MAIN-BELT ASTEROIDS OBSERVED FROM CS3: 2019 APRIL TO JUNE

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CCD photometric observations of 19 main-belt asteroids were obtained at the Center for Solar System Studies (CS3) from 2019 April to June.

The Center for Solar System Studies (CS3) has seven telescopes which are normally used for specific topic studies. The usual 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 primary targets being studied, targets of opportunity amongst the main-belt regions 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
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
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 CMC-15 or the ATLAS catalog (Tonry et al., 2018), which has Sloan *griz* magnitudes that were derived from the GAIA and Pan-STARR catalogs, among others. The authors state that systematic errors are generally no larger than 0.005 mag, although they can reach 0.02 mag in small areas near the Galactic plane. BVRI magnitudes were derived by Warner using formulae from Kostov and Bonev (2017). The overall errors for the BVRI magnitudes, when combining those in the ATLAS catalog and the conversion formulae, are on the order of 0.04-0.05 mag.

Even so, we found in most cases that nightly zero point adjustments for the ATLAS catalog to be on the order of only 0.02-0.03 mag were required during period analysis. There were occasional exceptions that required up to 0.10 mag. These may have been related in part to using unfiltered observations, poor centroiding of the reference stars, and not correcting for second-order extinction terms. Regardless, the systematic errors seem to be considerably less than other catalogs, which reduces the uncertainty in the results when analysis involves data from extended periods or the asteroid is tumbling.

In the lightcurve plots, the "Reduced Magnitude" is Johnson V corrected to a unity distance by applying $-5*\log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and the Earth-asteroid distances in AU. The magnitudes were normalized to the phase angle given in parentheses using $G = 0.15$. The X-axis rotational phase ranges from –0.05 to 1.05.

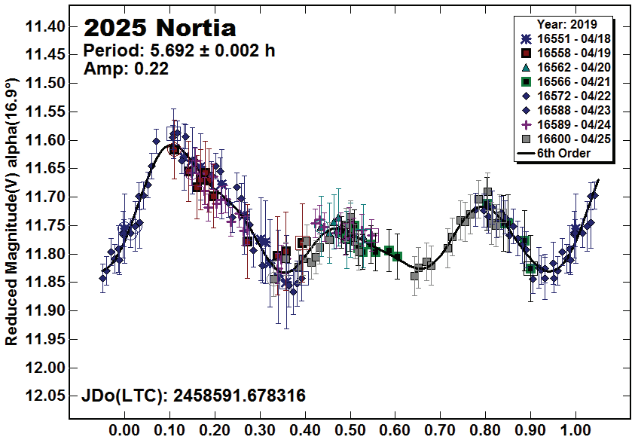
The amplitude indicated in the plots (e.g. Amp. 0.23) is the amplitude of the Fourier model curve and not necessarily the adopted amplitude of the lightcurve.

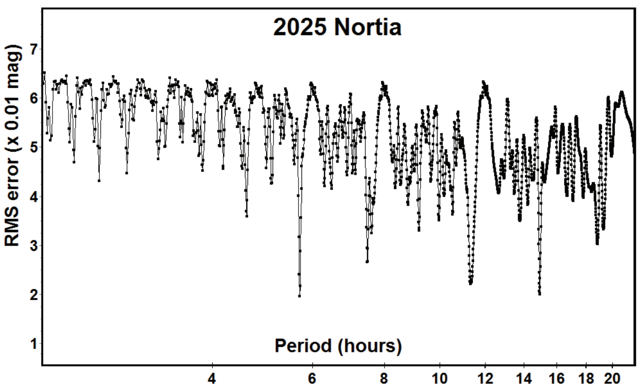
For brevity, only some of the previously reported rotational periods may be referenced. A complete list is available at the lightcurve database (LCDB; Warner et al., 2009).

Number	Name	2019 mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
2025	Nortia	04/18-04/22	17.0,17.1	136	1	5.522	0.002	0.33	0.03	MB-O
2378	Pannekoek	04/22-04/27	4.0,5.5	205	8	11.874	0.003	0.19	0.01	MB-O
2510	Shandong	06/08-06/18	20.1,23.6	223	5	5.949	0.001	0.29	0.04	FLOR
2778	Tangshan	06/09-06/11	17.2,17.8	220	4	3.468	0.003	0.26	0.02	FLOR
4160	Sabrina-John	04/21-04/25	25.2,25.5	145	-3	5.735	0.002	0.41	0.03	V
4892	Chrispollas	04/21-05/18	*25.4,28.4	167	-7	1584	16	0.71	0.05	MB-I
5627	1991 MA	04/15-04/18	*21.7,20.8	266	16	5.365	0.002	0.48	0.03	H
6310	Jankonke	06/08-06/10	22.7,23.3	224	15	3.071	0.002	0.18	0.01	H
6859	Datemasamune	06/11-06/28	31.4,27.4	312	20	5.944	0.001	0.12	0.01	H
9564	Jeffwynn	05/24-05/25	26.2,26.1	263	32	3.03	0.003	0.11	0.02	MC
10480	Jennyblue	04/24-04/26	24.3,24.6	159	3	5.356	0.003	0.92	0.03	FLOR
20936	Nemrut Dagi	05/18-05/21	23.0,24.1	198	-1	3.328	0.002	0.26	0.02	H
32772	1986 JL	05/14-05/24	9.4,12.0	228	12	6.046	0.001	0.25	0.03	H
33324	1998 QE56	06/01-06/06	24.8,24.7	261	35	6.188	0.001	0.64	0.02	H
53440	1999 XQ33	06/09-06/25	21.3,23.3	248	26	5.3276	0.0005	0.34	0.04	H
55854	Stoppani	06/11-06/25	26.3,28.7	214	2	3.06	0.001	0.45	0.03	H
66346	1999 JU71	05/14-05/22	4.7,8.4	229	7	5.233	0.004	0.14	0.03	FLOR
162820	2001 BK36	03/16-03/17	3.4,3.2	178	-5	3.95	0.01	0.33	0.03	EUN
302111	2001 MM3	06/06-06/08	25.5,25.6	274	31	3.217	0.001	0.38	0.03	MC

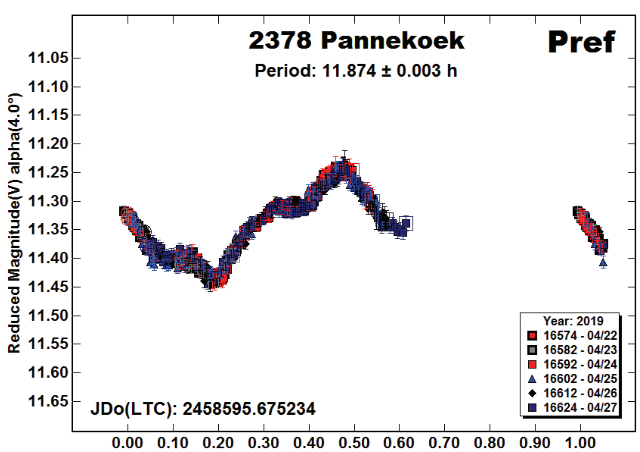
Table II. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009).

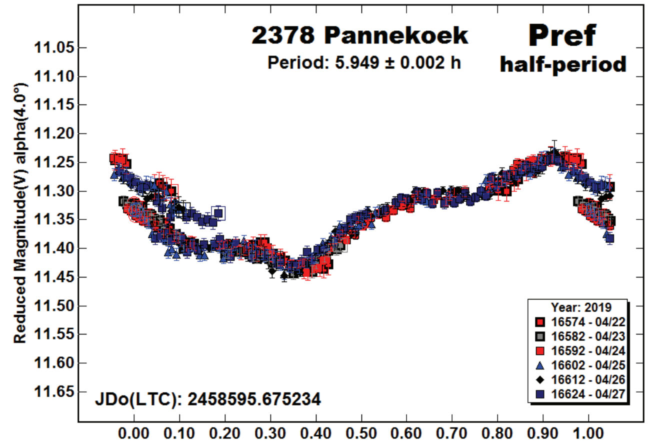
2025 Nortia. The LCDB listed no previous rotation periods for this outer main-belt asteroid. Assuming an albedo of 0.057, the estimated diameter is 40 km. The lightcurve shows three maximums. This is unusual but possible with low amplitudes and phase angles (Harris et al., 2014).

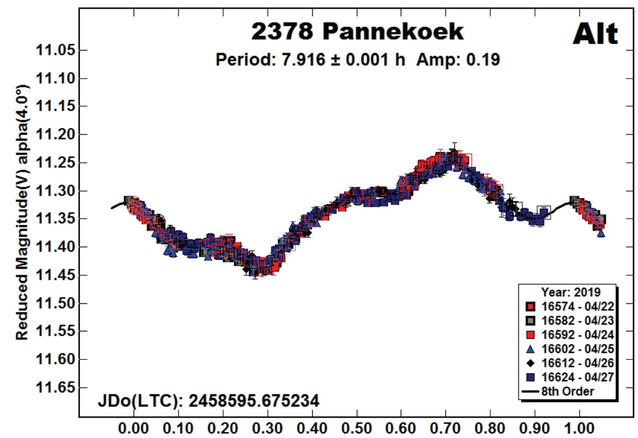




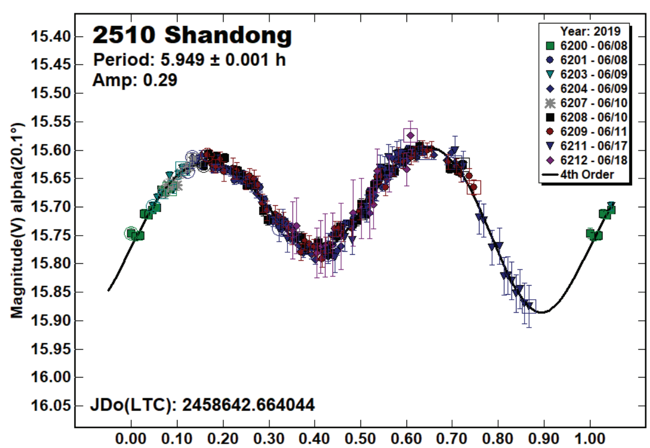
2378 Pannekoek. Previous results gave 5.943 h (Higgins, 2008) and 11.8806 h (Oey 2011 web), for this outer main-belt asteroid. Our results from 2019 show several aliases with our preference for $P = 11.874$ h even though the lightcurve is missing about 30% of a full rotation. This is based on the half-period plot showing the asymmetry of the full period solution. The spacing of extrema doesn't seem right for the near 7.9 h solution, but because of the amplitude, an unusual shape cannot be formally excluded (Harris et al., 2014), especially when the period spectrum shows sharp RMS minimums near 6 and 8 hours.



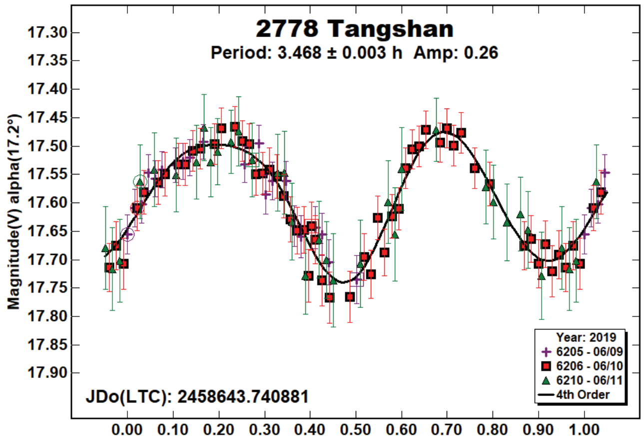




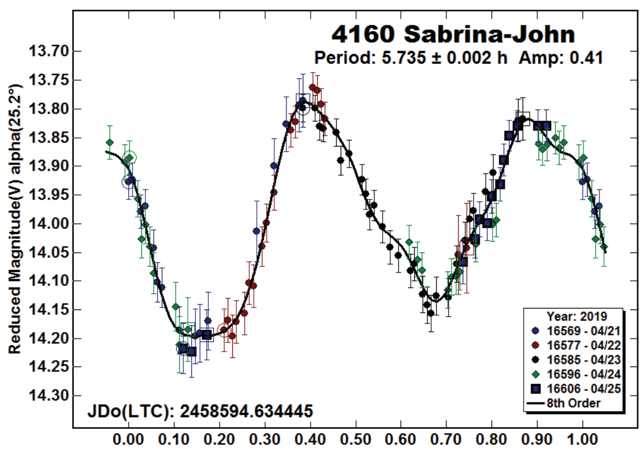
2510 Shandong. This inner main-belt asteroid has a diameter of about 9 km. Higgins and Goncalves (2007) found a period of 5.9463 h. Using a combination of dense and sparse lightcurve data, Hanus et al. (2013) found $P_{sidereal} = 5.94639$ h and a preferred spin axis with ecliptic coordinates λ,β = (256°, 27°)



2778 Tangshan. Rotational periods for this member of the Flora group near 3.46 h have been reported twice before (Behrend et al., 2018, Warner, 2004). The result found this year is in good agreement.

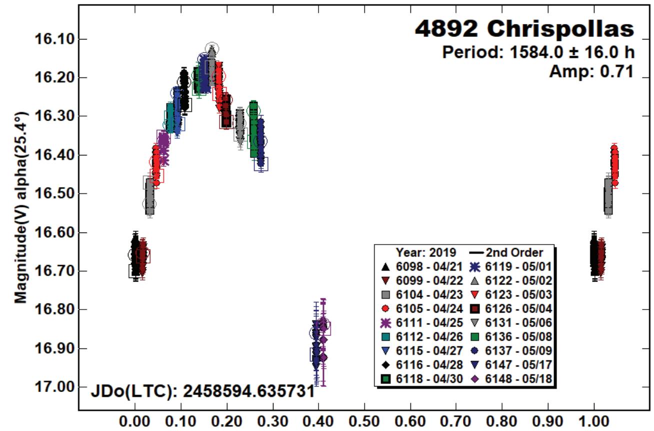


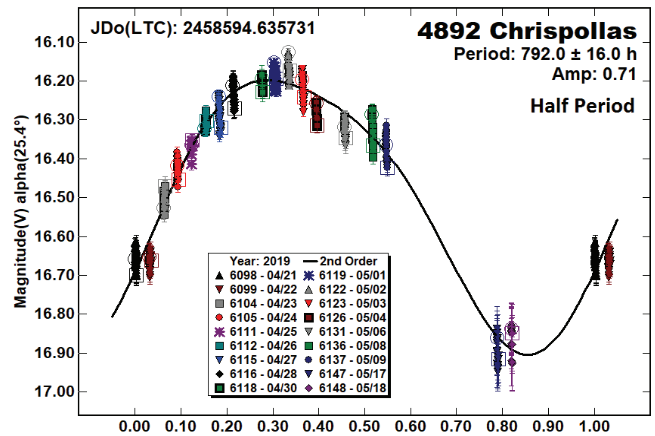
4160 Sabrina-John. This appears to be the first rotation period for Sabrina-John, which is classified as a Vestoid (i.e., possibly a fragment off Vesta) with a diameter of about 7 km.



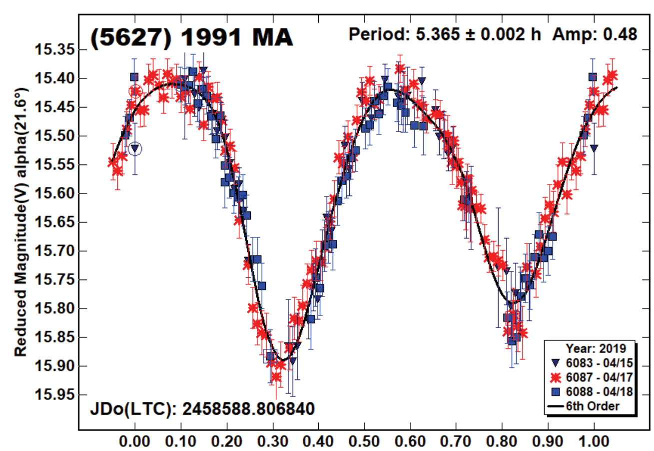
4892 Chrispollas. This 8-km inner main-belt asteroid had no previously reported period in the LCDB. There may be good reason for that: the extremely long period that we report here. In our data, night-to-night runs showed almost no ascending or descending trend. Given limited telescope time for many, this might have led most observers to give up in lieu of working other targets that had better opportunities for success.

Our program is dedicated to working potentially long-period objects until it is certain that the data are "flat" (low amplitude) or at least an approximate estimate of the period can be found. Even so, it was not possible to follow this asteroid long enough to obtain a full lightcurve and so our result is based on the presumed monomodal lightcurve at the half-period (Harris et al., 2014). Even this lightcurve is incomplete and so the true error in the resulting full-period is probably larger than the formal value given here. Because of the long period and estimated diameter, this is a good candidate for tumbling (Pravec et al., 2014; 2005). There are some indications of this with at least two sessions falling below the Fourier curve.

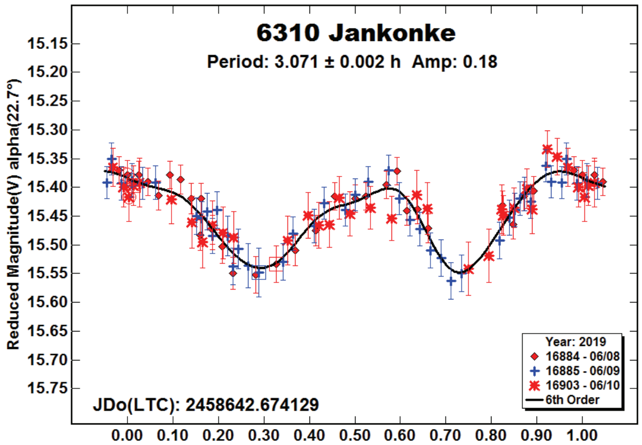




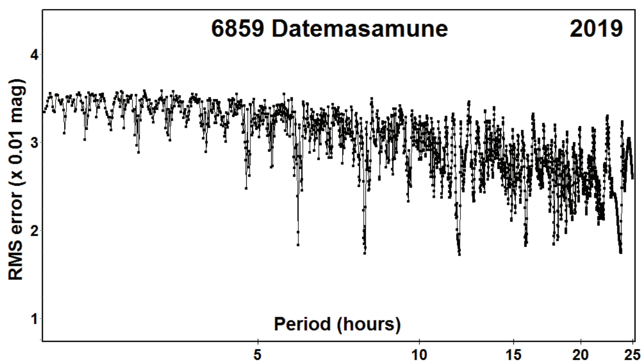
(5267) 1991 MA. Our result is about 0.15 h longer than previous results: Waszczak et al. (2015) and Zeigler et al. (2017). The former is a survey with a "dense sparse" data set. Zeigler et al. had two non-consecutive nights that produced a lightcurve that did not have full double coverage. For these reasons, we have high confidence in our result.

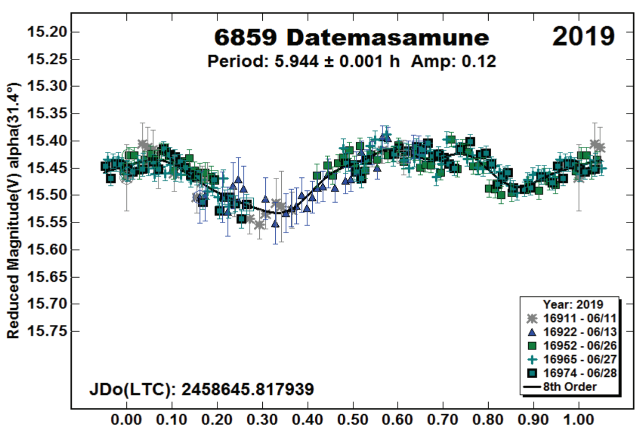


6310 Jankonke is a Hungaria asteroid that has been observed at several previous apparitions, in particular by Warner (see LCDB references) as part of an on-going project to find spin axes for members of the group. The period given here is consistent with previous results; the data should improve a preliminary spin axis.



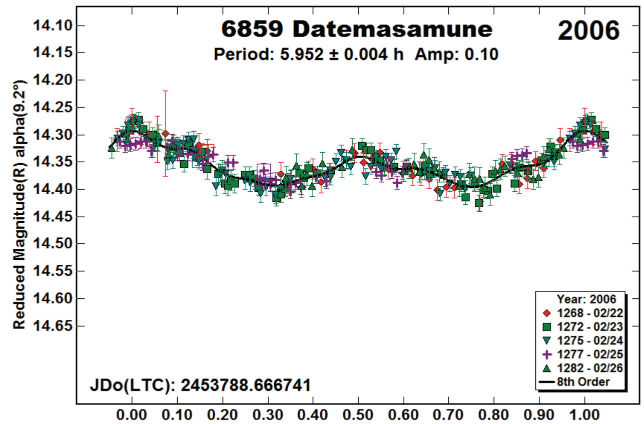
6859 Datemasamune is another Hungaria member that is part of the spin axis project. Finding the period has been difficult because of amplitudes < 0.2 mag. Previous results by Warner are 2006, 12.95 h; 2010, 22.1 h; 2011, 86.1 h.; and 2016b, 5.2879 h. The 2019 data excluded the very long periods and favored one close to the 2016 result. We have adopted the 2019 period of 5.944 h, but other solutions cannot be formally excluded.

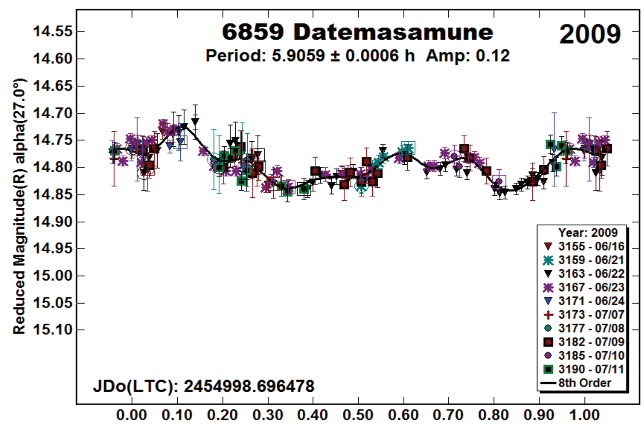


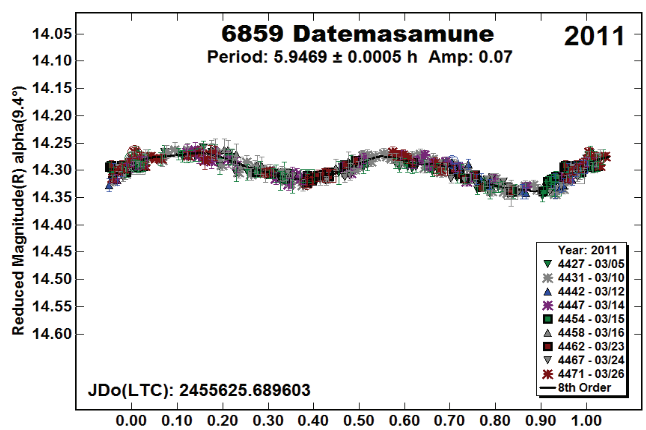


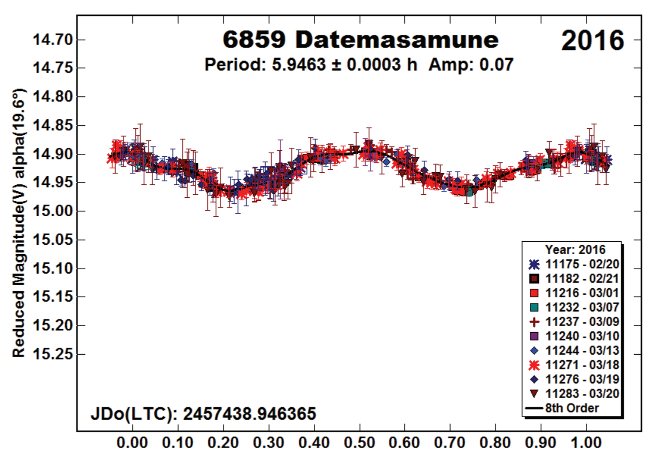
The data sets from 2006-2016 were reanalyzed to see if they would support the adopted period given here. The fits in 2006, 2011, and 2016 are very plausible. The 2009 data set was somewhat noisy and so the fit to the new period is not as convincing.

We note that having the ATLAS star catalog with highly-reliable magnitudes played an important role in our 2019 analysis because there was high confidence in zero point matching from night-to-night. In previous years, as can be seen with the wide range of periods, zero point adjustments were much more arbitrary.

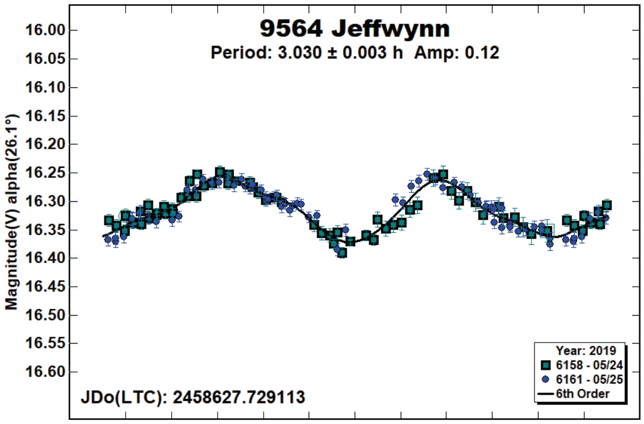




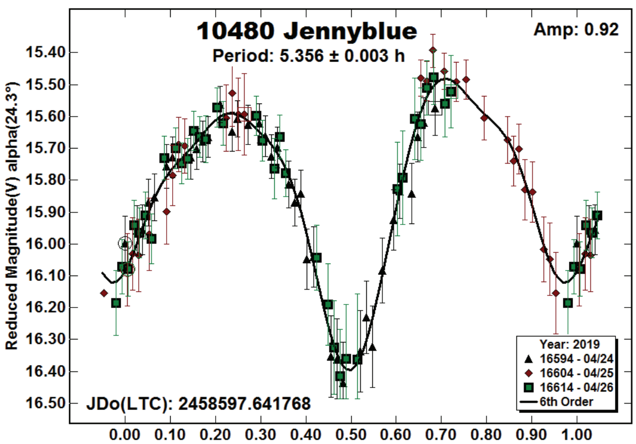




9564 Jeffwynn. The only previously reported period (3.035 h) was by Warner (2013a). Our most recent result is in good agreement.

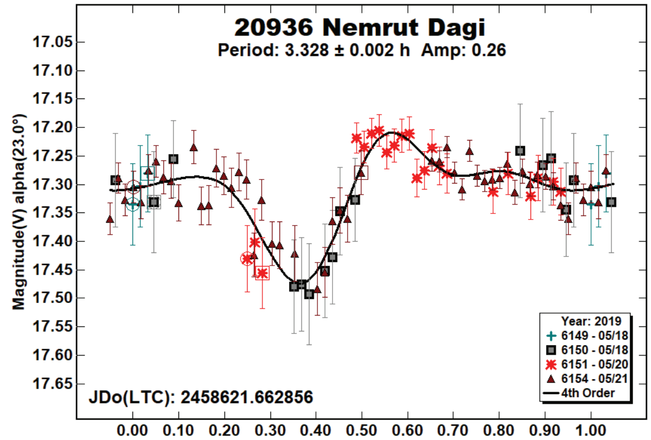


10480 Jennyblue. This was a target of opportunity in the field of a Hilda asteroid. Waszczak et al. (2015) found a period of 6.019 h. Forcing the 2019 data to something near that has the maximums only 0.4 rotation phase apart. There's a good chance of a *rotational alias* being involved since the two periods differ by almost exactly 0.5 rotations over 24 hours. Given the sparser data set used by Waszczak et al., it's reasonably safe to adopt our period of 5.356 h as the more likely.

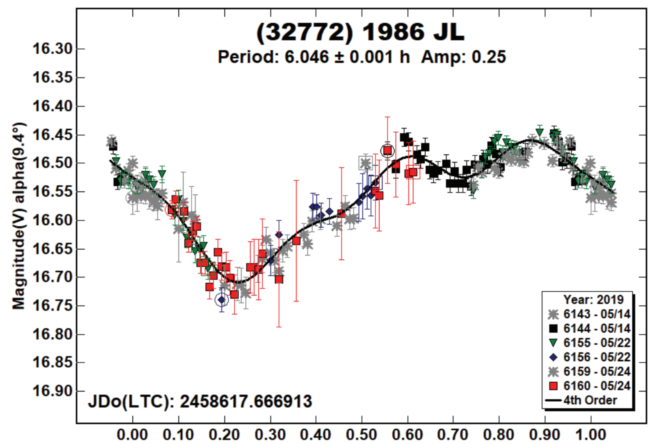


20936 Nemrut Dagi. There are several previous results in the LCDB for this 5-km Hungaria, e.g. Skiff (2011, 3.293 h) and Warner (2016a, 3.2754 h). Our data set was relatively sparse compared to others, enough that we had to force the period search to a small range covering a range a little larger than the full range of reported periods.

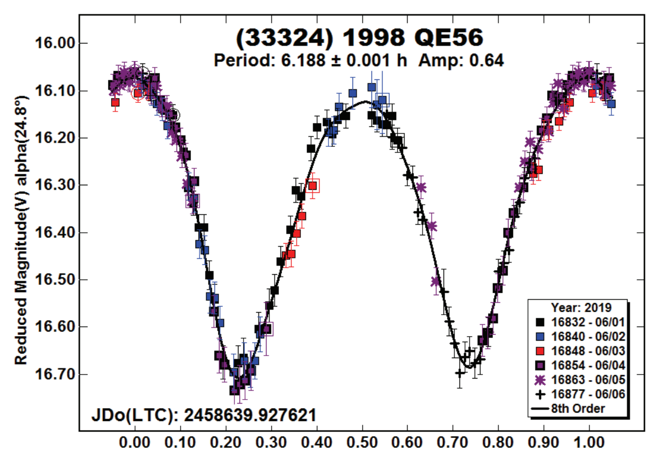
While the 2019 data can be fit to 3.328 h, the solution is hardly conclusive. Regardless, the data will be used to try to improve a preliminary spin axis.



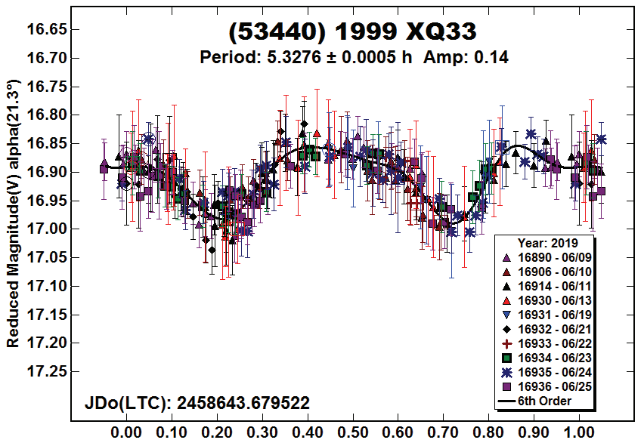
(32772) 1986 JL. We observed this twice before: Warner (2013c) and Stephens (2016). Those two and our result are in excellent agreement. The seemingly monomodal solution in 2019 is unusual given the amplitude, but not impossible (Harris et al., 2014).



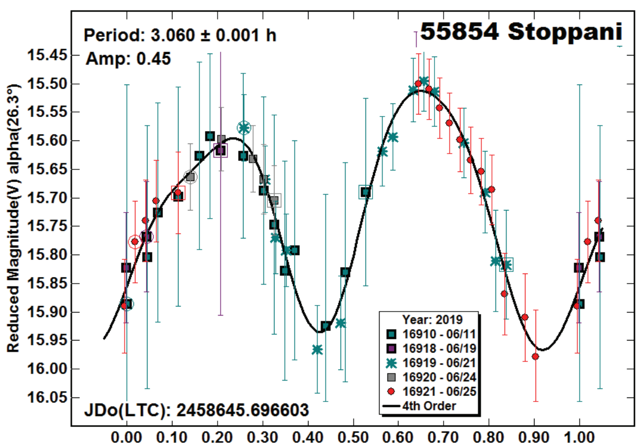
(33324) 1998 QE56. The latest data set extends our dense lightcurve observations from 2011 to 2019 (see LCDB references). As a result, we hope that, combined with sparse data, a good spin axis model can be developed.



(53440) 1999 XQ33. This appears to be the first reported rotation period for 1999 XQ33. It is another member of the Hungaria group. It would be required to determine its taxonomic class before calling it a family member.

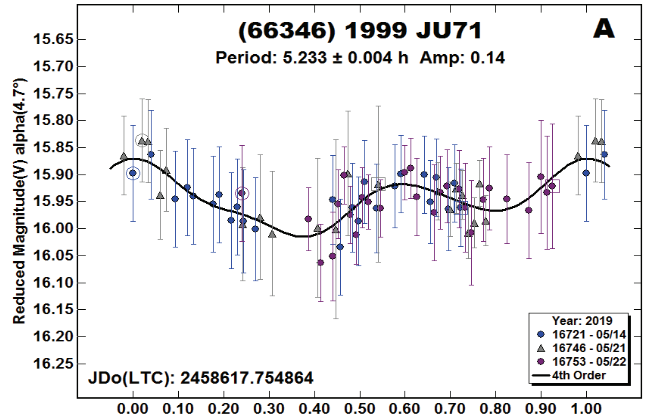


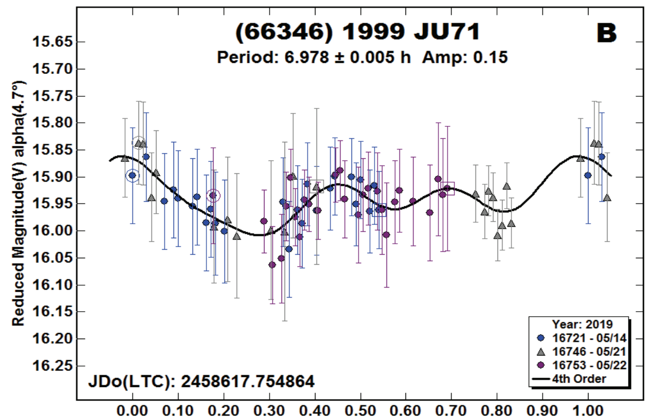
55854 Stoppani. Previous results from Skiff (2011) and Warner (2011, 2013b) are all in close agreement with our 2019 analysis. Were it not for the large amplitude overcoming the noisy data on some nights, it may not have been possible to find a period.



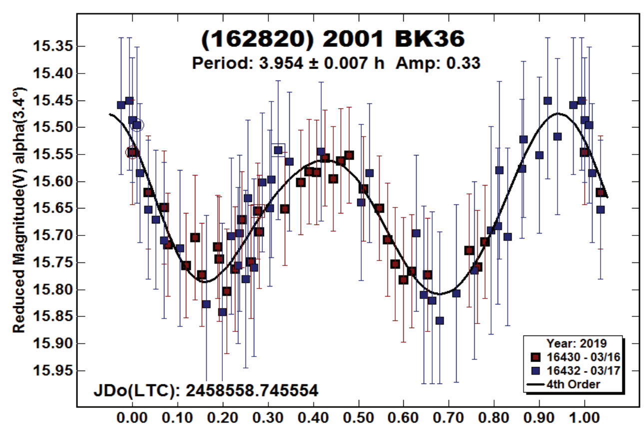
(66346) 1999 JU71. This is a member of the Flora group but it could actually belong to one of the subgroups in the region. The estimated diameter, assuming $p_V = 0.24$, is 2.3 km. There were no previously reported periods in the LCDB to serve as a starting point for analysis. Unfortunately, the data set was too noisy and too sparse to allow finding a definitive solution.

We show two plots phased to two of the possible solutions. Both have gaps in coverage, which might imply a *fit by exclusion*, which is when the Fourier algorithm finds a local RMS minimum that minimizes the number of overlapping data points. The two periods do not seem to be harmonically related.

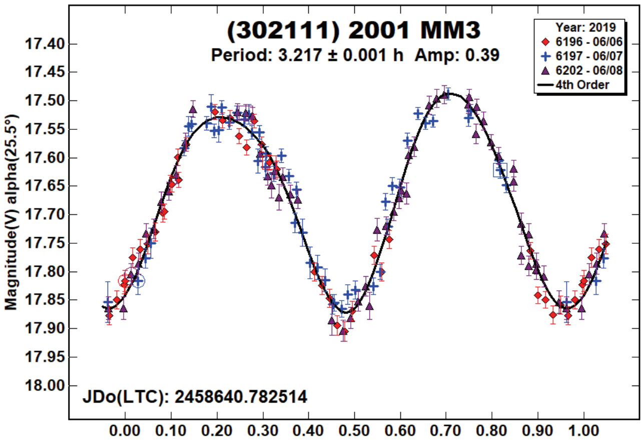




(162820) 2001 BK36. Assuming a default albedo of 0.21 for Eunomia group (or at least region) members gives an estimated diameter of 2.5 km. However, Mainzer et al. (2016) found the asteroid to have an albedo of 0.062. Using $H = 15.10$, this gave a diameter of 4.8 km.



(302111) 2001 MM3. We observed this Mars-crosser for three nights in 2019 June. The resulting data was of high quality and almost covered the adopted period of 3.217 h completely each night. That and the large amplitude make the period solution secure. There were no previous period results in the LCDB.



Acknowledgements

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1744 HARRIET: ANOTHER VERY SLOWLY ROTATING ASTEROID

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Minor planet 1744 Harriet has a synodic rotation period near 724 hours, amplitude increasing from 0.95 ± 0.05 magnitudes to 1.10 ± 0.05 magnitudes.

The Asteroid Lightcurve Data Base (Warner et al., 2009) lists no previous observations of 1744 Harriet. First author Pilcher found very slow magnitude change in his first three nights of observation 2019 Apr. 11-14 and recognized that 1744 Harriet has a very long rotational period. He invited Daniel Klinglesmith and Julian Oey to collaborate in obtaining a long series of observations. Both graciously accepted the invitation and contributed many useful sessions.

Pilcher at Organ Mesa Observatory used a Meade 0.35 meter f/10 Meade LX200 GPS SCT and SBIG STL-1001E CCD to obtain sessions 860, 861, 863, 865, 867, 869, 874, 875, 885, 887, 888, 893, 896, 898, 902, 903, 904, 916, 920, 923, 925, 926, 930. 936, 937, 941, 944, 950. Klinglesmith at Etscorn Campus Observatory used a 0.35 cm Celestron SCT and SBIG STL-11000M CCD to obtain sessions 870, 872, 873, 889, 897, 899, 901, 918, 928, 929, 932, 938, 945, 946, 947, 948, 949. Oey at Blue Mountains Observatory used a 14 inch Schmidt Cassegrain telescope and SBIG ST8XME CCD to obtain sessions 877, 878, 879, 881, 882, 883, 884, 906, 907, 908, 909, 910, 911, 912, 913, 933, 934, 935, 952, 953, 954, 955, 956. The three observers obtained 69 sessions, many of them only one to two hours, 2019 Apr. 11 – June 26.

Petr Pravec (private communication) has kindly analyzed the data and finds no evidence of tumbling (Par = +2, Pravec, 2005) or any short term variation with amplitude > 0.038 magnitude. For all sessions 2019 Apr. 11 – June 2 for which the phase angle is less than 16 degrees, he finds a period 724 ± 5 hours. At larger phase angles the amplitude is appreciably greater and this period does not strictly apply.

The authors have performed a separate period search with *MPO Canopus* software. For 50 sessions with phase angle <16 degrees, 2019 Apr. 11 – June 2, they find a period 723.8 ± 0.4 hours,

Number	Name	yyyy/mm/dd	Pts	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E	Amp	A.E.
1744	Harriet	2019/04/11-2019/06/26	2401	13.6, 1.2, 24.1	224	-2	719.5	0.4	1.0	0.1

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date, unless a minimum (second value) was reached. LPAB and BPAB are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris *et al.*, 1984).