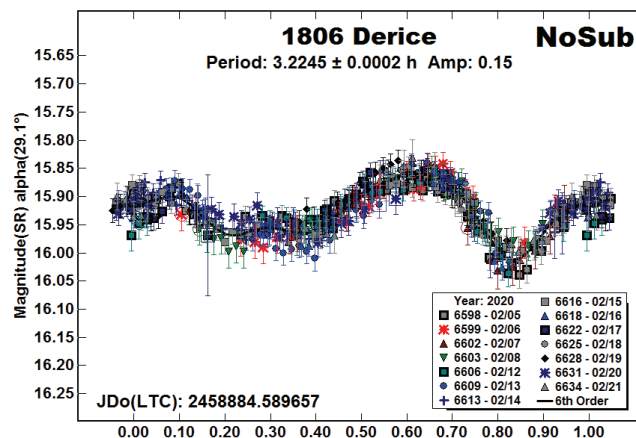
We observed it from 2020 February to March and used the iterative dual-period search in *MPO Canopus* to find a primary period of $P_1 = 2.9274$ h and reveal the mutual events due to the satellite with an orbital period of $P_2 = 13.408$ h. Our fit was also not very good and is a 4:1 alias of the Pravec P_2 result. The next good opposition for the northern hemisphere will be in 2022 October.

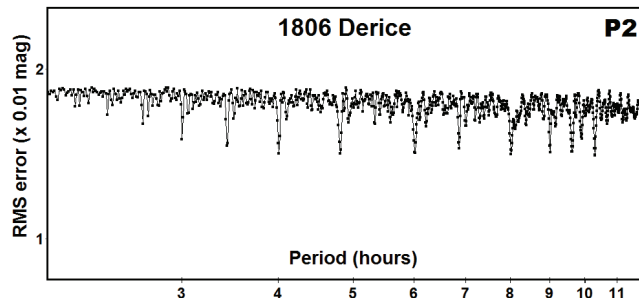
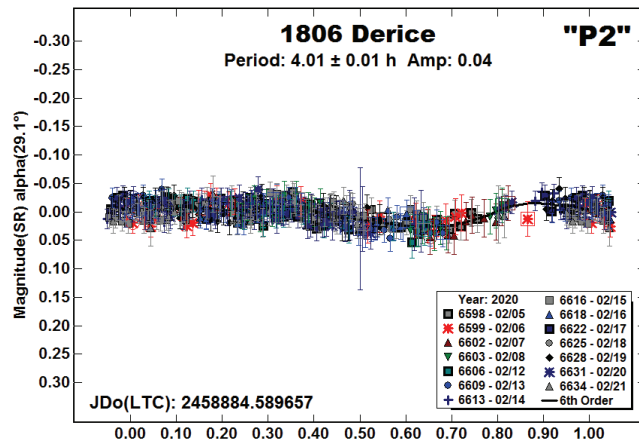
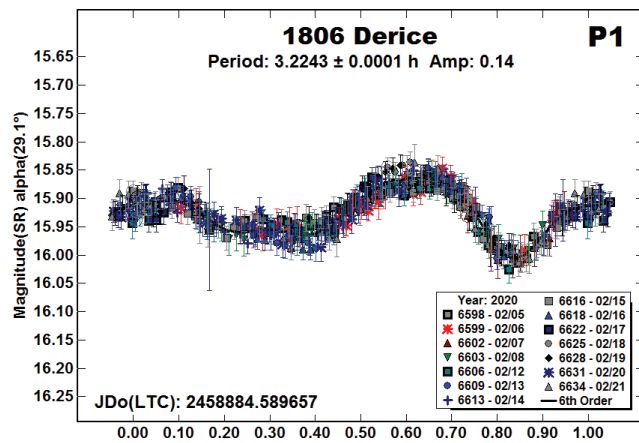


1589 Fanatica. We observed this Vestoid three times in the past (Warner, 2004; Stephens, 2015; Stephens and Warner, 2019) each time finding a period near 2.58 h. This year's result is in good agreement with those prior findings.



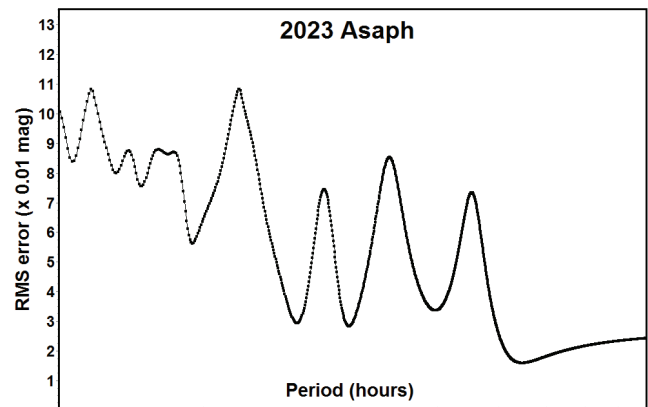
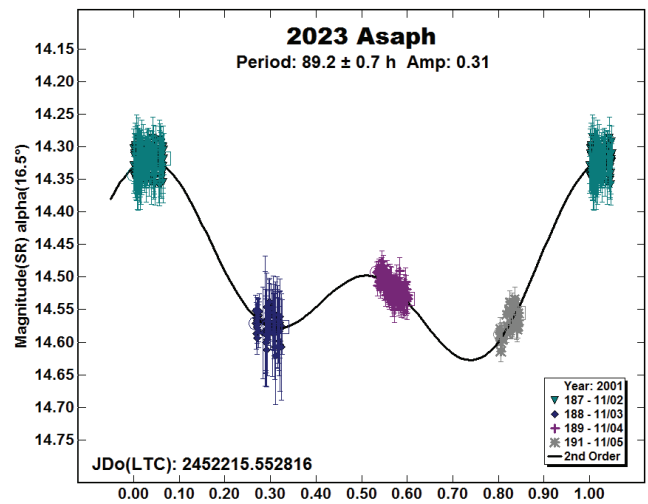
1806 Derice. This member of the Flora family has been observed several times by the Photometric Survey for Asynchronous Binary Asteroids (Pravec, 2009web; 2011web; 2012web; 2016web) as being a 'Prime Suspect' of being a binary asteroid. In the 2009 data, minor deviations from the curve suggested the presence of attenuation events, but an orbital period could not be determined. At each opposition the survey found a primary rotational period near 3.224 h.



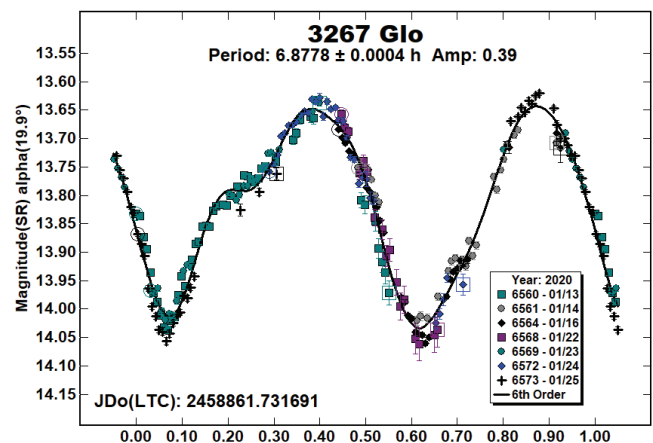


Our data in 2020 February also showed slight deviations from the curve. While promising at the start, more data made the solution increasingly unlikely. Running the dual-period search in *MPO Canopus* acted more as a “noise filter” with P_2 having no physical meaning. It is likely the P_2 found here is just a harmonic.

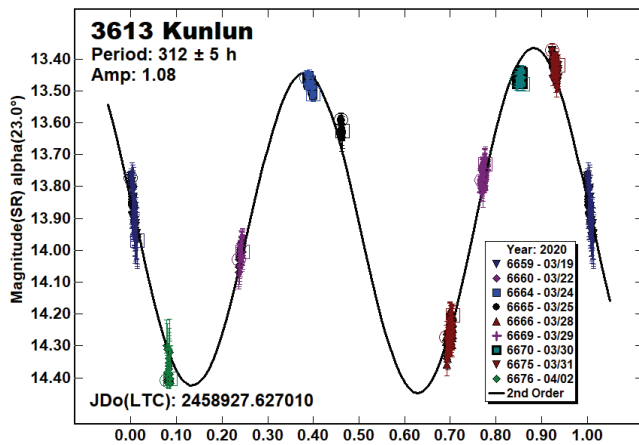
2023 Asaph. This outer main-belt asteroid was observed three times in the past. Behrend (2001web; 2006web) reported a period of 9.19 h ($U = 1$) while Warner (2003) reported a period of 4.74 h. Pál et al. (2020), using data from TESS, reported a period of 88.3197 h. On seeing this new result, we remeasured our images from 2003 using ATLAS SR magnitudes. In 2003, *MPO Canopus* relied on older star catalogs and did not have the Comp Star Selector feature to limit the comparison stars to near solar color. Our new result, although limited by having only four consecutive nights, is close to the Pál et al. result.



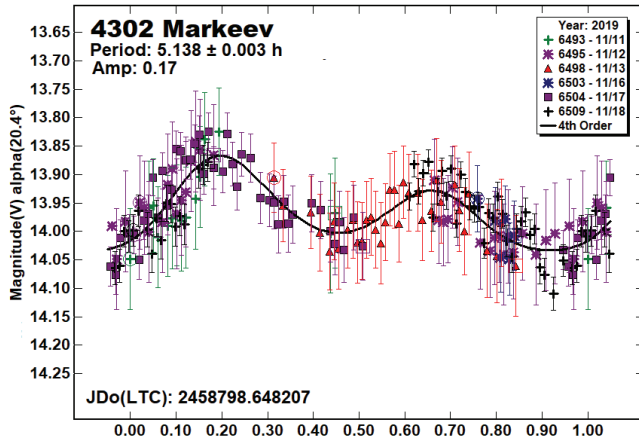
3267 Glo. Pravec et al. (2006web) observed this Mars-crosser and found a synodic rotational period of 6.8782 h. Our period is in good agreement with those results.



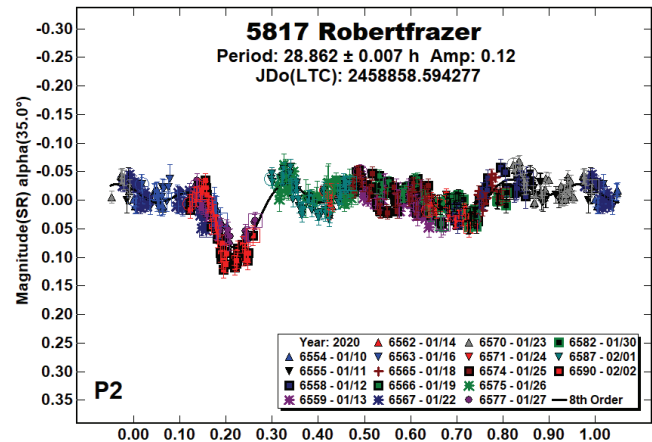
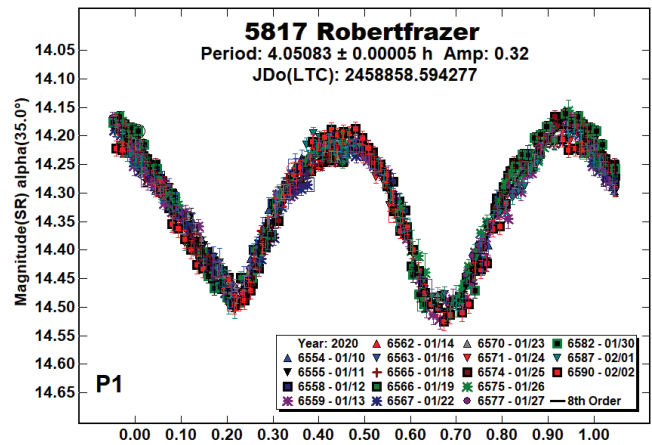
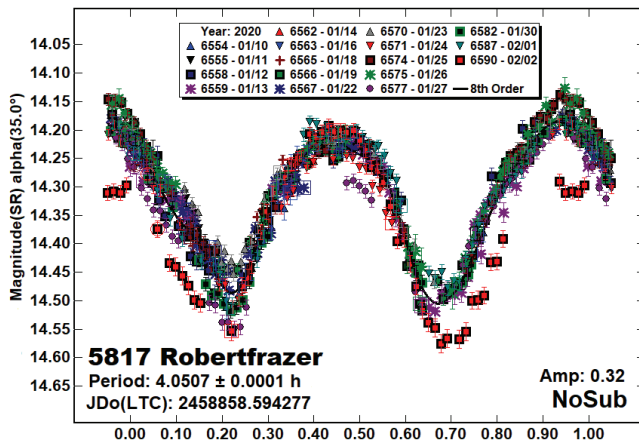
3613 Kunlun. Given the long rotational period, it is not surprising that there are no previously reported lightcurves in the LCDB for this Vestoid. After three weeks of observations, there was sufficient coverage of the lightcurve to have confidence in the primary rotational period, which is longer than the period where tumbling would be more likely than not (Pravec et al., 2005).



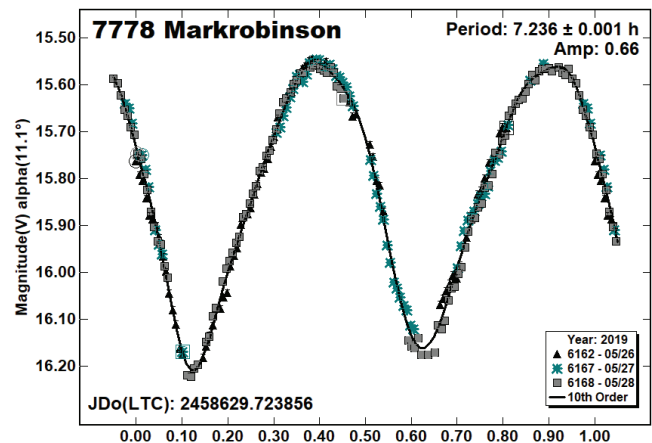
4302 Markeev. The 2019 observations of this 9 km Vestoid escaped publication in our last quarterly article. We previously observed it in 2015 (Stephens, 2016) finding a period of 5.134 h. This year's result is in good agreement.



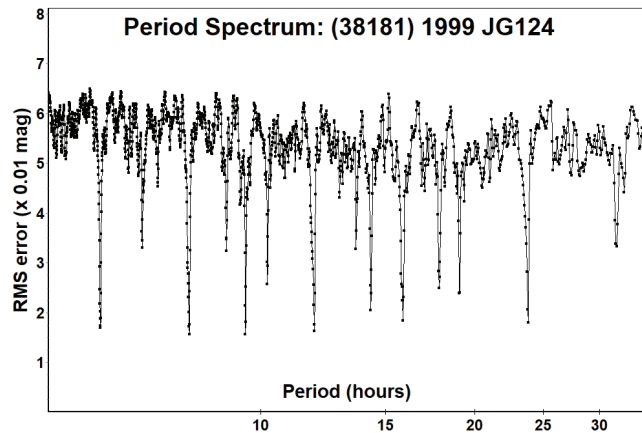
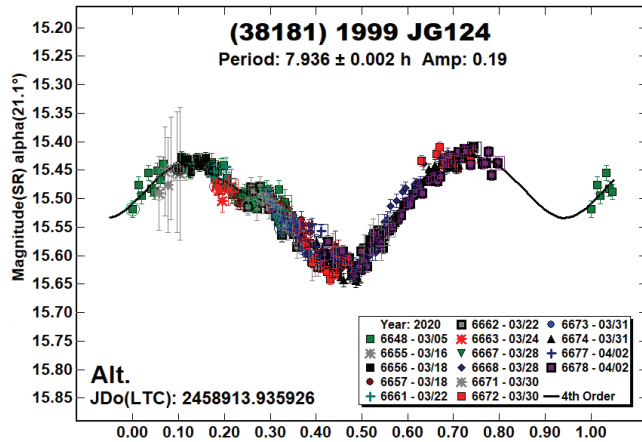
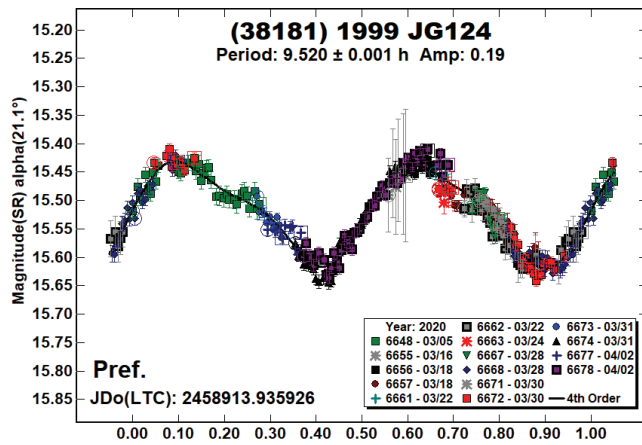
5817 Robertfrazier. Behrend et al. (2004web) and Koff (2005) observed this inner main-belt asteroid determining the rotational period to be 4.051 h. Our initial sessions showed significant deviations that had the traits of *mutual events* (occultations/eclipses) due to a satellite. We used the iterative dual-period search in *MPO Canopus* to find the period of the primary, $P_1 = 4.05083$ h, and reveal the mutual events due to the satellite that has an orbital period of $P_2 = 28.862$ h.



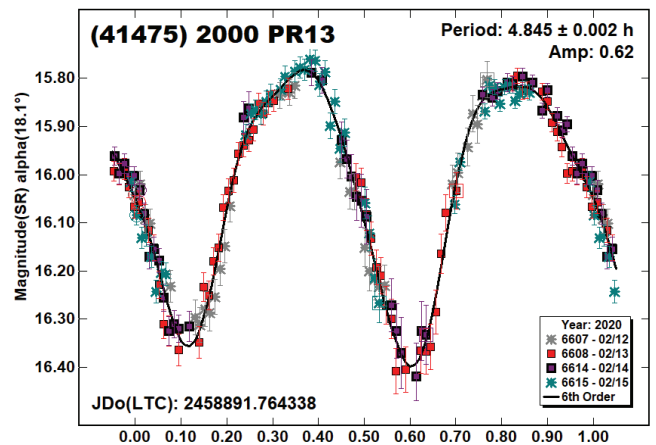
7778 Markrobinson. Behrend (2008web; 2019web) reported periods for this Mars-crosser near 7.23 h. We observed it twice in the past (Warner 2009a; Stephens, 2017) also finding periods near 7.23 h. This year's result is in good agreement with those prior findings and provides additional data for a pole solution.



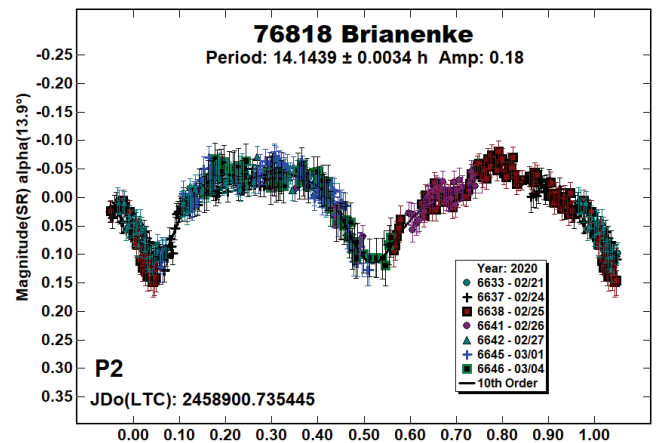
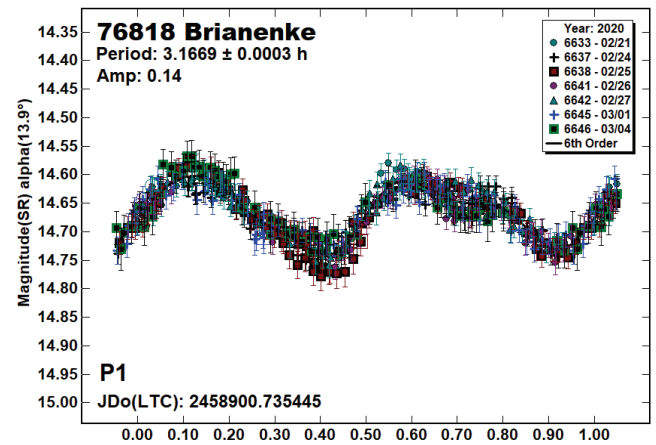
(38181) 1999 JG124. No records were found in the LCDB for this Mars-crosser. Complicating the analysis, winter weather prevented us from getting many consecutive nights of observations. The period spectrum shows many competing aliases, but most were improbable or a fit-by-exclusion. The two periods that seem the most plausible are 9.520 h and 7.936 h. The 7.936 h period is 2/3 of an Earth's day making it impossible to fill in the lightcurve from a single longitude at this opposition. We favor the 9.520 h period because the extrema are 0.50 phase apart and so create a more symmetrical bimodal lightcurve.



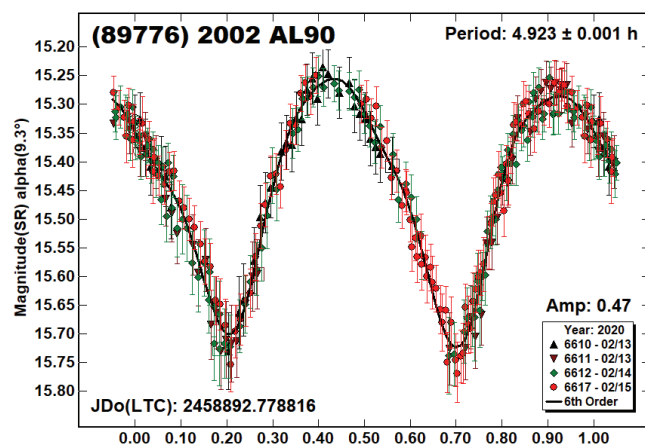
(41475) 2000 PR13. We found no reported lightcurves for this Mars-crosser in the LCDB. Assuming an equatorial view of the asteroid and simple triaxial shape, the 0.62 mag amplitude indicates an a/b ratio of about 1.8:1.



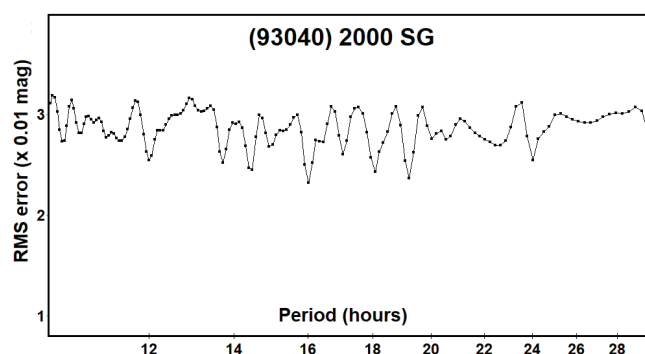
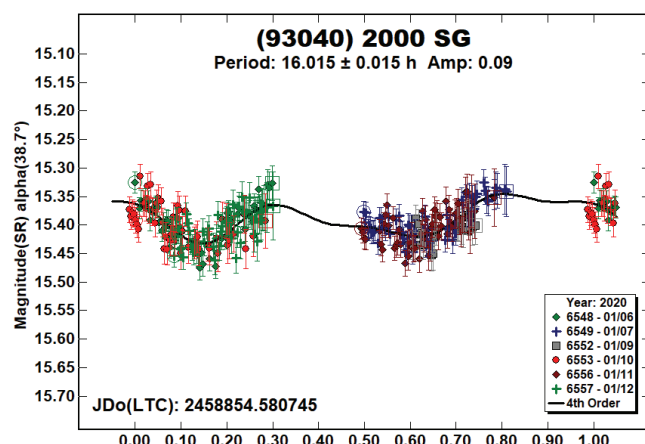
76818 Brianenke. This Hungaria has been well studied in the past, both by us and as part of the Photometric Survey for Asynchronous Binary Asteroids. Pravec et al. (2005web; 2008web) reported a primary period of $P_1 = 3.16639$ h and an orbital period of $P_2 = 14.11960$ h. We previously reported (Warner et al. 2005; 2011; Warner and Stephens, 2009) a primary period of $P_1 = 3.1666$ h and an orbital period of $P_2 = 14.126$ h. To further characterize the system, we undertook observations in 2020 and found primary and orbital periods consistent with prior results.



(89776) 2002 AL90. No records were found in the LCDB for this Mars-crosser, making this another new discovery of an asteroid rotational period from CS3.



(93040) 2000 SG. Per the LCDB, this Mars-crosser does not have a reported rotational period. Because of winter weather and the encroaching Full Moon, we could get only six nights of observations. The period spectrum showed several possible aliases with the most plausible being near 16 hours (2/3 of an Earth's day). Therefore, it was not possible to complete the lightcurve from a single longitude.



Acknowledgements

Observations at CS3 and continued support of the asteroid lightcurve database (LCDB; Warner et al., 2009) are supported by NASA grant 80NSSC18K0851.

This work includes data from the Asteroid Terrestrial-impact Last Alert System (ATLAS) project. ATLAS is primarily funded to search for near earth asteroids through NASA grants NN12AR55G, 80NSSC18K0284, and 80NSSC18K1575; byproducts of the NEO search include images and catalogs from the survey area. The ATLAS science products have been made possible through the contributions of the University of Hawaii Institute for Astronomy, the Queen's University Belfast, the Space Telescope Science Institute, and the South African Astronomical Observatory.

The purchase of a FLI-1001E CCD cameras was made possible by Gene Shoemaker NEO Grants from the Planetary Society (2007, 2013). These were used to purchase some of the telescopes and CCD cameras used in this research.

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Number	Name	2019 mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
463	Lola	02/06-02/11	26.1, 26.3	72	12	6.203	0.002	0.44	0.02	MB-I
914	Palisana	2008 11/07-11/15	10.2, 11.0	40	19	^A 8.686 15.916	0.002 0.005	0.03 0.03	0.01 0.01	PHO
1106	Cydonia	01/06-01/09	19.0, 19.4	45	15	2.678	0.001	0.35	0.03	EUN
1169	Alwine	02/16-03/04	12.1, 19.2	128	-5	2.9274	0.0001	0.32	0.02	FLOR
	Sat. orbital period					13.408	0.002	0.09	0.02	
1589	Fanatica	03/07-03/16	5.2, 3.2	176	7	2.5832	0.0002	0.20	0.02	V
1806	Derice	02/05-02/21	29.1, 28.8	62	1	3.22443	0.0001	0.14	0.01	FLOR
2023	Asaph	2001 11/03-01/05	16.5, 16.8	12.2	9.3	89.2	0.7	0.31	0.02	MB-O
3267	Glo	01/13-01/25	19.9, 24.4	89	-7	6.8778	0.0004	0.39	0.02	MC
3613	Kunlun	03/19-04/02	23.0, 25.6	133	9	312	5	0.08	1.08	V
4302	Markeev	2019 11/11-11/18	20.5, 21.4	356	-4	5.138	0.003	0.17	0.02	V
5817	Robertfrazier	01/10-02/02	35.0, 36.0	70	28	4.05083	5.0001	0.32	0.01	MC
	Sat. orbital period					28.862	0.007	0.12	0.02	
7778	Markrobinson	2019 05/26-05/28	11.1, 10.8	253	14	7.236	0.001	0.66	0.02	MC
38181	1999 JG124	03/05-04/02	*21.2, 22.6	188	25	^A 9.520 7.936	0.001 0.002	0.19 0.19	0.02 0.02	MC
41475	2000 PR13	02/12-02/15	18.1, 19.9	118	-3	4.845	0.002	0.62	0.02	MC
76818	Brianenke	02/21-03/04	13.9, 19.4	137	-15	3.1669	0.0003	0.14	0.01	H
	Sat. orbital period					14.1439	0.0034	0.18	0.01	
89776	2002 AL90	02/13-02/15	9.3, 8.1	157	4	4.923	0.001	0.47	0.02	MC
93040	2000 SG	01/06-01/12	38.7, 39.1	56	28	16.015	0.015	0.09	0.02	MC

Table II. Observing circumstances and results. ^AThe preferred period of an ambiguous solution. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009). For a binary, the first line gives the rotation period of the primary and the second line gives the orbital period of the satellite.

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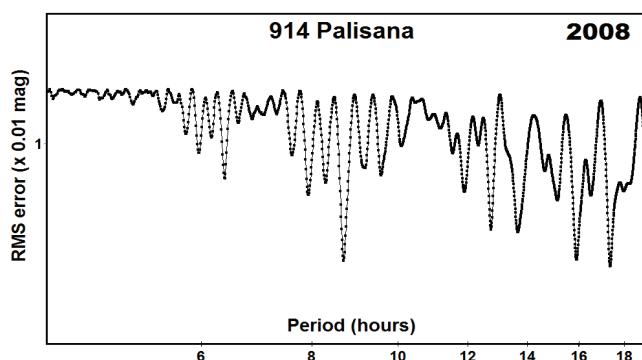
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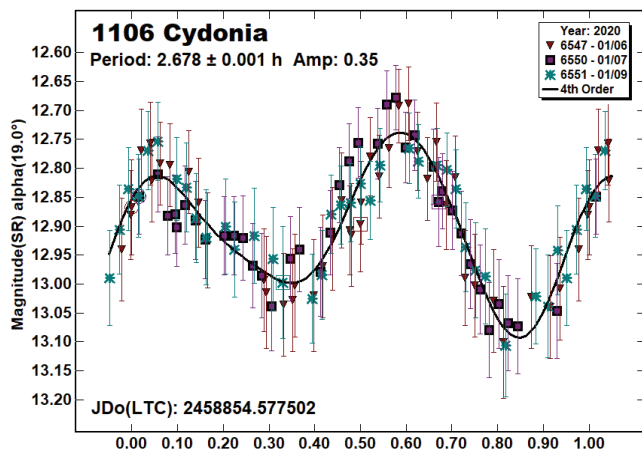
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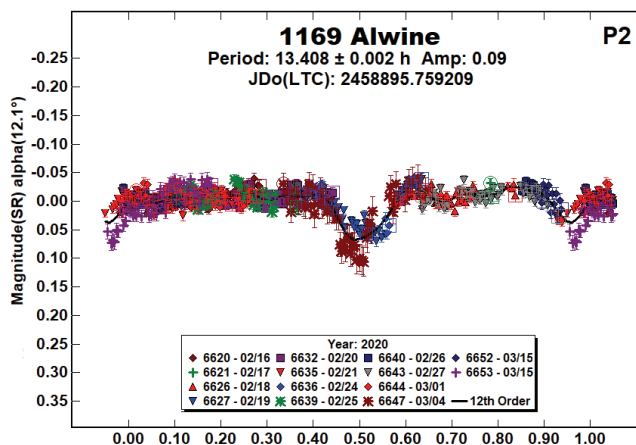
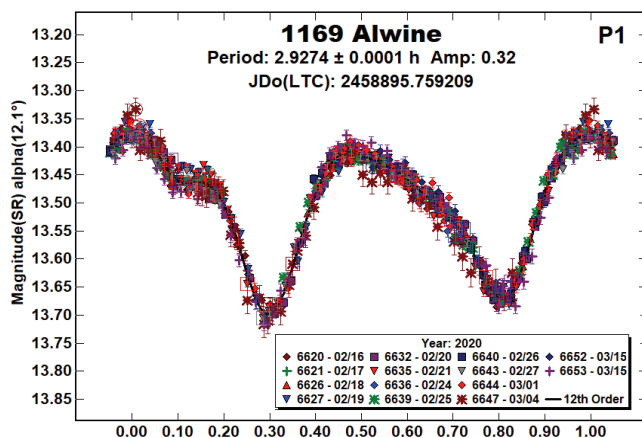


1106 Cydonia. This member of the Eunomia family has been observed twice before. KlingleSmith et al. (2016, 2.679 h) and Aznar (2017, 2.67 h) each found periods similar to our result.

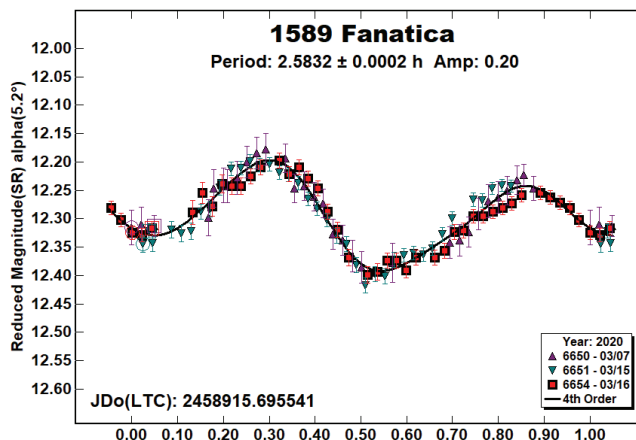


1169 Alwine. This member of the Eunomia family was observed between 2019 December and 2020 March by the Photometric Survey for Asynchronous Binary Asteroids (Pravec, 2020web) as a ‘Prime Suspect’ of being a binary asteroid. They found a primary period of $P_1 = 2.9274$ h and several attenuations that only roughly fit an orbital period of $P_2 = 54.45$ h.

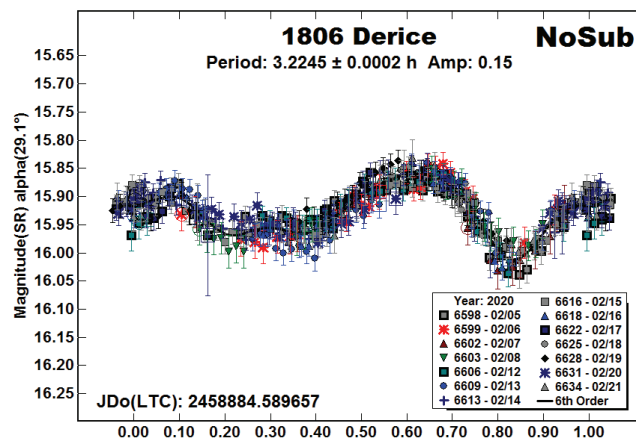
We observed it from 2020 February to March and used the iterative dual-period search in *MPO Canopus* to find a primary period of $P_1 = 2.9274$ h and reveal the mutual events due to the satellite with an orbital period of $P_2 = 13.408$ h. Our fit was also not very good and is a 4:1 alias of the Pravec P_2 result. The next good opposition for the northern hemisphere will be in 2022 October.

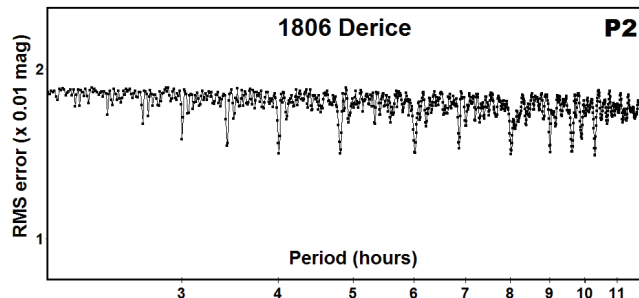
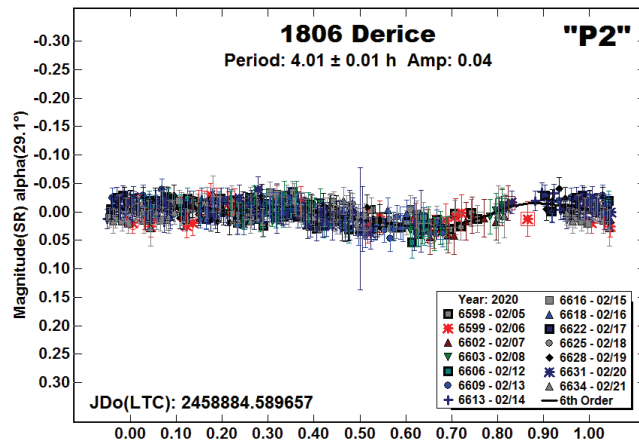
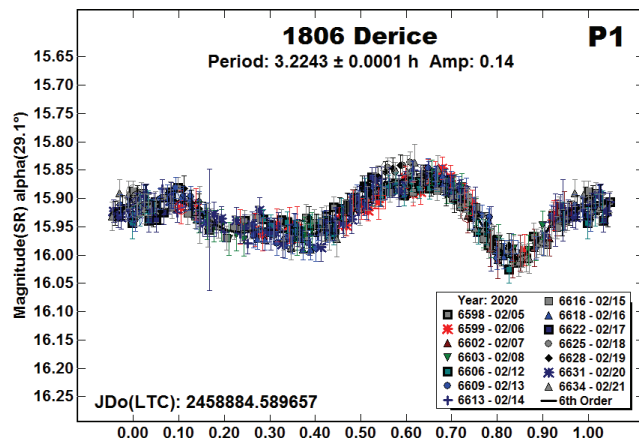


1589 Fanatica. We observed this Vestoid three times in the past (Warner, 2004; Stephens, 2015; Stephens and Warner, 2019) each time finding a period near 2.58 h. This year’s result is in good agreement with those prior findings.



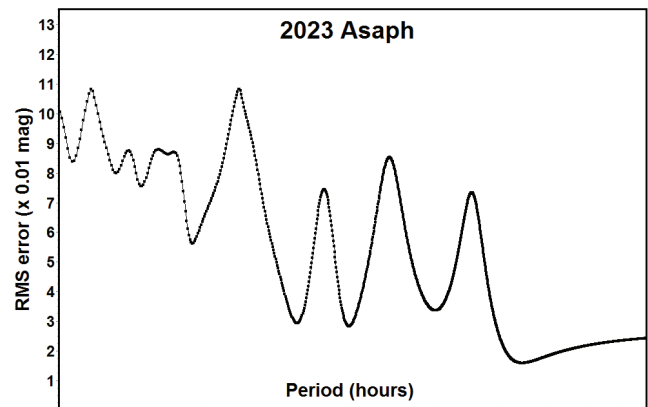
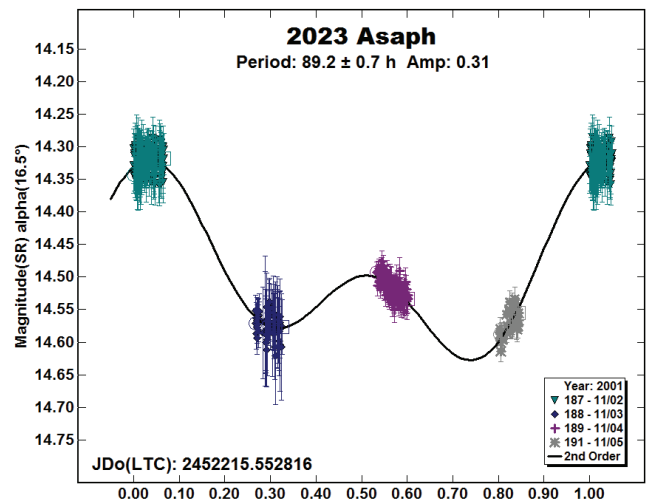
1806 Derice. This member of the Flora family has been observed several times by the Photometric Survey for Asynchronous Binary Asteroids (Pravec, 2009web; 2011web; 2012web; 2016web) as being a ‘Prime Suspect’ of being a binary asteroid. In the 2009 data, minor deviations from the curve suggested the presence of attenuation events, but an orbital period could not be determined. At each opposition the survey found a primary rotational period near 3.224 h.



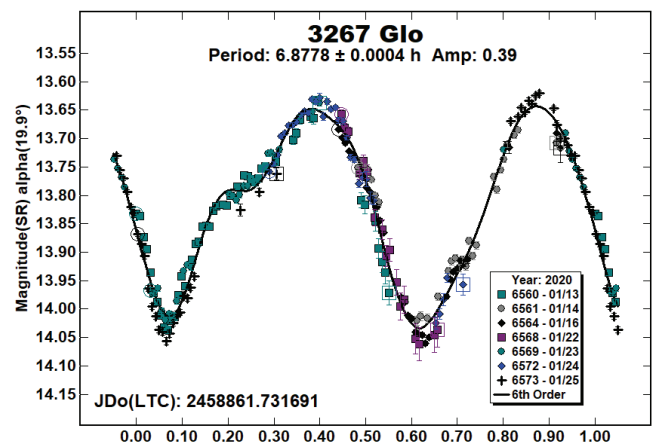


Our data in 2020 February also showed slight deviations from the curve. While promising at the start, more data made the solution increasingly unlikely. Running the dual-period search in *MPO Canopus* acted more as a “noise filter” with P_2 having no physical meaning. It is likely the P_2 found here is just a harmonic.

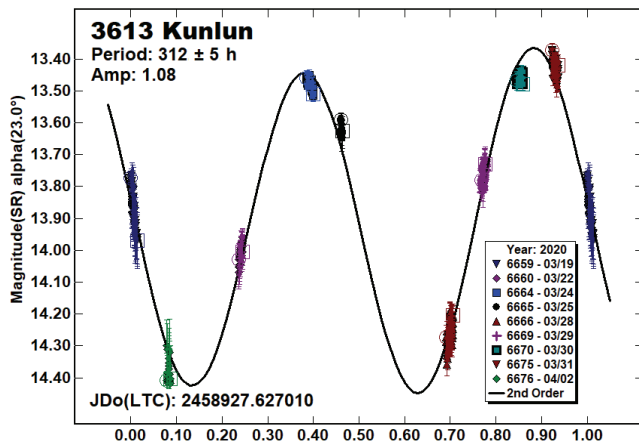
2023 Asaph. This outer main-belt asteroid was observed three times in the past. Behrend (2001web; 2006web) reported a period of 9.19 h ($U = 1$) while Warner (2003) reported a period of 4.74 h. Pál et al. (2020), using data from TESS, reported a period of 88.3197 h. On seeing this new result, we remeasured our images from 2003 using ATLAS SR magnitudes. In 2003, *MPO Canopus* relied on older star catalogs and did not have the Comp Star Selector feature to limit the comparison stars to near solar color. Our new result, although limited by having only four consecutive nights, is close to the Pál et al. result.



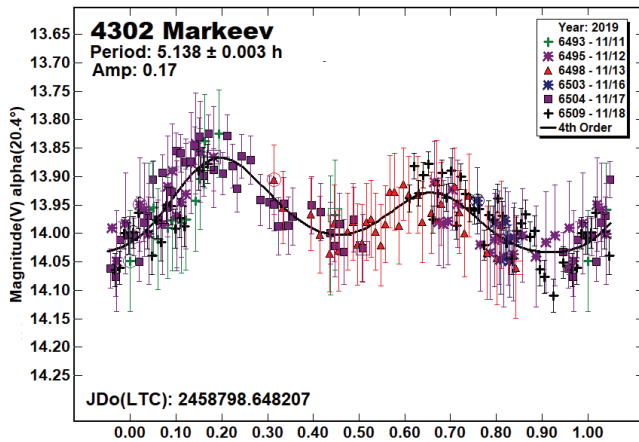
3267 Glo. Pravec et al. (2006web) observed this Mars-crosser and found a synodic rotational period of 6.8782 h. Our period is in good agreement with those results.

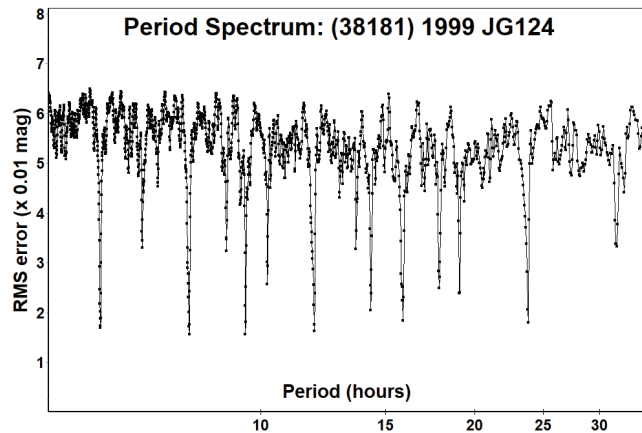
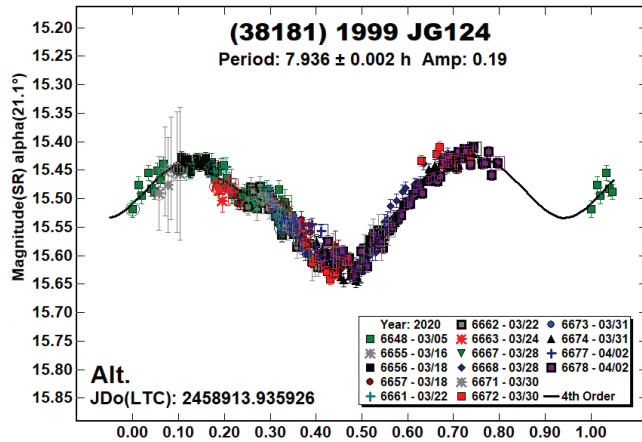
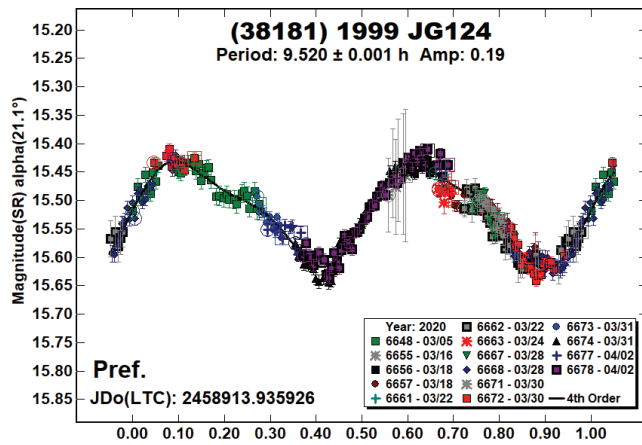


3613 Kunlun. Given the long rotational period, it is not surprising that there are no previously reported lightcurves in the LCDB for this Vestoid. After three weeks of observations, there was sufficient coverage of the lightcurve to have confidence in the primary rotational period, which is longer than the period where tumbling would be more likely than not (Pravec et al., 2005).

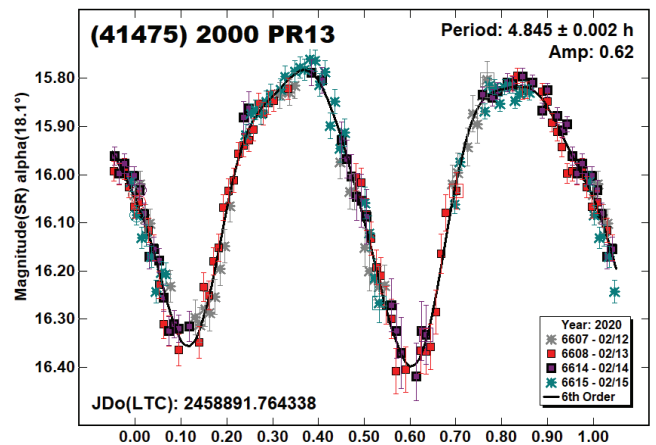


4302 Markeev. The 2019 observations of this 9 km Vestoid escaped publication in our last quarterly article. We previously observed it in 2015 (Stephens, 2016) finding a period of 5.134 h. This year's result is in good agreement.

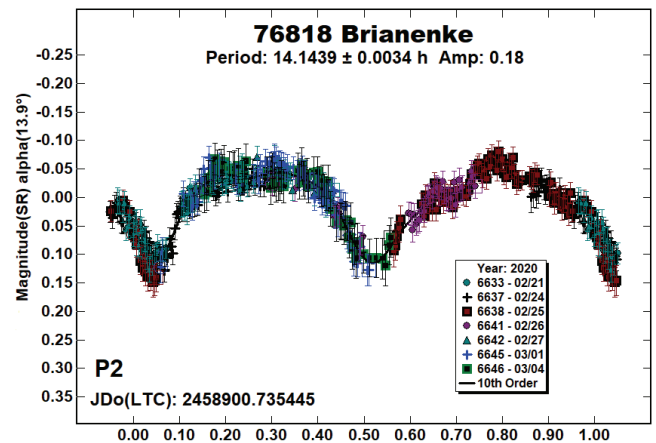
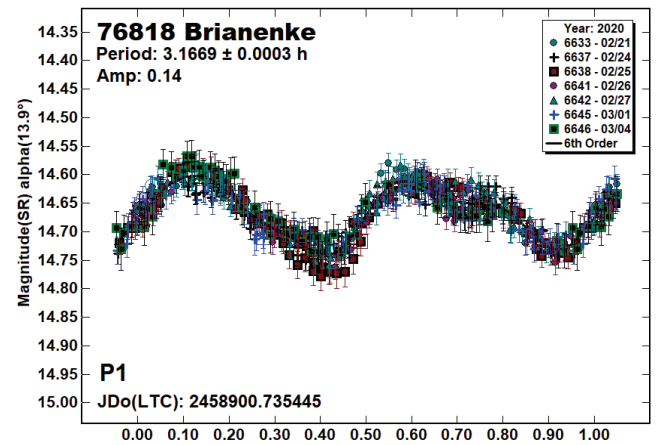




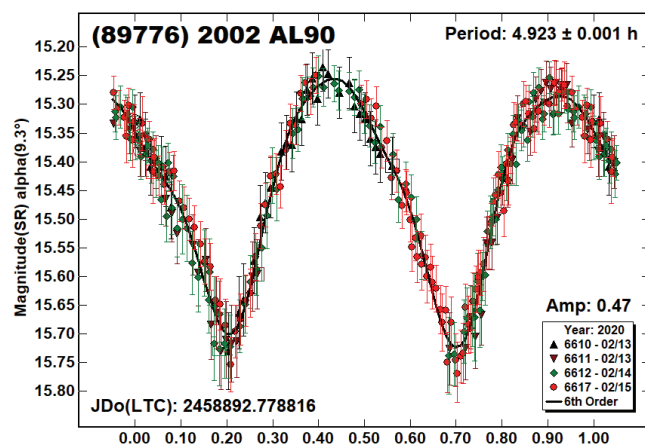
(41475) 2000 PR13. We found no reported lightcurves for this Mars-crosser in the LCDB. Assuming an equatorial view of the asteroid and simple triaxial shape, the 0.62 mag amplitude indicates an a/b ratio of about 1.8:1.



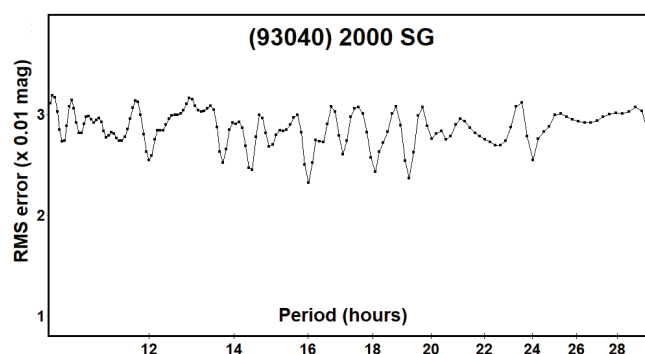
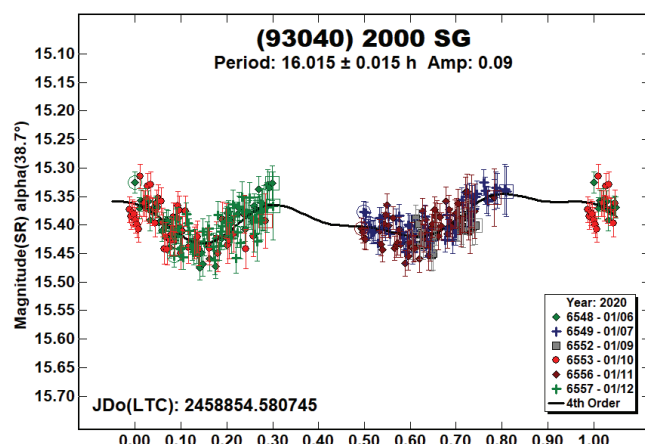
76818 Brianenke. This Hungaria has been well studied in the past, both by us and as part of the Photometric Survey for Asynchronous Binary Asteroids. Pravec et al. (2005web; 2008web) reported a primary period of $P_1 = 3.16639$ h and an orbital period of $P_2 = 14.11960$ h. We previously reported (Warner et al. 2005; 2011; Warner and Stephens, 2009) a primary period of $P_1 = 3.1666$ h and an orbital period of $P_2 = 14.126$ h. To further characterize the system, we undertook observations in 2020 and found primary and orbital periods consistent with prior results.



(89776) 2002 AL90. No records were found in the LCDB for this Mars-crosser, making this another new discovery of an asteroid rotational period from CS3.



(93040) 2000 SG. Per the LCDB, this Mars-crosser does not have a reported rotational period. Because of winter weather and the encroaching Full Moon, we could get only six nights of observations. The period spectrum showed several possible aliases with the most plausible being near 16 hours (2/3 of an Earth's day). Therefore, it was not possible to complete the lightcurve from a single longitude.



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Observations at CS3 and continued support of the asteroid lightcurve database (LCDB; Warner et al., 2009) are supported by NASA grant 80NSSC18K0851.

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