

MAIN-BELT ASTEROIDS OBSERVED FROM CS3: 2022 APRIL-JUNE

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(Received: 2022 July 5)

CCD photometric observations of 22 main-belt asteroids were obtained at the Center for Solar System Studies (CS3) from 2022 April-June. One revised period from observations obtained in 2005 is also reported.

The Center for Solar System Studies (CS3) has nine telescopes which are normally used in program asteroid family studies. The focus is on near-Earth asteroids, Jovian Trojans and Hildas. When it is not the season to study a family, or 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
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
0.40-m f/10 Schmidt-Cass	FLI Proline 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.

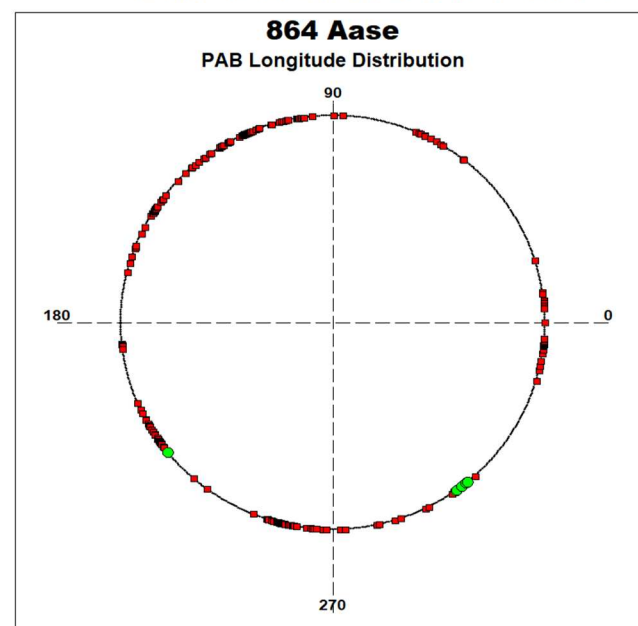
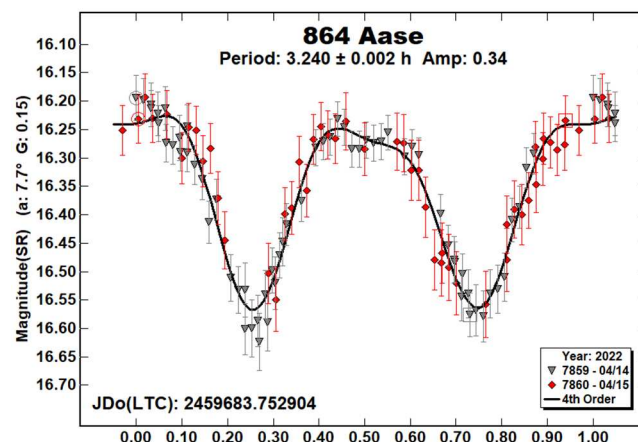
Image processing, measurement, and period analysis were done using *MPO Canopus* (Bdw Publishing), which incorporates the Fourier analysis algorithm (FALC) developed by Harris (Harris et al., 1989). The Comp Star Selector feature in *MPO Canopus* was used to limit the comparison stars to near solar color. 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 and are “native” magnitudes of the catalog. Those adjustments are usually ± 0.03 mag. The rare greater corrections may have been related in part to using unfiltered observations, poor centroiding of the reference stars, and not correcting for second-order extinction.

The Y-axis values are ATLAS SR “sky” magnitudes. The two values in the parentheses are the phase angle (α) and the value of G used to normalize the data to the comparison stars used in the earliest session. This, in effect, made all the observations seem to

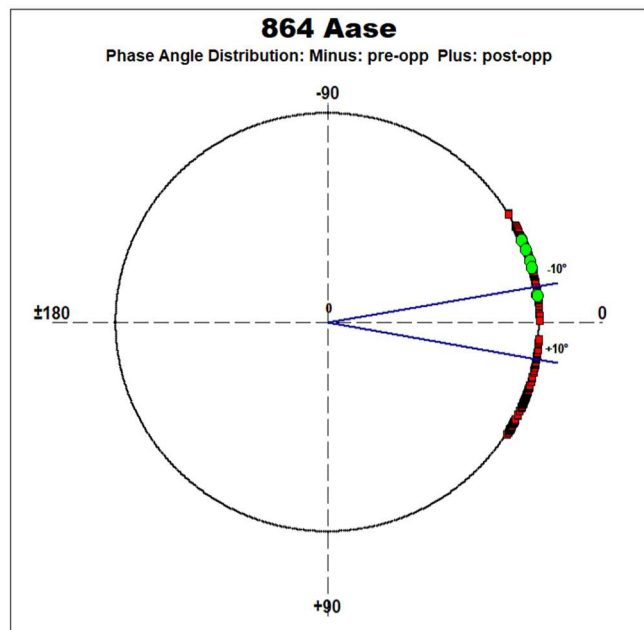
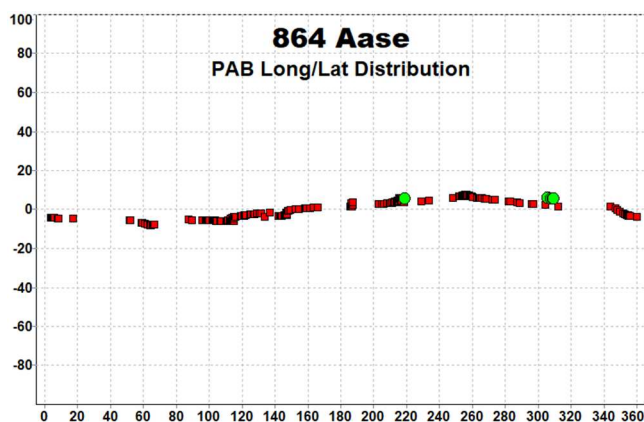
be made at a single fixed date/time and phase angle, leaving any variations due only to the asteroid’s rotation and/or albedo changes. The X-axis shows rotational phase from -0.05 to 1.05. If the plot includes the amplitude, e.g., “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

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

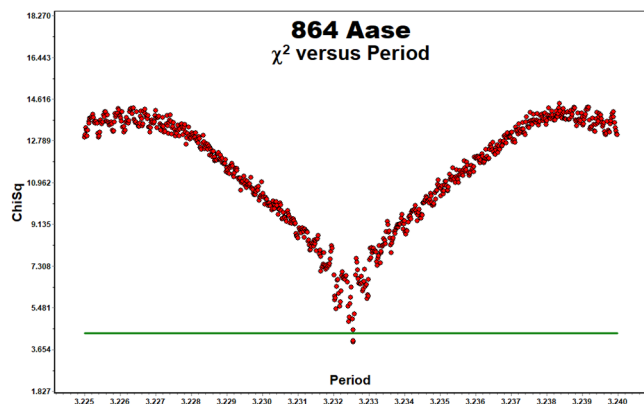
864 Aase. Rotational periods for this member of the Flora dynamical family have been observed several times in the past. Kryszczyńska et al. (2012), Pilcher (2017), Behrend (2019web), and Erasmus et al. (2020) all reported periods near 3.23 h. This year’s result is in good agreement with those prior findings.



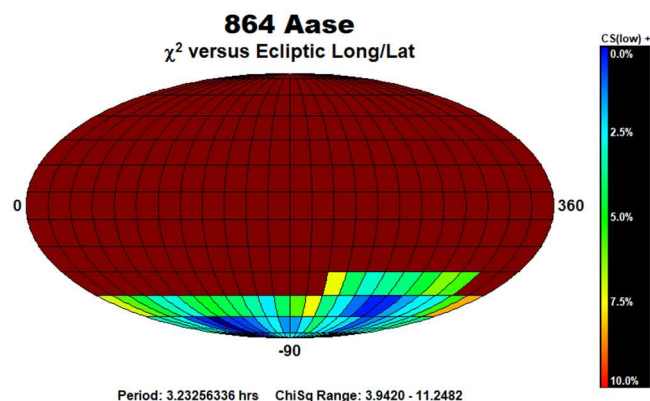
Because of the availability of the Pilcher data on the Asteroid Lightcurve Data Exchange Format database (ALCDEF, 2020) web site, we attempted to create a pole/shape model. We added these two dense data sets to additional sparse data from the AstDyS-2 site (AstDyS-2, 2020). We were able to use sparse data from the ATLAS, Zwicky Transient Factory, and USNO surveys. The following plots show the PAB longitude, latitude and phase angle distributions. Green dots represent the three dense datasets, and red dots represent sparse data from the three surveys.



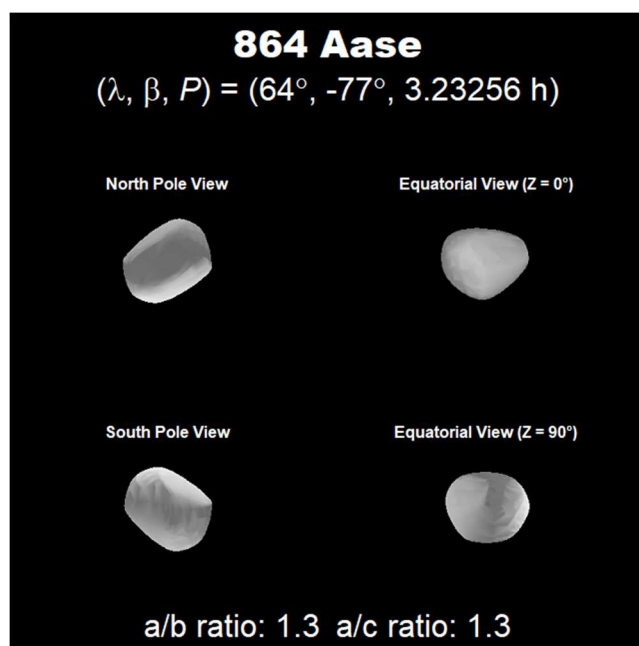
The data were combined using *MPO LCInvert* (Bdw Publishing). This Windows-based program incorporates the algorithms developed by Kaasalainen and Torppa (2001) and Kaasalainen et al. (2001) and converted by Josef Durech from the original FORTRAN to C. A period search was made over a sufficiently wide range to assure finding a global minimum in χ^2 values. The sparse data were weighted between 30% and 50%.

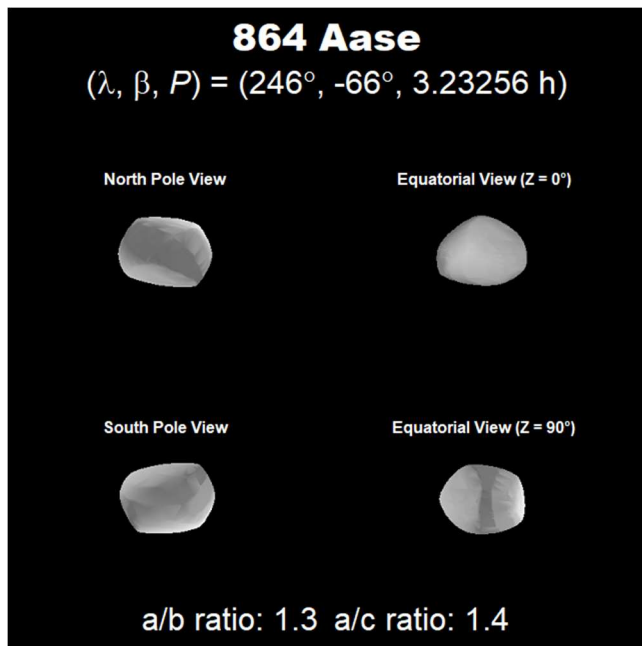


As is often the case, the pole model showed two possible solutions 180° apart; $(\lambda, \beta, P) = (64^\circ, -77^\circ, 3.23256 \text{ h})$ and $(\lambda, \beta, P) = (246^\circ, -66^\circ, 3.23256 \text{ h})$. Both solutions are very close to the south ecliptic pole indicating the rotation is retrograde, but makes the longitude of the spin axis hard to find with certainty. Our preferred solution is the $(64^\circ, -77^\circ)$ pole position.

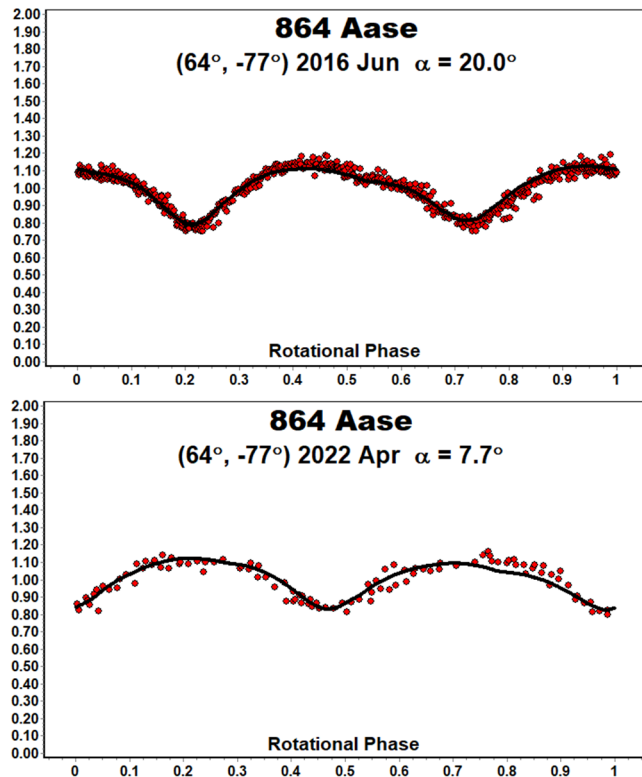


The two pole solutions created similar models, both with a/b ratios of 1.3 and a/c ratios of 1.3 or 1.4.



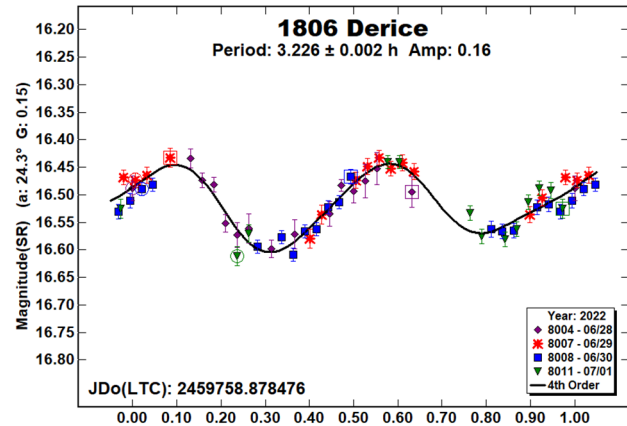


To test the model, the dense datasets were plotted against the predicted lightcurve for each dataset. Each plot resulted in a very good match, giving confidence in the pole/shape model result.

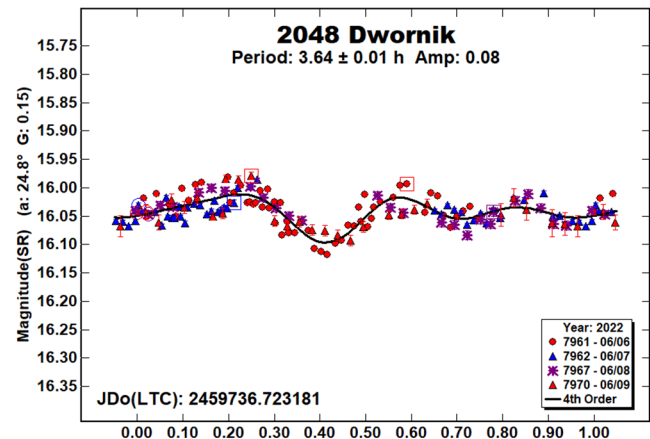


To further refine the model, the next favorable opposition is in 2023 December.

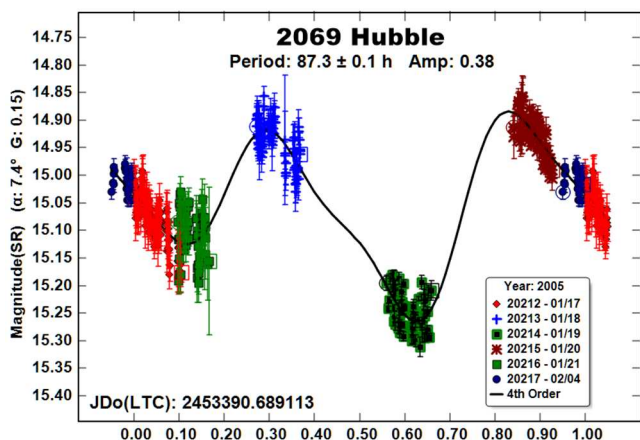
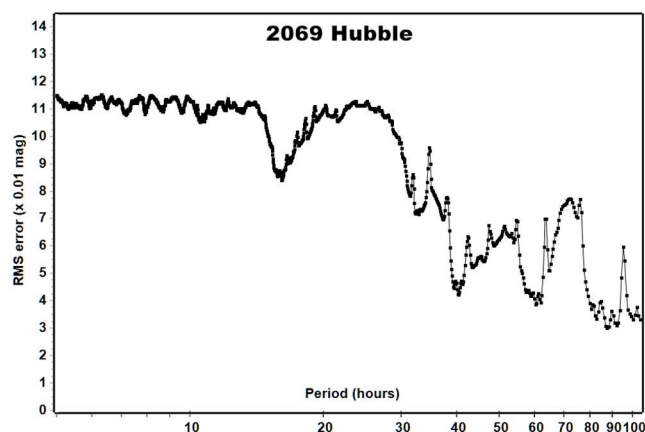
1806 Derice. This member of the Flora dynamical family has been observed many times in the past by the Photometric Survey for Asynchronous Binary Asteroids (Pravec et al., 2009web; 2011web; 2012web; 2016web) as a ‘Prime Suspect’ of being a binary asteroid, each time finding a period near 3.224 h. We observed it in 2020 (Stephens and Warner; 2020) finding a period of 3.2243 h with slight deviations from the lightcurve, but no indication of a secondary period. Our result this year is in good agreement with those prior results. The sparser data set this year also did not show any indication of a secondary frequency.



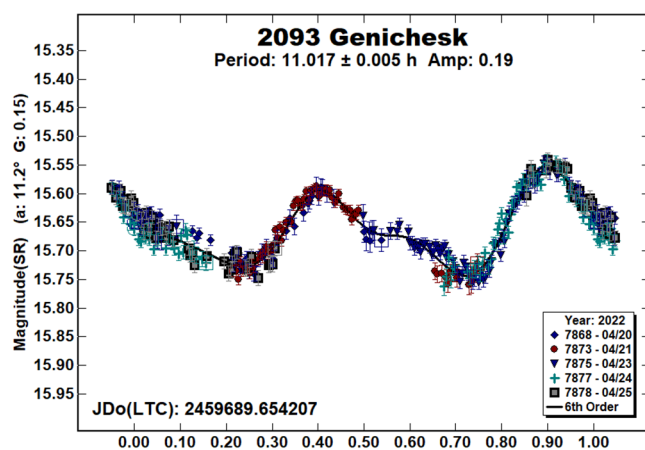
2048 Dwornik. Several periods are reported in the LCDB for this member of the Hungaria dynamical family Warner (2016; and references therein) and Skiff et al. (2019a) report many periods near 3.7 h with an amplitude rarely exceeding 0.16 h. Our result this year is a little faster than those prior results, but the low amplitude and proximity to the galactic bulge makes the result less certain.



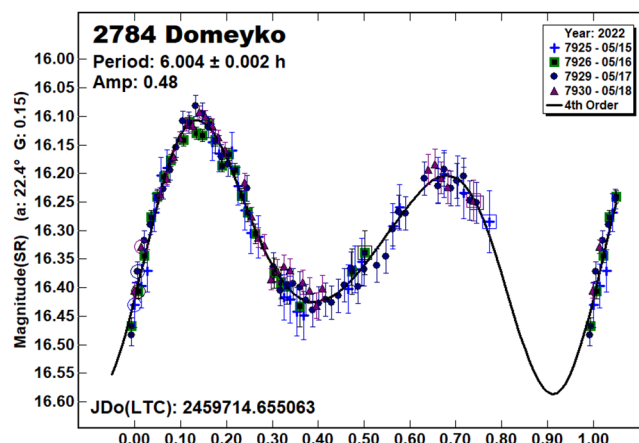
2069 Hubble. We first observed this outer Main-belt asteroid in 2005, obtaining a very noisy dataset where the error bars met or exceeded the amplitude of the lightcurve; the derived period was 32.52 h. Polakis (2022) reported a period of 44.62 h using a much higher-quality data set. This prompted us to revisit our work by first remeasuring the images and using SR (Sloan r') magnitudes from the ATLAS catalog (Tonry et al., 2018). This gave a significantly cleaner data set with nightly zero-point shifts less than 0.04 mag. Our revised period of 87.3 h is nearly double that found by Polakis. Given our sparse dataset, the two results are in good agreement.



2093 Genichesk. This member of the Baptistina dynamical family has been observed three times in the past. Behrend (2002web) and Warner (2008c) found periods near 11.02 h. Using data from the Palomar Transient Factory Survey, Waszczak et al. (2015) also found a period near 11.02 h. Our result this year is in good agreement with those prior results.

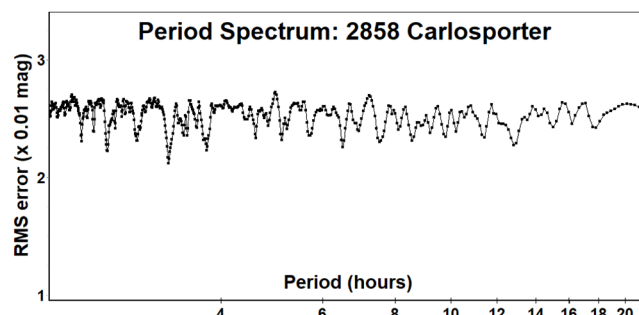


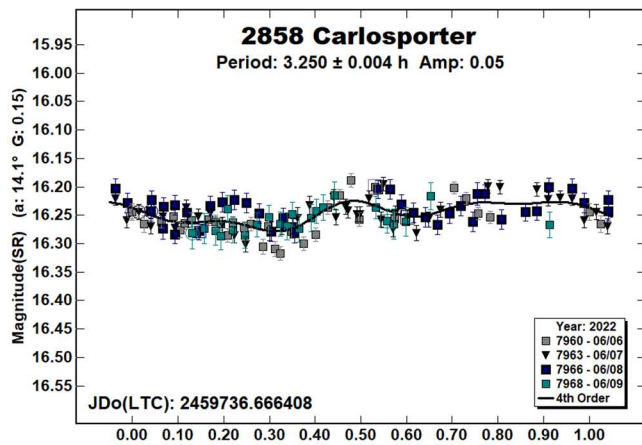
2784 Domeyko. This inner Main-belt asteroid has been observed twice in the past. Almeida et al. (2004) reported a period of 5.98 h. Polakis (2019) found a period of 6.025. Our result this year was a full moon project, and because the period is commensurate with an Earth day, could not completely cover the lightcurve. Still, it is in good agreement with those prior results.



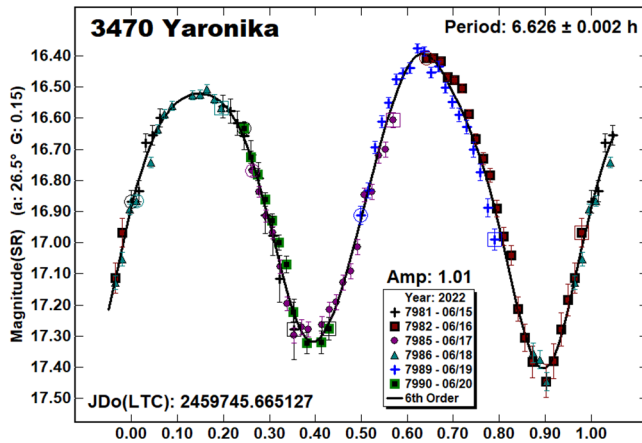
2858 Carlosporter. Carbognani (2014) reported a period of 3.336 h for this member of the Baptistina dynamical family. That period was derived from two sets of observations, two months apart. The first set was a single night, and the second set on three nights spanning two weeks. That second set had a night in which the magnitude of the asteroid dropped, then rose 0.45 magnitude over the course of 30 minutes. While it is possible that was caused by a mutual event, it seems unlikely and was not repeated on any of the other three nights. It is more likely the drop was caused by an observational effect. The earlier single night of observations a month earlier was cleaner and seems to have an amplitude of about 0.10 mag.

Our observations this year occurred near a full moon when the asteroid was also near the galactic bulge. That hampered getting high quality data points. Compounding the situation, the lightcurve was also very low amplitude. A period search suggested a number of possibilities, with the strongest being between 3 and 4 hours. With an amplitude of only 0.05 mag, there is no assurance of a bimodal lightcurve (Harris et al., 2014). However, given Carbognani's first session, it is likely the true period is less than 4 hours.

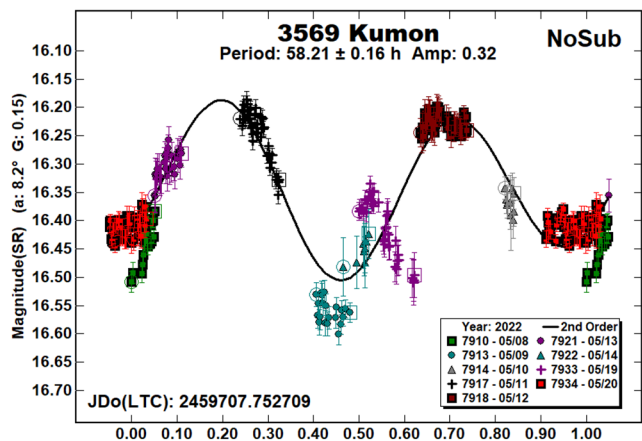




3470 Yaronika. There are only two prior periods in the LCDB for this inner Main-belt asteroid. Ditteon (2019) reported a period of 6.63 h. Also, using data from the ATLAS survey, Ďurech et al. (2020) created a pole/shape model with a sidereal period of 6.63157 h. Our results this year is in good agreement with those prior results.

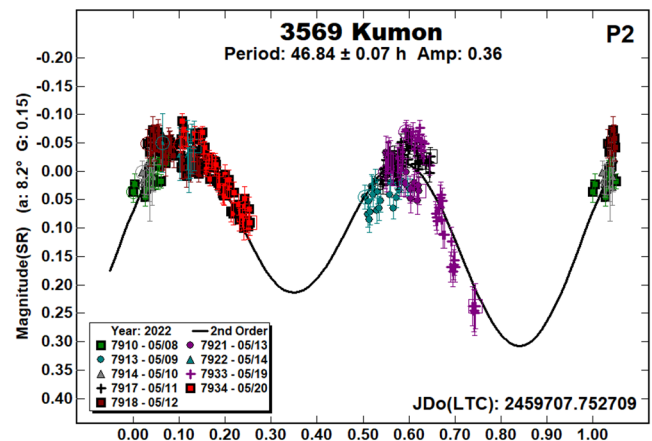
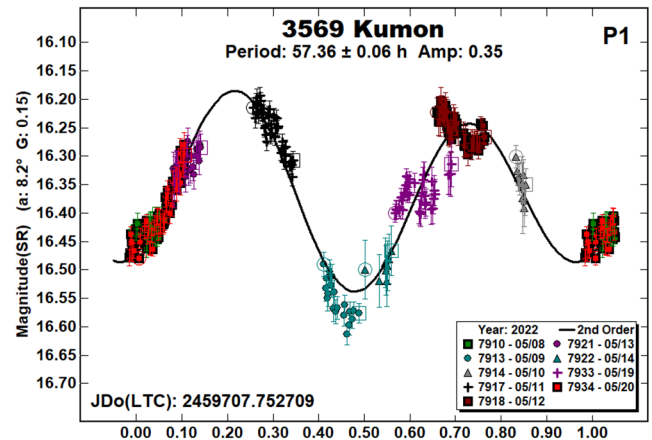


3569 Kumon. This member of the Eunomia family (Nesvorný, 2015; Nesvorný et al., 2015) was observed once before. Clark (2019) reported a period of 7.49 h, but commented that the scatter in the data precluded any reasonable period determination.



Our observations immediately suggested a long period. The initial analysis showed that the solution was dominated by a period near 58 hours. However, our data showed very distinctive signs of being

in a tumbling state (“NoSub” plot). There were signs of a second period, one that was unlikely due to a satellite.

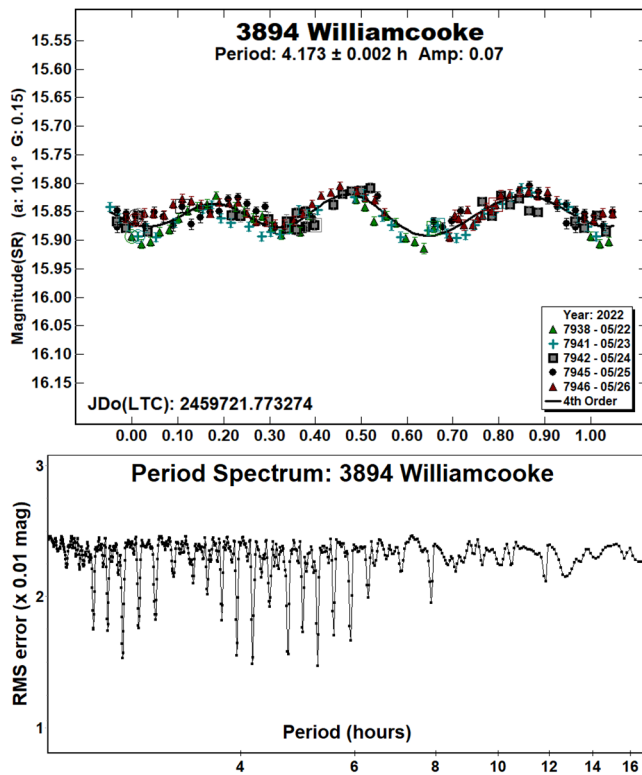


A dual-period search was done using *MPO Canopus*, which is not equipped to work with tumbling asteroids. This resulted in a pretty good fit to a period of 57.36 h (“P1”), close to the single-period solution. It is highly unlikely that the secondary period lightcurve near 47 h (“P2”) has a physical cause, other than the asteroid being a tumbler.

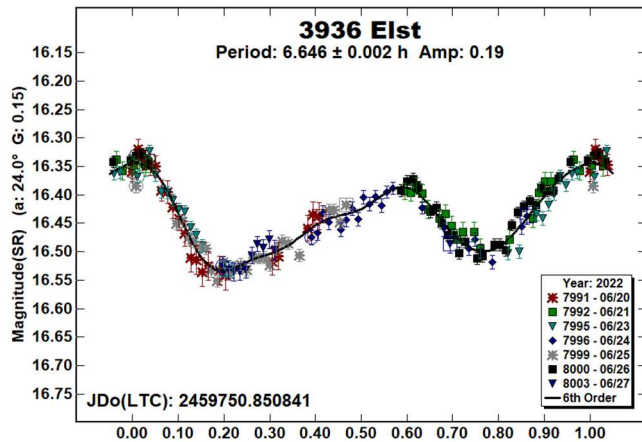
3894 Williamcooke. This member of the Eunomia dynamical family has been observed three times in the past. Macias (2015) found a period of 3.10 h, but it was a quadrimodal lightcurve with an amplitude of 0.09 mag. With an amplitude of only 0.10 mag., there is no assurance of a bimodal lightcurve (Harris et al., 2014).

In 2018 July, we found a period of 4.16 h with an amplitude of 0.20 mag. (Stephens 2019). The 2015 Macias period is a 3:4 alias of the 4.16 h period we found in 2018. Also in 2018 July, Behrend (2018web) reported a period of 8.3343 h. That lightcurve had six extrema and is a 2:1 alias of our period.

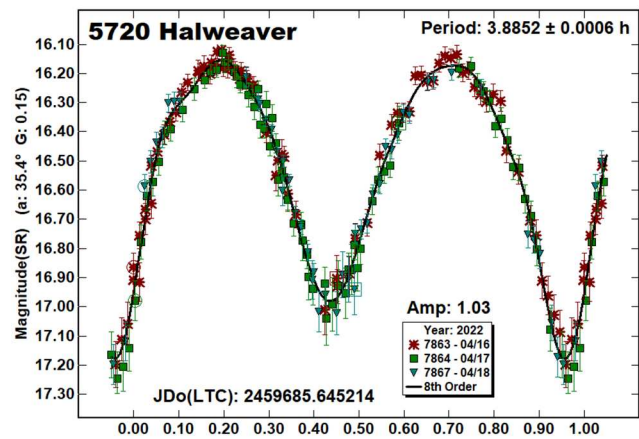
Our period this year is in good agreement with our prior result, with the lowest amplitude seen to date. The period spectrum shows possible solutions near 2.6 h, 4.2 h, and 5.2 h, and with such a low amplitude, single modal, bimodal, trimodal, and quadrimodal lightcurves are all possible. We tried rephasing the lightcurve to the 3.10 h Macias period, and excluded it as a possibility. The 2.6 h period produced a bimodal lightcurve. Our 2018 data could not be phased to that period. By the process of elimination, a 4.173 h period was the only period that could be phased to both our 2018 and 2022 data.



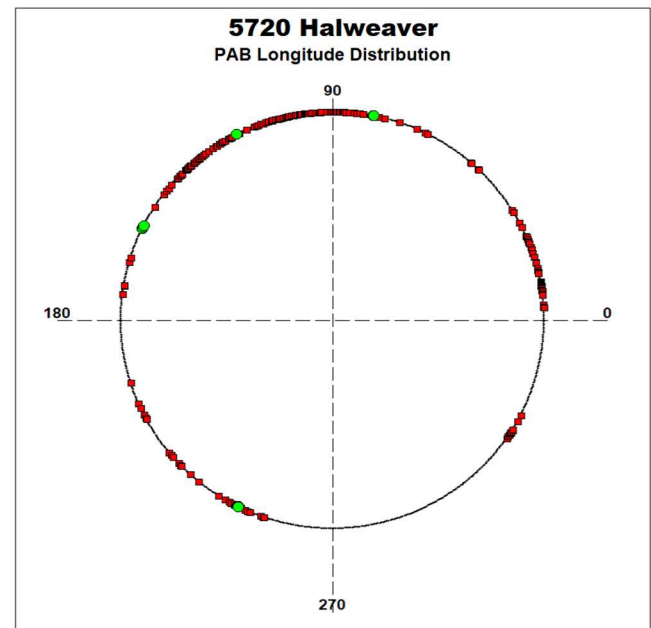
3936 Elst. There is only one previously reported period in the LCDB for this Vestoid. Pravec et al. (2007web) reported a period of 6.6322 h. Our result this year is in good agreement with the Pravec et al. period.

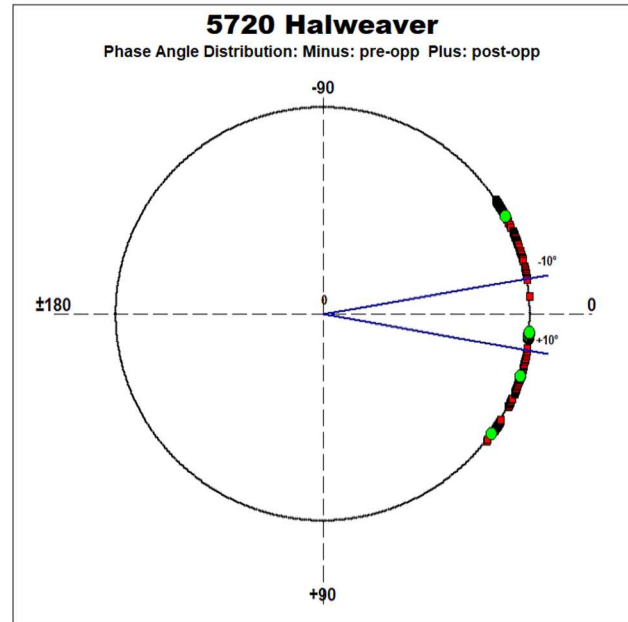
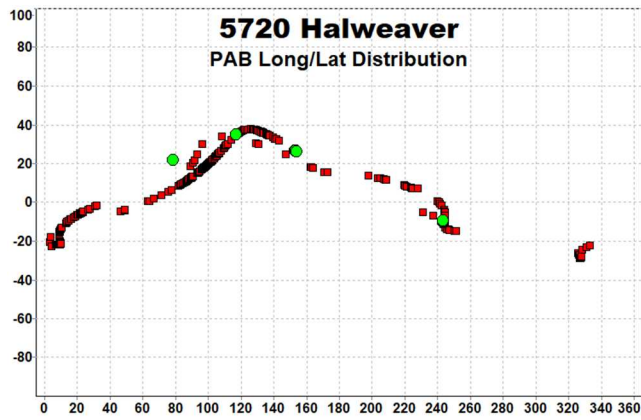


5720 Halweaver. Two rotational periods were found in the LCDB for this Mars-crosser. Warner (2008b) reported a period of 3.8883 h. Using data from the TESS spacecraft, Pál et al. (2020) found a period of 3.88689 h. This year's result is in good agreement with those prior findings.

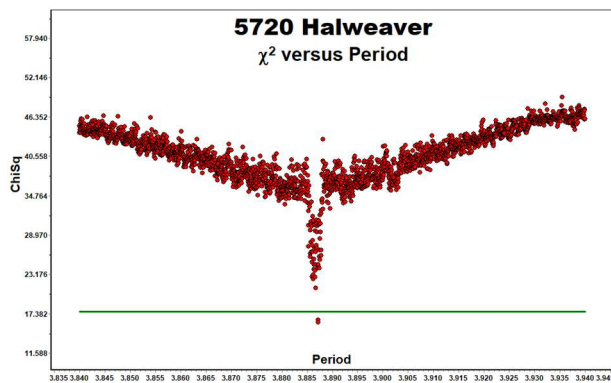


Because of our previous data from 2008, the availability of the Pál et al. data, and other unpublished data from Hopkins on the Asteroid Lightcurve Data Exchange Format database (ALCDEF, 2020) web site, we attempted to create a pole/shape model. We added additional sparse data from the AstDyS-2 site (AstDyS-2, 2020). We were able to use sparse data from ATLAS, Zwicky Transient Factory and the Catalina Sky Survey. The following plots show the PAB longitude, latitude and phase angle distributions. Green dots represent the three dense datasets, and red dots represent sparse data from the three surveys. The Pál et al. data is located at (PABL = 244° , PABB = -10° , Phase = 5.2°).

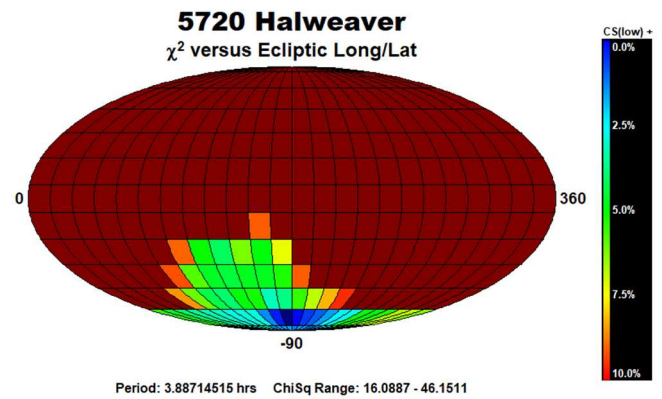




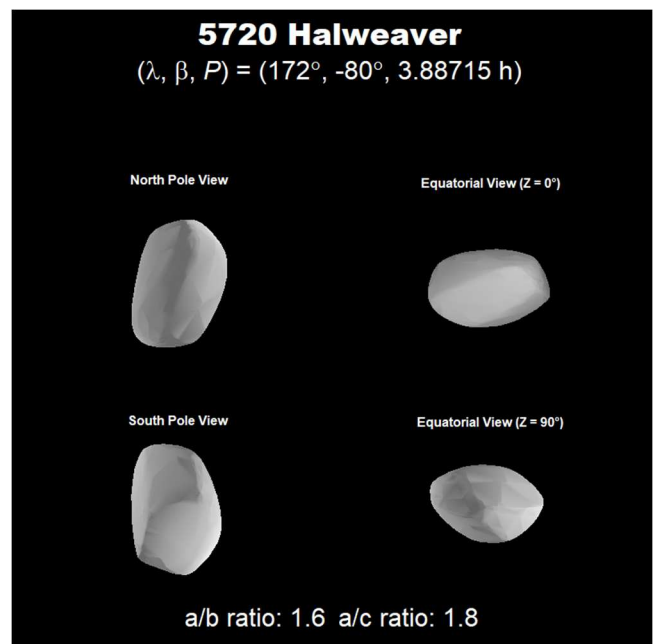
The data were combined using *MPO LCInvert* (Bdw Publishing) described in the 864 Aase section of this article. Only two unique periods below the 10% χ^2 line was found.



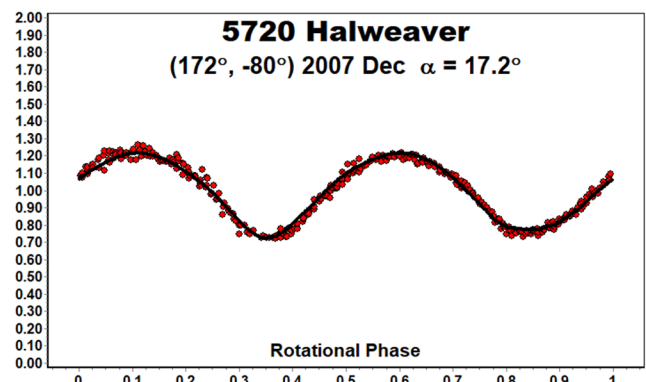
Only one unique solution was found (172° , -80°). It was within 10 degrees of the south ecliptic pole, indicating the rotation is retrograde, but because of its proximity to the pole, the longitude can be ambiguous.

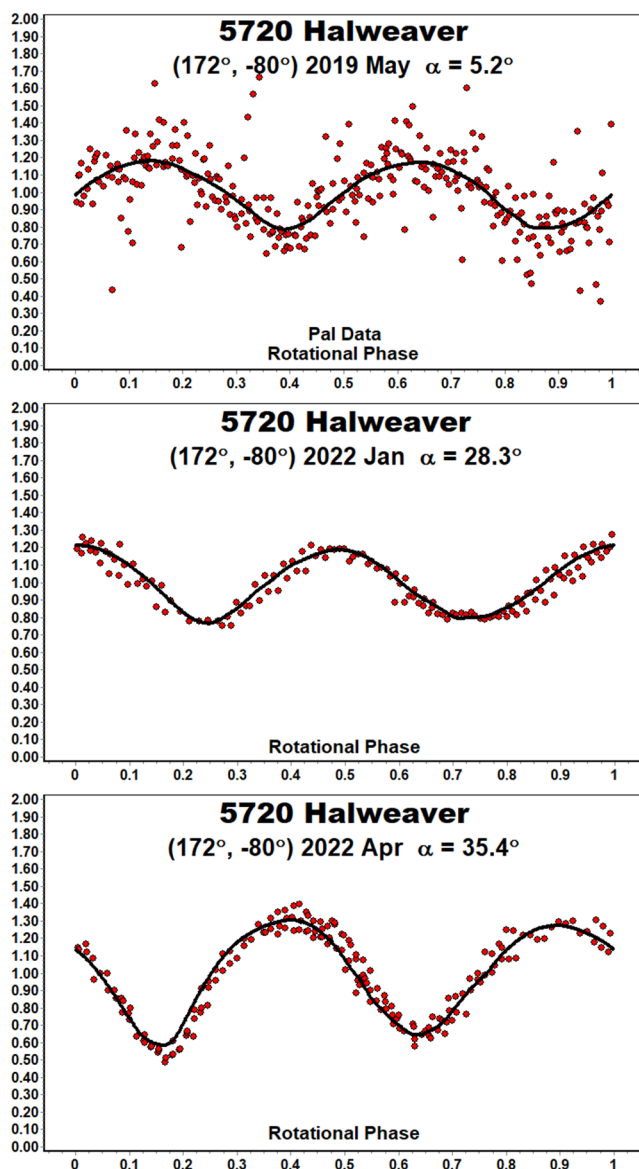


The resulting model presents an elongated body. This is expected given that all of the amplitudes reported in the LCDB are between 0.45 and 1.02 mag.



To test the model, these dense datasets were plotted against the predicted lightcurve for each dataset. Each plot for the (172° , -80°) pole position resulted in a good match. Even the Pál et al data from the TESS spacecraft, which had an expected number of outliers, was a good match to the predicted lightcurve giving high confidence in the pole/shape model result. The 2022 Jan. plot was a single night, unpublished lightcurve found in the Asteroid Lightcurve Data Exchange Format database.



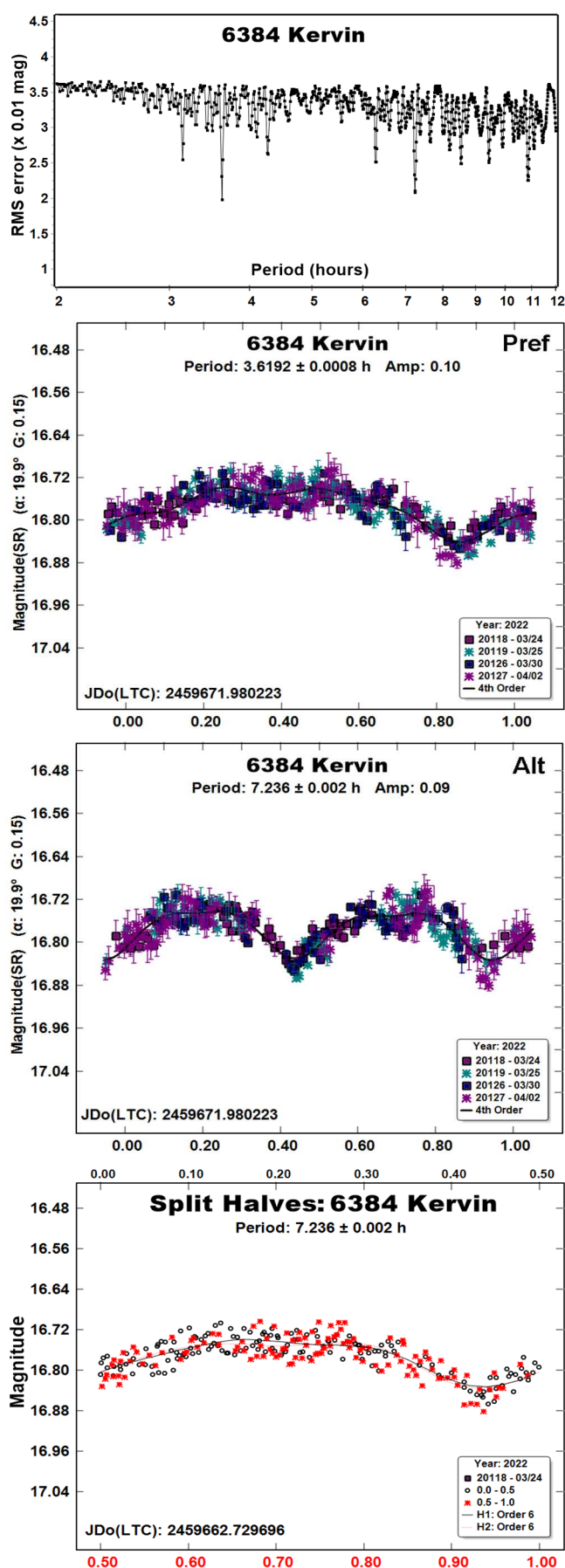


It will be several years before its next favorable opposition for northern hemisphere observers.

6384 Kervin. This Hungaria member has been observed numerous times in the past. Pravec et al. (2006web) found a period of 3.6200 h. We observed the asteroid five times before as part of the continuing program on the Hungaria asteroids. All results were close to 3.62 h. The 2022 data produced a period of 3.6192 h if assuming a monomodal lightcurve.

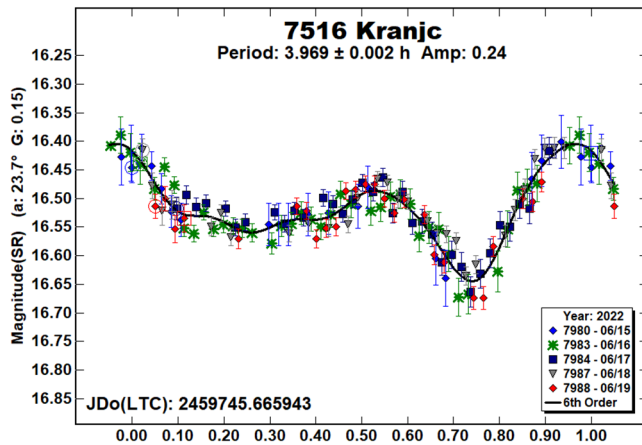
However, given the low amplitude of only 0.10 mag, the true lightcurve might be bimodal or even multimodal (Harris et al., 2014). The maximum amplitude found in the LCDB is only 0.16 mag, which can still make the modality of the lightcurve uncertain.

We present an alternate period of 7.236 h with a bimodal lightcurve. However, the so-called *Split Halves* plot (see Harris et al., 2014) shows that the two halves of the lightcurve are essentially identical, which significantly reduces the likelihood of the longer period being the correct solution.

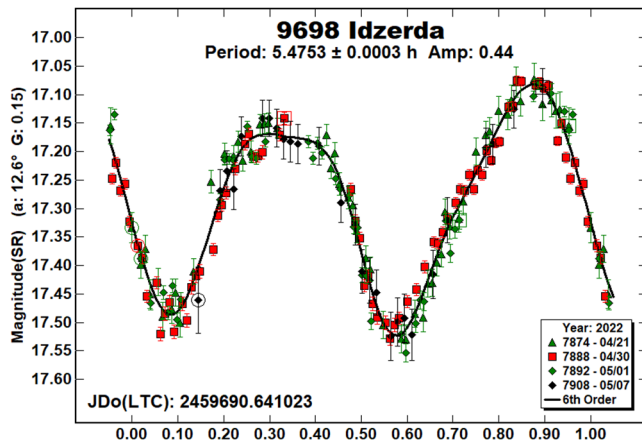


7516 Kranjc. This inner Main-Belt asteroid has been observed four times in the past. As part of a campaign for the Photometric Survey of Asynchronous Binary Asteroids (Pravec et al., 2006), Oey et al. (2009) observed it over two months finding a period of 3.96776 ± 0.00005 h. They detected a single mutual event spanning a dozen data points over 1-1/2 h. No other mutual event was ever detected in any other datasets.

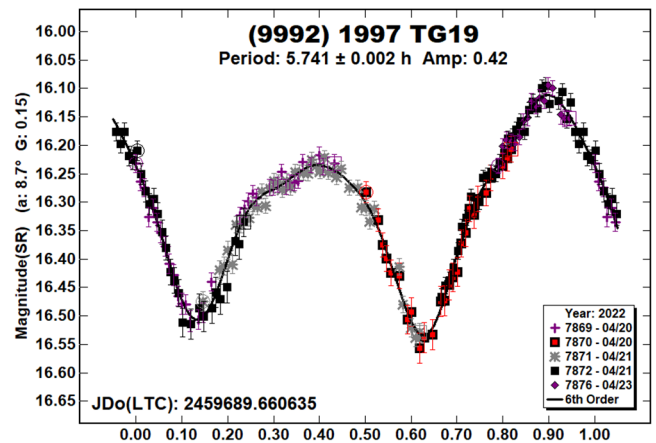
About the same time, Warner (2009) observed it finding a period of 3.982 h. More recently, the Photometric Survey of Asynchronous Binary Asteroids observed it again (Pravec et al., 2019web) finding a period of 3.9702 h. Our result this year is in good agreement with those prior results.



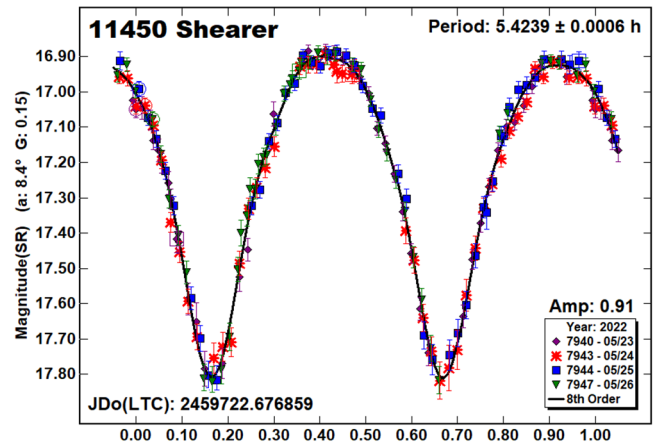
9698 Idzerda. This member of the Vesta dynamical family has been observed twice by surveys in the past. Using data from the Asteroid Terrestrial-impact Last Alert System (ATLAS) survey, Erasmus et al. (2020) found a period of 5.475 h. With data from the TESS spacecraft, Pál et al. (2020) found a period of 5.47439 h. Our result this year is in good agreement with those prior survey results.



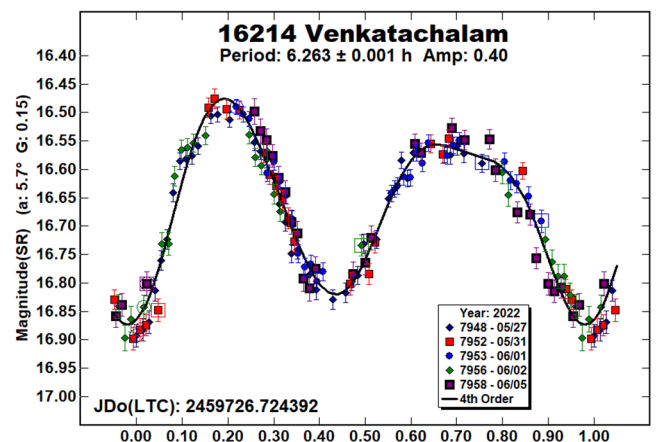
(9992) 1997 TG19. This Mars-crosser has been observed twice in the past. Higgins et al. (2006) reported a period of 5.7402 h. Using data from the Palomar Transient Factory Survey, Waszczak et al. (2015) found a period near 5.730 h. Our period this year is in good agreement with those prior results.



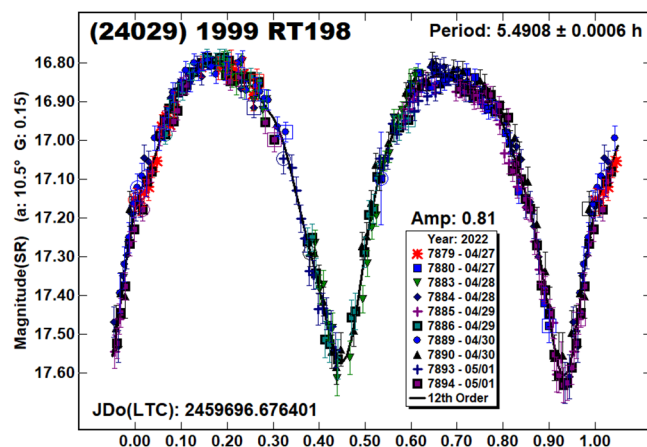
11450 Shearer. Using data from the Palomar Transient Factory Survey, Waszczak et al. (2015) reported a period of 5.422 h. Our period this year is in good agreement with that prior result.



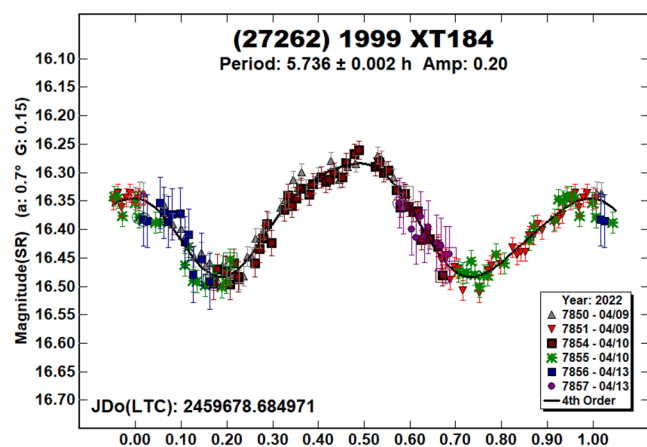
16214 Venkatachalam. Using data from the Palomar Transient Factory Survey, Waszczak et al. (2015) reported a period of 6.272 h. Our period this year is in good agreement with that prior result.



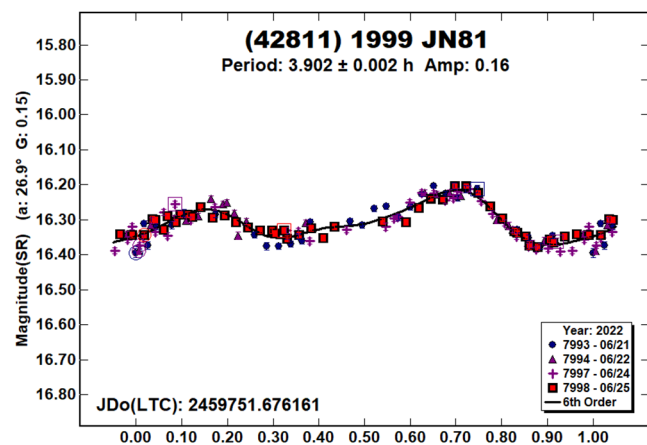
(24029) 1999 RT198. This Mars-crosser was observed at Lowell in 2010 and 2017 (Skiff et al., 2019b), both times finding a period near 5.49 h and an amplitude over 0.7 mag. The period we found this year is in good agreement with those prior results.



(27262) 1999 XT184. Using data from the TESS spacecraft, Pál et al. (2020) previously reported a period of 5.74263 h for this Vestoid. Our period this year is in good agreement with that prior result.

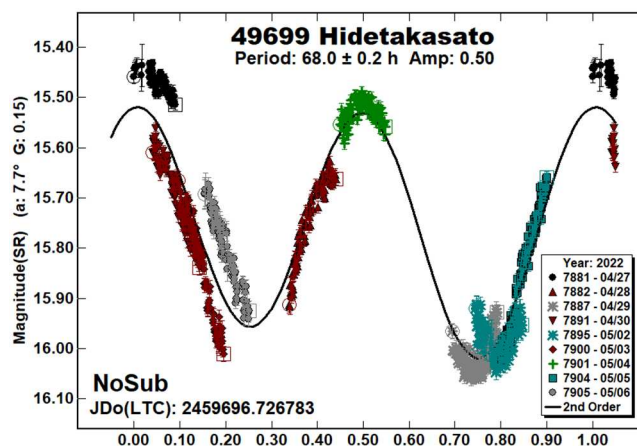
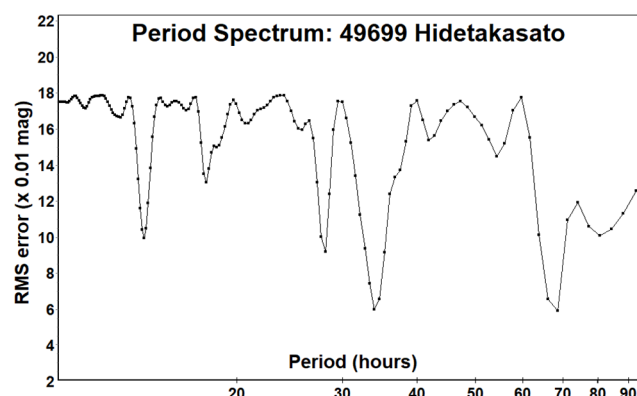


(42811) 1999 JN81. This member of the Hungaria dynamical family has been observed several times in the past. Warner (2008a, 2012), Benishek (2018), Skiff et al. (2019b), and Pál et al. (2020) all found periods near 3.9 h. The period we found this year is in good agreement with those prior results.

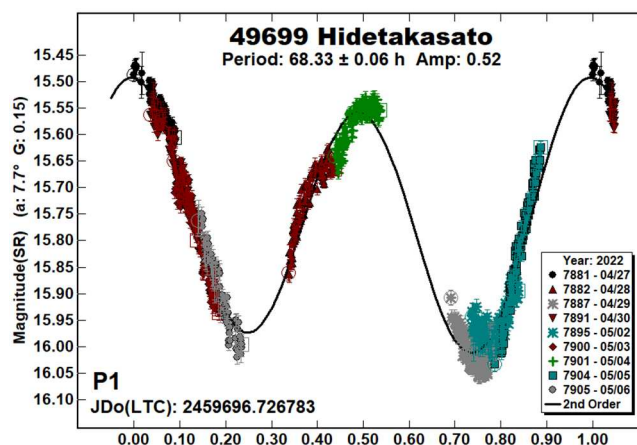


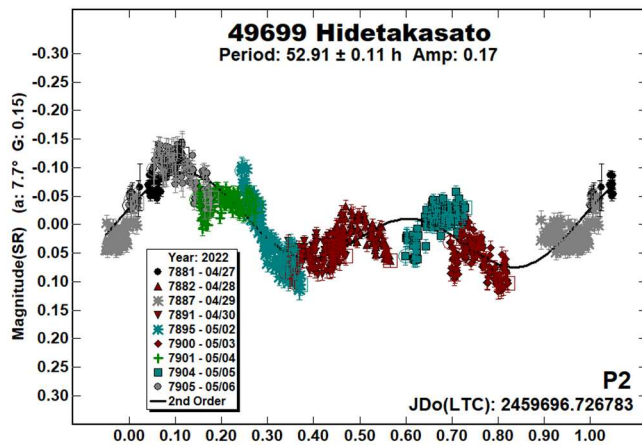
49699 Hidetakasato. There are no entries in the LCDB for this dynamical member of the Phocaea family (Nesvorný, 2015; Nesvorný et al., 2015). We observed it in 2022 March and April. Initial observations pointed towards a long period, but a decisive wobble suggestive of a tumbling state was quickly apparent. That is not a surprise given its long period and that the asteroid is tumbling, which is likely given the damping time is between 1 - 3 Gy (Pravec et al., 2005; 2014).

The initial analysis showed that the solution was dominated by a period near 68 hours (“NoSub”), but there were signs of a second period, one that was unlikely due to a satellite.



The tumbling frequencies cannot be confirmed from our data set alone, but we attempted to solve for the dominant period of the solution using *MPO Canopus*, which is not equipped to work with tumbling asteroids. The plot labeled “P1” is the dominant frequency, after subtracting a secondary frequency of 52.91 h.





The cleanup on P1 is noteworthy with P2 being reasonable compared to P1. There's a limit to the difference in periods based on the amplitude. As a rule of thumb, the rotation and wobble frequencies cannot be separated by more than a factor of about the inverse amplitude of variation (Alan Harris, *private communication*). Thus, for something varying by 0.5 mag., the two periods must be within 200% of each other. So, the two periods are plausible. The inability for *MPO Canopus* to work accurately with tumbling asteroids could well be the reason for the shape and amplitude of the P2 lightcurve.

Acknowledgements

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 authors gratefully acknowledge 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	2021/mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.
864	Aase	04/14-04/15	7.8,7.3	219	6	3.240	0.002	0.34	0.05
1806	Derice	06/28-07/01	24.3,24.1	341	4	3.226	0.002	0.16	0.02
2048	Dwornik	06/06-06/09	24.8,24.3	277	33	3.64	0.01	0.08	0.01
2069	Hubble	2005 01/17-02/04	7.3,13.5	104	10	87.3	0.1	0.34	0.03
2093	Genichesk	04/20-04/25	11.2,13.8	192	6	11.017	0.005	0.19	0.02
2784	Domeyko	05/15-05/18	22.4,23.3	192	9	6.004	0.002	0.48	0.05
2858	Carlosporter	06/06-06/09	*14.1,15.5	190	7	3.250	0.004	0.05	0.02
3470	Yaronika	06/15-06/20	26.5,27.3	213	-1	6.626	0.002	1.01	1.02
3569	Kumon	05/08-05/20	*8.2,8.0	234	17	57.36 46.84	0.06 0.007	0.35 0.36	0.01 0.05
3894	Williamcooke	05/22-05/26	10.1,9.3	255	17	4.173	0.002	0.07	0.01
3936	Elst	06/20-06/27	*24.0,22.2	271	6	6.646	0.002	0.19	0.02
5720	Halweaver	04/18-04/18	35.4	154	26	3.8852	0.0006	1.03	0.01
6384	Kervin	2022 03/24-04/02	*19.9,19.8	187	35	3.6192 7.236	0.0008 0.002	0.10 0.09	0.01 0.01
7516	Kranjc	06/15-06/19	23.8,25.2	227	10	3.969	0.002	0.24	0.01
9698	Idzerda	04/21-05/07	12.7,19.0	189	-2	5.4753	0.0003	0.44	0.02
9992	1997 TG19	04/20-04/23	8.8,10.8	198	1	5.741	0.002	0.42	0.02
11450	Shearer	05/23-05/26	8.4,9.3	235	11	5.4239	0.0006	0.91	0.01
16214	Venkatachalam	05/27-06/05	5.7,8.5	244	9	6.263	0.001	0.40	0.02
24029	1999 RT198	04/27-05/01	10.5,12.3	196	1	5.4908	0.0006	0.81	0.01
27262	1999 XT184	04/09-04/10	0.7,1.2	198	1	5.736	0.002	0.20	0.02
29606	1998 QN94	05/02-05/21	25.9,30.1	192	26	2.8965	0.0001	0.17	0.01
42811	1999 JN81	06/21-06/25	27.0,27.2	277	35	3.902	0.002	0.16	0.02
49699	Hidetakasato	04/27-05/06	*7.7,8.1	218	10	68.33 52.91	0.06 0.11	0.52 0.17	0.50 0.03

Table II. Observing circumstances and results. ^TDominant period for a tumbling asteroid. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extremum 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). If more than one line for an asteroid, the first line gives the dominant solution and has a ^T superscript. Subsequent lines are additional, not alternate, periods. See the text for more details.

Number	Name	λ	β	Period	λ	β	Period	a/b ratio	a/c ratio
864	Aase	64	-77	3.23256	246	-66	3.23256	1.3	1.3
5720	Halweaver	172	-80	3.88715				1.6	1.8

Table III. Results of Pole/Shape modeling. The preferred solution is listed first in bold text. For the ratios, $c = 1.0$.

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ROTATIONAL PERIOD DETERMINATION AND TAXONOMIC CLASSIFICATION FOR ASTEROIDS 417 SUEVIA, 554 PERAGA, AND 747 WINCHESTER

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CCD photometric observations of three main-belt asteroids were made between 2022 January and March in order to measure their rotation periods and define their taxonomic class. The observations used instrumentation available at our two observatories.

CCD photometric observations of three main-belt asteroids were carried out in 2022 January and March at the Osservatorio Astronomico Margherita Hack (A57) and Osservatorio Astronomico Hypatia (L62). The Osservatorio Astronomico Margherita Hack is equipped with a 0.35-m *f*/8.25 Schmidt-Cassegrain telescope, an SBIG ST10 XME CCD camera, and Johnson-Cousins BVRc photometric filters. The pixel scale was 1 arcsec when binned at 2×2 pixels. The Osservatorio Astronomico Hypatia is equipped with a 0.25-m *f*/5.6 Ritchey-Chretien telescope and a Moravian G2-8300 CCD camera having the pixel scale of 0.81 arcsec at 1×1 binning, and Rc photometric filter. Data processing and analysis were done with *MPO Canopus* (Warner, 2021). All images were calibrated with dark and flat field frames using *Astroart 6.0* and *MaximDL*. Table I shows the observing circumstances and results.

417 Suevia was discovered at Heidelberg on 1896 May 6 by M.F. Wolf. It is a main-belt asteroid with a semi-major axis of 2.800 au, eccentricity 0.135, inclination 6.65 deg, and orbital period of 4.69 years. Its absolute magnitude is $H = 9.56$ (JPL, 2022; MPC, 2022).

In this case, our observations were conducted in two steps. The first step consisted in collecting 192 data points during two nights on 2022 Feb 23 and 24. The period analysis shows a bimodal solution for a rotational period $P = 7.034 \pm 0.002$ h with an amplitude $A = 0.12 \pm 0.02$ mag. The split-halves plot let us resolve the potential ambiguity between monomodal and bimodal solution by showing that the two halves of the 7.034 h solution are not superimposable. This makes the bimodal solution much more probable. As a further check, we consulted the asteroid lightcurve database (LCDB; Warner et al., 2009) and found three previously reported periods: Barucci et al. (1992, 7.034 h), Fauvaud and Fauvaud (2013, 7.020 h), and Martikainen et al. (2021, 7.0185 h). The period we found seems to be in good agreement with those previous results.

Number	Name	2022 mm/dd	Pts	Phase	LPAB	BPAB	Period(h)	P.E.	Amp	A.E.	Grp
417	Suevia	02/22	192	3.37	152	-6	7.034	0.002	0.12	0.014	MBA
554	Peraga	01/13	391	6.53	103	1	13.715	0.002	0.18	0.01	MBA
747	Winchester	03/01	513	5.46	168	14	9.418	0.002	0.13	0.016	MBA

Table I. Observing circumstances and results. Pts is the number of data points. The phase angle is given for the first and last date. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009).