ASTEROID LIGHTCURVE ANALYSIS AT THE CENTER FOR SOLAR SYSTEM STUDIES PALMER DIVIDE STATION: 2023 MAY-JULY

Brian D. Warner
Center for Solar System Studies (CS3)
446 Sycamore Ave.
Eaton, CO 80615 USA
brian@MinPlanObs.org

(Received: 2023 July 10)

CCD photometric observations of twenty asteroids were made at the Center for Solar System Studies Palmer Divide Station during 2023 May and July. Data analysis found two likely binary asteroids: 2449 Kenos and (236716) 2007 FV42. Hungaria asteroids 3225 Hoag and 4232 Aparicio have unexplained secondary periods, and the near-Earth asteroid (467336) 2002 LT38 is very likely to be in non-principal axis rotation, i.e., it is a tumbler.

CCD photometric observations of twenty asteroids were carried out at the Center for Solar System Studies Palmer Divide Station (CS3-PDS) during 2023 May to July as part of an ongoing general study of asteroid rotation periods with a concentration on near-Earth, Hungaria, and Hilda group/family asteroids.

Telescope	Camera
0.30-m *f*/6.3 SCT	SBIG STL-1001E
0.35-m *f*/9.1 SCT (x3)	FLI Microline 1001E
0.50-m *f*/8.1 Ritchey-Chrétien	FLI Proline 1001E

Table I. List of available telescopes and CCD cameras at CS3-PDS. The exact combination for each telescope/camera pair can vary due to maintenance or specific needs.

Table I lists the five telescope/CCD cameras pairs used at CS3-PDS. All the cameras use CCD chips from the KAF 1001 blue-enhanced family and so have essentially the same response. The pixel scales ranged from 1.24-1.60 arcsec/pixel. All lightcurve observations were made with no or a clear filter. The exposures varied depending on the asteroid's brightness.

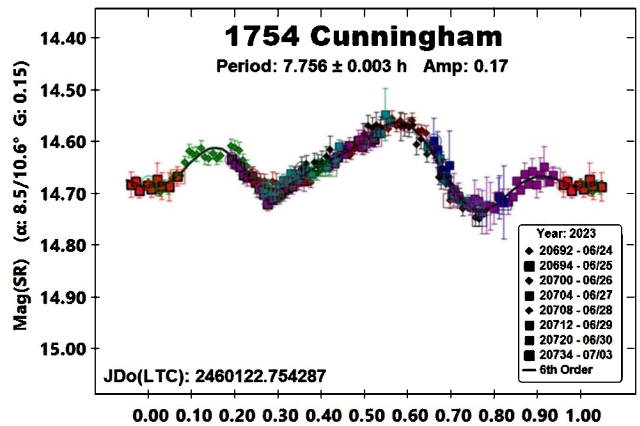
To reduce the number of times and amounts of adjusting nightly zero-points, the ATLAS catalog r´ (SR) magnitudes (Tonry et al., 2018) are used. Those adjustments are usually ≤ ±0.03 mag. The rare larger corrections may have been related in part to using unfiltered observations, poor centroiding of the reference stars, and not correcting for second-order extinction. Another cause may be selecting what appears to be a single star but is actually an unresolved pair.

The Y-axis values are ATLAS SR "sky" (catalog) magnitudes. The values in the parentheses give the phase angle(s), *a*, along with the value of *G* used to normalize the data to the comparison stars and asteroid phase angle used in the earliest session. This, in effect, adjusts all the observations so that they seem to have been made at a single fixed date/time and phase angle. Presumably, any remaining variations are due only to the asteroid's rotation and/or albedo changes.

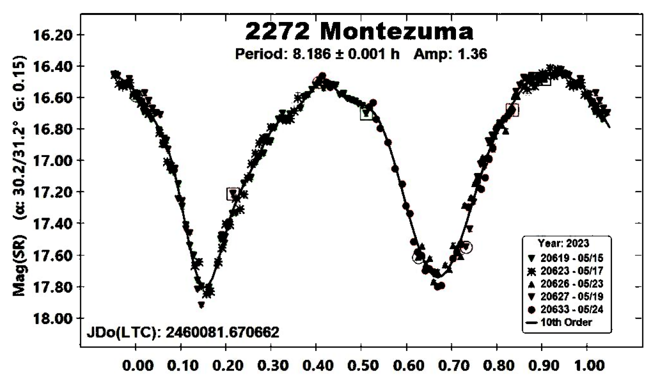
There can be up to three phase angles If two, the values are for the first and last night of observations. If three, the middle value is the extrema (maximum or minimum) reached between the first and last observing runs. The X-axis shows rotational phase from -0.05 to 1.05. If the plot includes the amplitude, 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 previous results are referenced. A more complete listing is in the asteroid lightcurve database (Warner et al, 2009; "LCDB" from here on).

1754 Cunningham. This member of the Hilda orbital group has been studied many times, e.g., Stephens (2015; 7.7416 h), and twice later at CS3: Warner and Stephens (2018, 7.709; 2021, 7.737 h). The data from 2023 June led to $P = 7.756 \pm 0.003$ h, $A = 0.17 \pm 0.01$ mag.



2272 Montezuma is a Hungaria orbital group member, i.e., not part of the collisional group named after 434 Hungaria (Nesvorny, 2015; Nesvorny et al., 2015). The asteroid had been previously observed four times at CS3 with the derived periods all close to 8.18 h. The 8.186 h period from the 2023 observations is in good agreement.

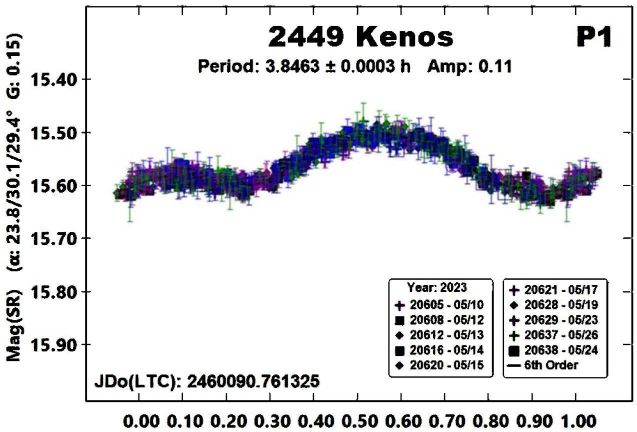


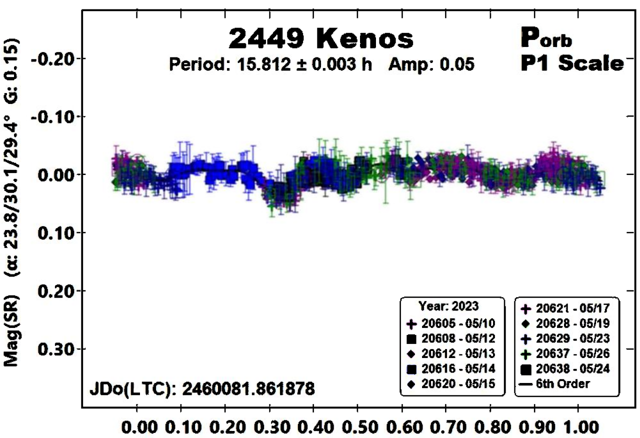
2449 Kenos. Observations of this Hungaria (group) in 2015 (Warner, 2015b) led to speculation that the asteroid might be binary with an orbital period for the satellite of 15.85 h. The 2023 observations further supported the supposition.

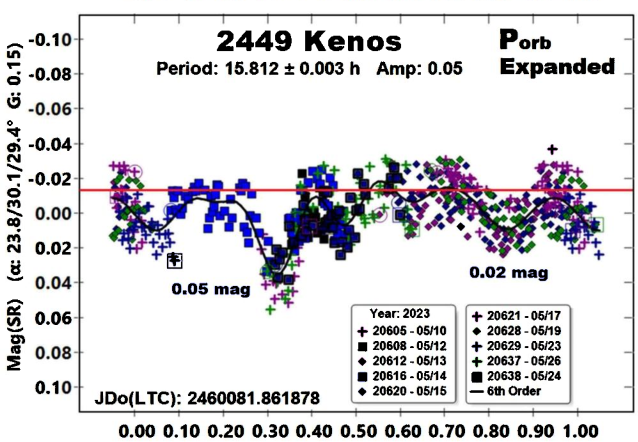
The adopted period for the primary, $P_1 = 3.8463 \pm 0.0003$ h, is consistent with previous results, e.g., Warner (2007a, 3.846 h; 2018, 3.8387 h). The proposed orbital period ($P_{ORB} = 15.812 \pm 0.003$ h) is also consistent when the effect of the very low amplitudes of the events is taken into account. In 2023, those events were 0.02-0.05 mag in depth. This is at the very edge of the limit for discovering a satellite using ground-based photometry alone (Pravec et al., 2006).

There are two plots for the satellite's lightcurve. "P1 Scale" uses the same Y-axis scaling as that used for the primary's lightcurve. The "Expanded" plot significantly expands the Y-axis scale to help show the events. In addition, the error bars were hidden since they made seeing the events difficult, especially the shallower one. It is that event (0.02 mag) that was used to compute the effective secondary-to-primary diameter ratio of $Ds/Dp \geq 0.16 \pm 0.04$.

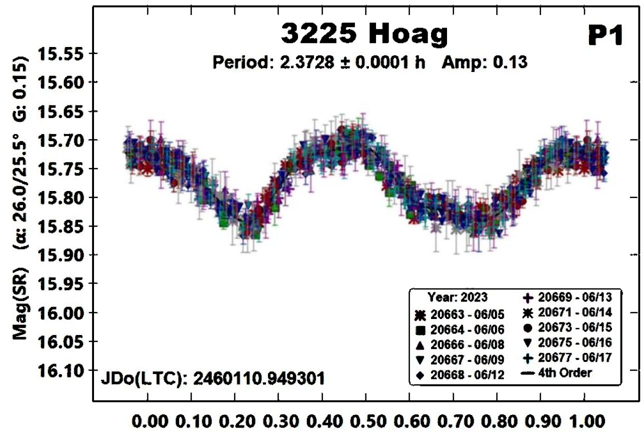
Given the two sets of results from observations at similar phase angle bisector longitudes (2015: 190°; 2023: 210°), the case for the asteroid being a binary is stronger but with the shallow events (so far), strict confirmation from ground-based photometry may not be possible.

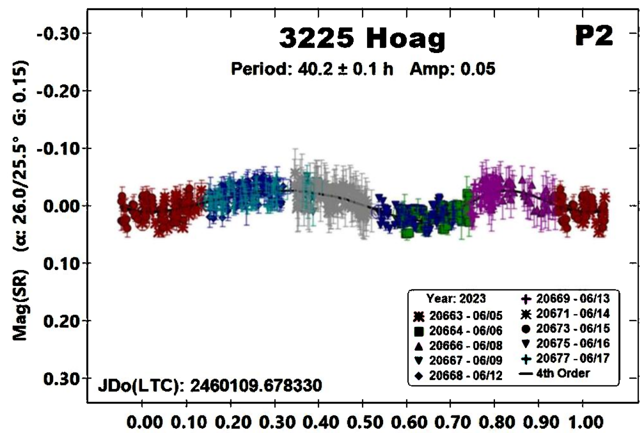




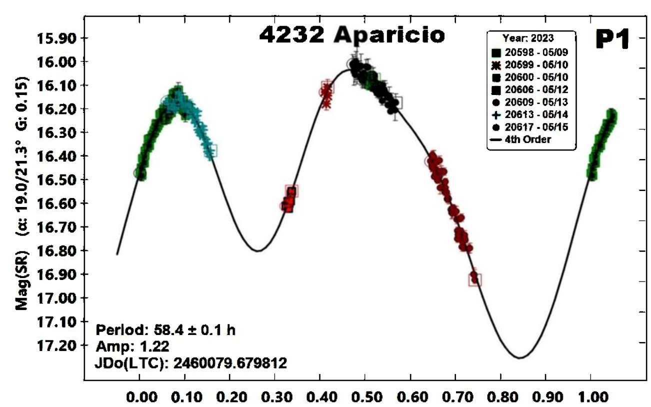


3225 Hoag. Another Hungaria group member, Hoag has been observed by the author at eight different apparitions since 2007, and yet there may still be some doubt about its true nature. The results from the seven previous apparitions have been close to 2.372 h and did not include suspicions of the asteroid being binary. However, the 2023 observations seem to show a previously unreported secondary period of 40.2 ± 0.1 h with a bimodal lightcurve amplitude of 0.05 mag. Assuming the secondary period is valid, one explanation might be a slightly elongated satellite tidally locked to its orbital period. Observations at future apparitions may verify, or refute, this concept.

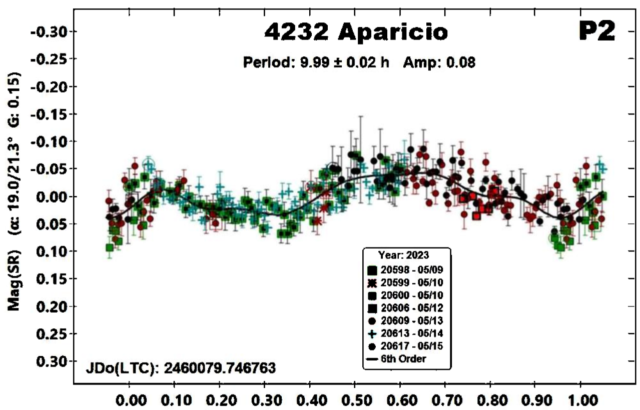




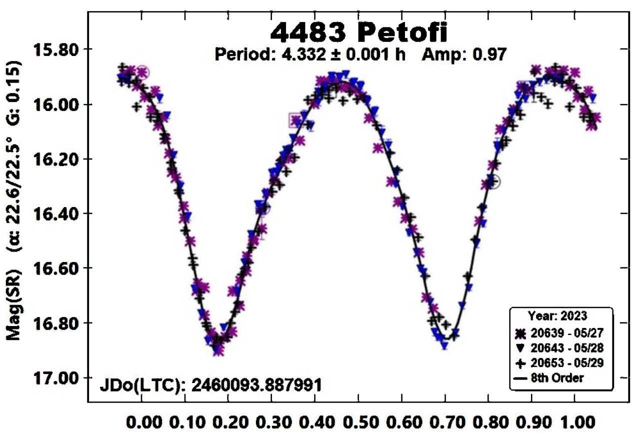
4232 Aparicio. Previous results for this member of the Hungaria collisional family (Nesvorny, 2015; Nesvorny et al., 2015) average 54.2 ± 0.2 h, e.g., Warner (2015c). The data from 2023 were too sparse to duplicate that result exactly buy they did lead to a plausible solution of 58.4 h. The stated amplitude in the plot is likely overstated.



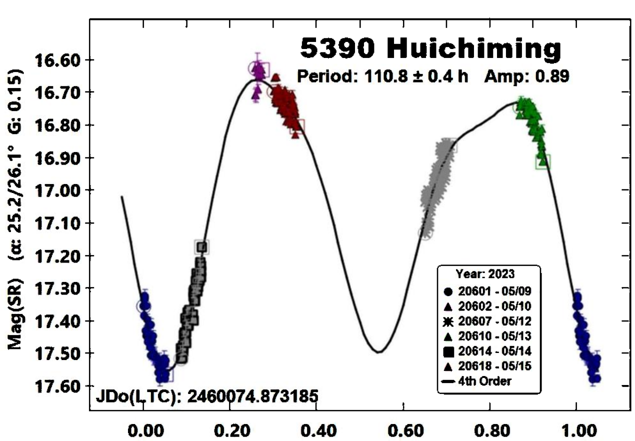
A secondary period affected the quality of the fit for those parts of the lightcurve with overlapping data from different sessions. A dual-period search using *MPO Canopus* extracted a weak solution of P_2 = 9.99 ± 0.02 h, A_2 = 0.08 ± 0.01 mag. If due to a physical cause, the asteroid might be a *very wide binary*. (Warner, 2016).



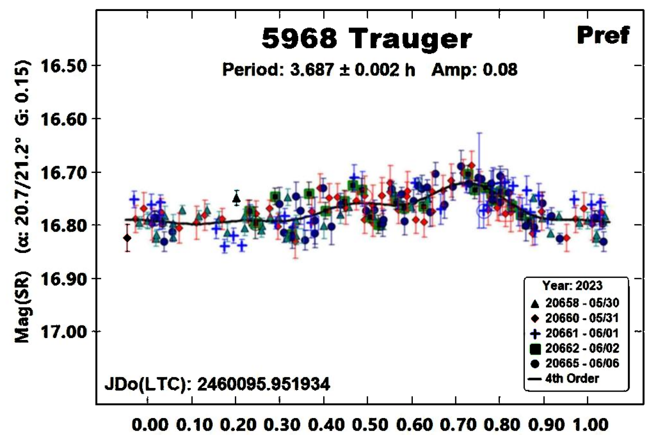
4483 Petofi. Six previous results from the author, e.g., Warner (2012b), have a rotation period very close to 4.33 h. The 2023 results are consistent. The amplitude is about the average of the range reported in the LCDB.

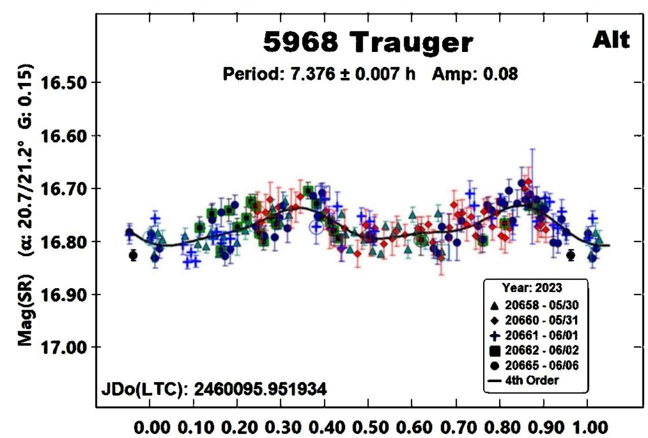


5390 Huichiming. The first time the author observed this Hungaria family member (Warner, 2007b), a period of 33.6 h was reported. This turned out to be "curving a fit," i.e., forcing the data to fit an assumed, incorrect, period. Later observations (Warner, 2009) led to P = 111 h. The 2007 data were revisited (Warner, 2011) and a new value, P = 110 h, was found. Despite the lack of lightcurve coverage, the comparison star magnitudes from the highly-reliable ATLAS rf2 catalog (Tonry et al., 2018) allowed a reasonable fit to a consistent solution of P = 110.8 h.

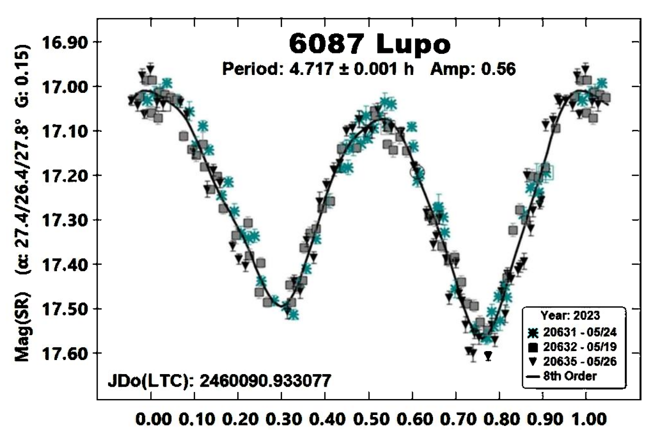


5968 Trauger. A period close to 3.786 h for this Hungaria seems to be the consensus among the LCDB results. The possibility that the asteroid was binary was made by Warner (2014a). No signs of such were seen in the 2023 data. Unfortunately, they led to an ambiguous solution, with one being 3.687 h and the other nearly the double-period. A split-halves plot for the longer period shows that the lightcurve is very symmetrical about the two halves, which favors, but does not assure, that the shorter period is correct.



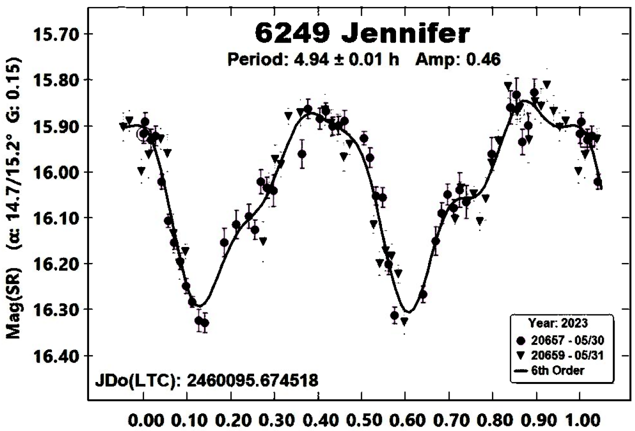


6087 Lupo. Observations by the author at three previous apparitions led to a highly consistent period of 4.71 h, e.g., Warner (2015a; 4.717 h). When modeling the asteroid, Hanuš et al. (2016) found a sideral period in keeping with the synodic periods found before.

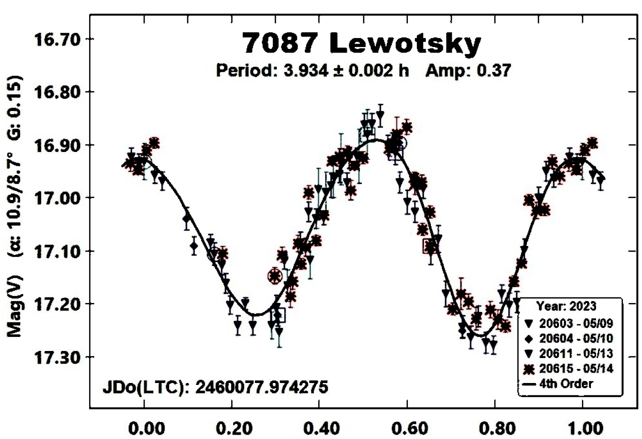


6249 Jennifer. Only a sparse dataset could be managed for the 2023 apparition. However, the resulting period of 4.94 h was consistent with previous results such as Stephens and Warner (2022;

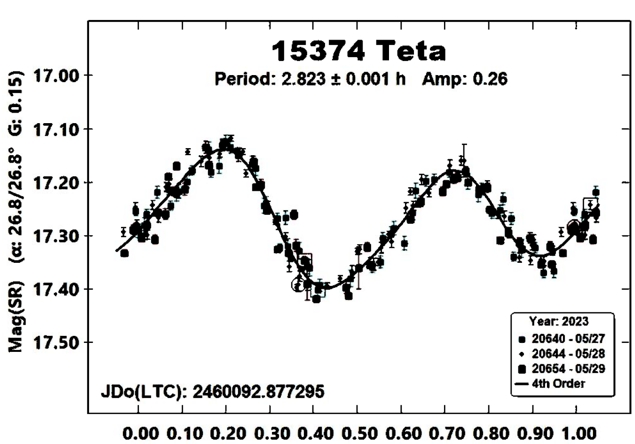
4.958 h). The LCDB reported amplitude range is 0.06-0.55 mag. The large amplitude in 2023 helped overcome the sparse dataset.



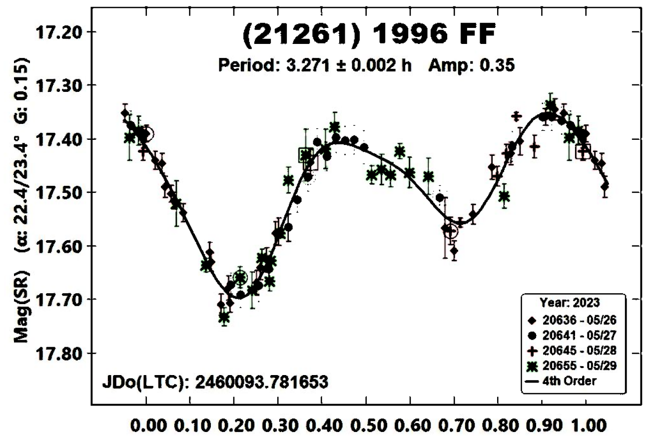
7087 Lewotsky. The primary period for this suspected binary asteroid has been reported many times to be close to 3.942 h. Warner and Stephens (2022) found a weak indication of a satellite with an orbital period of 17.11 h. The dataset was too sparse to support that result. No evidence of a satellite was seen in the 2023 data. Observations at phase angle bisector longitudes near 10° (the value in 2021 September), or 190° are encouraged for future observations.



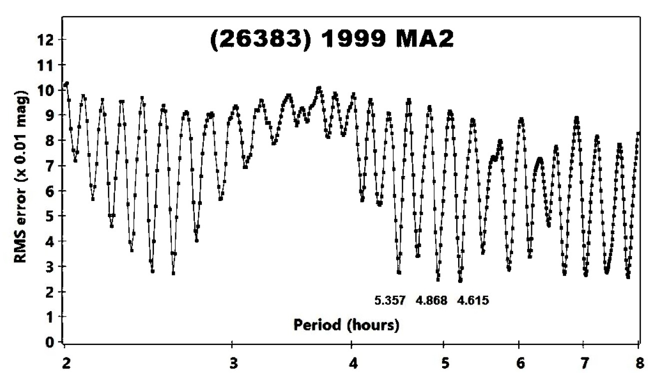
15374 Teta. Observations in 2023 led to a period of 2.823 h, which is consistent with reports from two previous apparitions (Warner, 2010, 2.8204 h; 2014b, 2.820 h). This is the smallest amplitude to-date in the LCDB, the previous range being 0.30-0.39 mag.

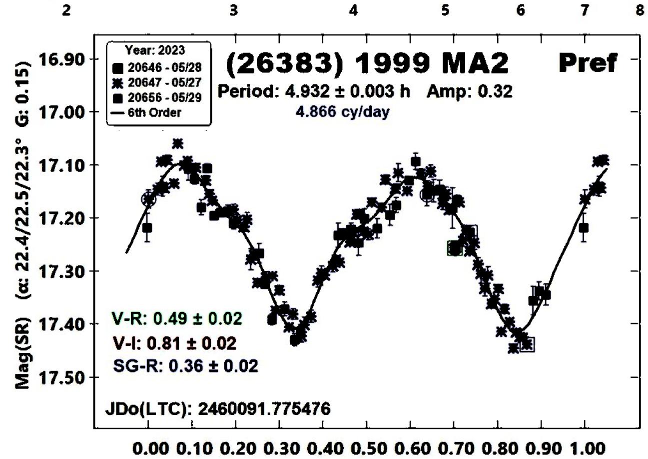


(21261) 1996 FF is a "chip off the block," meaning it is a piece of the parent body of the Hungaria asteroid family. The only previous period in the LCDB was 3.260 h (Warner, 2015c).



(26383) 1999 MA2. This Hungaria family member served double-duty. The first was a demonstration of "fit by exclusion," which is where the wrong solution can be found, no matter how "good" it looks. The period spectrum shows a number of nearly identical solutions with a group at 2-3 hours and another in the 4.5-5.9 h range. The numbers below the three minima are the cycles/day at the minimum period. When a number of similar solutions differ by about 0.5 rotation per day and the lightcurve is fairly symmetrical, it's easy to fall into the trap of accepting the period with the lowest RMS fit to the Fourier curve as being the correct one.

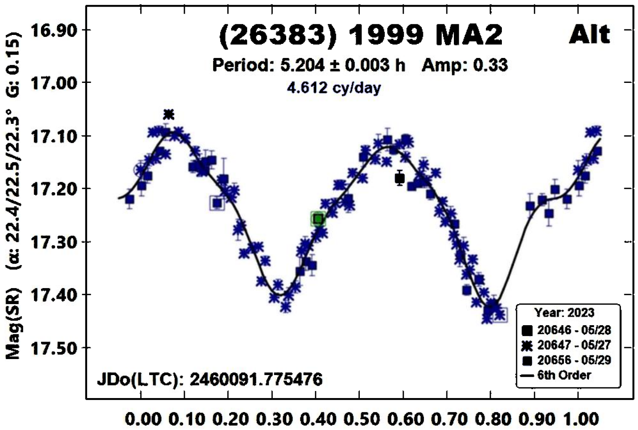




Previous results, e.g., Warner (2012a) are near 4.92 h. This was not the period found in the initial search, but was the alternate period below of 5.204 h.

Keep in mind that the Fourier algorithm finds the lowest possible RMS fit, many times by reducing the number of overlapping data points for a given period, thus the gap in coverage at the far right of both plots. This is a "fit by exclusion," meaning reducing the number of overlapping data points.

An indication of the longer period being incorrect is the way that the Fourier curve has to bend to try to fit the data at large rotation phases. It has lost the symmetry seen in the 4.9 h solution.

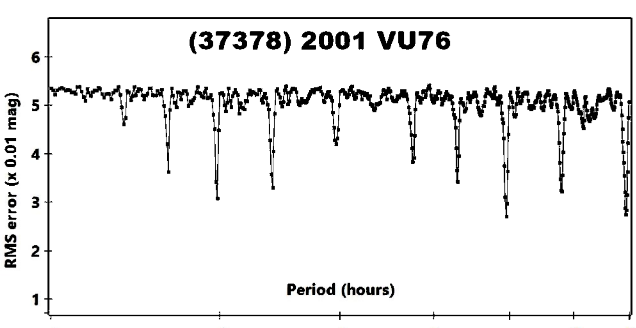


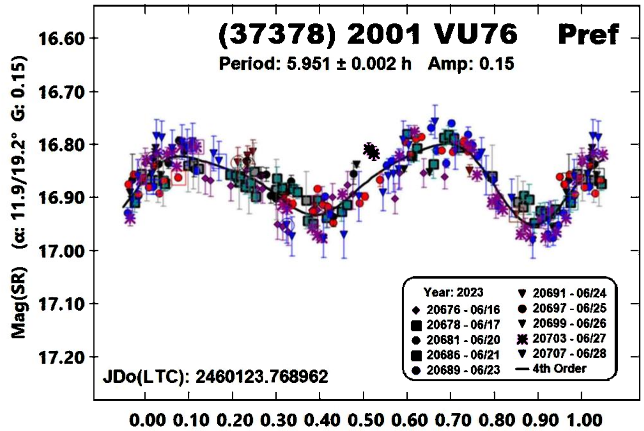
The second duty served was by a serendipitous accident. When editing the script used to image the asteroids on the second night, it was overlooked that the script would take filtered images in Clear/V/R/SG order throughout the night instead of using only a clear filter. The unintended data were used to find three color indexes. The same data could also be used to find the second-order extinction terms for V-R and SG-R. That was left for another time.

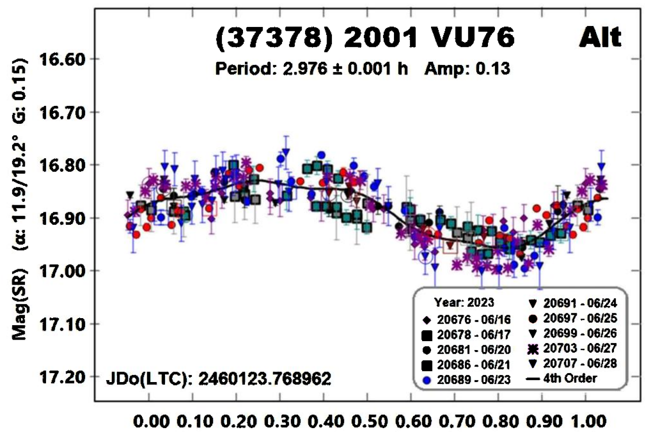
(37378) 2001 VU76. Two datasets from 2018, one obtained in late June and the other in early August, both led to a period of about 1.785 h (Warner, 2019). Despite being so fast, no other "more common" (longer) periods could be found. Both results are now considered entirely wrong.

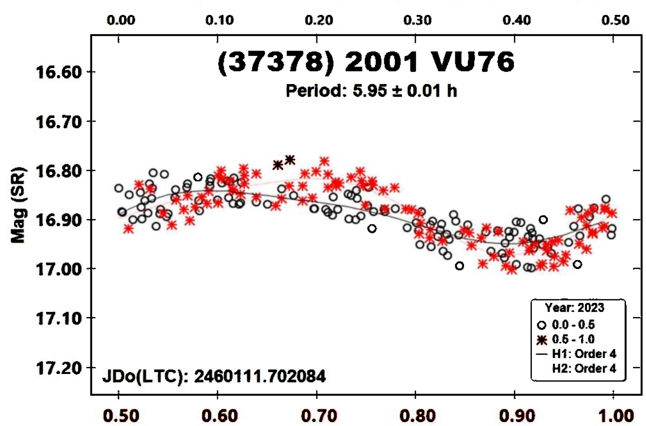
The period spectrum using data from the 2023 observations shows several possible solutions, about 3 h and 6 h in particular. Lightcurves at 2.976 h and 5.951 h are monomodal and bimodal, respectively. Neither one is necessarily correct since at low amplitudes, multimodal lightcurves are possible (Harris et al., 2014).

The split-halves plot led to adopting the 5.951 h period because of the asymmetry of the two halves. Had they been the same, then the shorter period might have been just as valid of a solution.





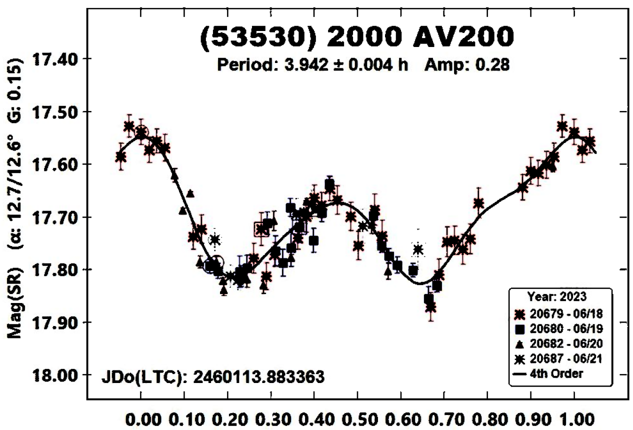


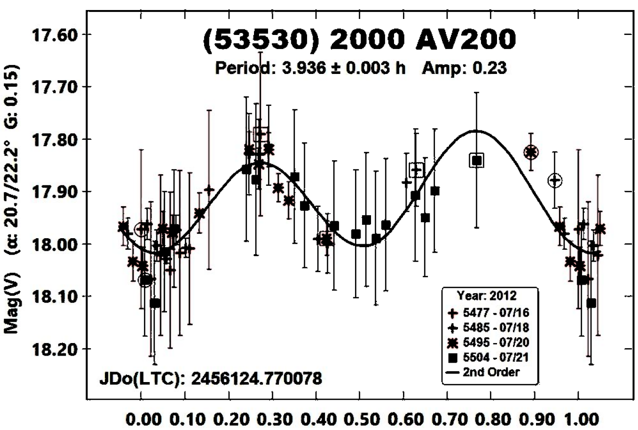


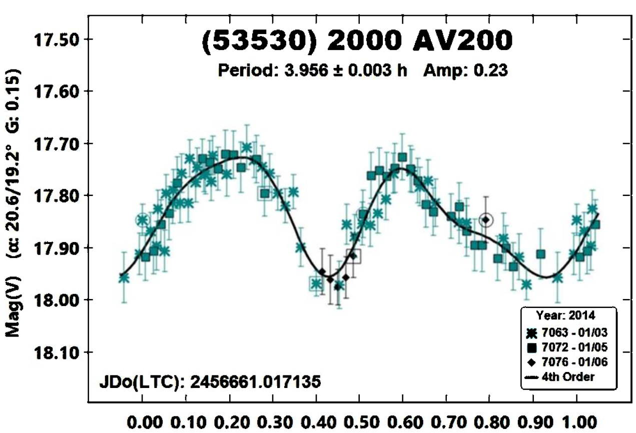
(53530) 2000 AV200. Previous work on this Hungaria collisional member found different periods. Using data from 2012, Warner (2013) found 3.628 h while 2014 data led to a period of 4.310 h (Warner, 2014b). These two periods differ by almost exactly one rotation over 24 hours.

Analysis of the 2023 dataset found a period of 3.942 h. This happens to be about one-half rotation different over a day from either of the other two periods. The earlier datasets were reviewed with the period forced to be near the 2023 solution.

The 2012 dataset was noisy and sparse, so it was easy to see how a false solution might have been found. The forced fit produces an acceptable bimodal lightcurve. The 2014 dataset was better, both in noise and number of data points. It, too, could be fit to a period near 3.94 h. On the other hand, forcing the 2023 data to one of the earlier periods produced "almost good, but not good enough" fits to a bimodal lightcurve.



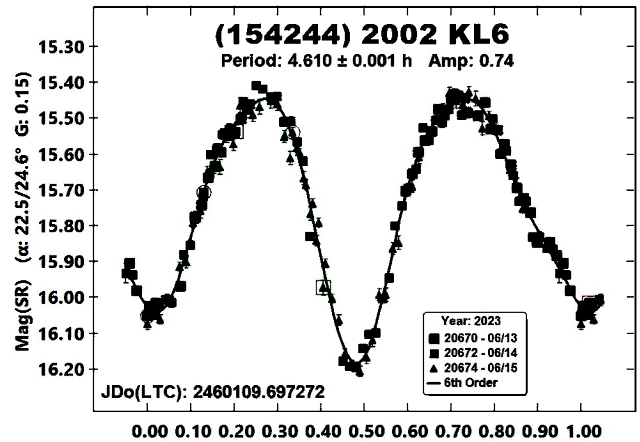




(154244) 2002 KL6. Galad et al. (2010) have the earliest reported results in the LCDB: P = 4.6063 h, A = 1.00 mag. There are more than a dozen other period analysis results in the LCDB, all of them with a period close to 4.60 h. The analysis of the 2023 data gives P = 4.610 h, making it consistent with earlier results.

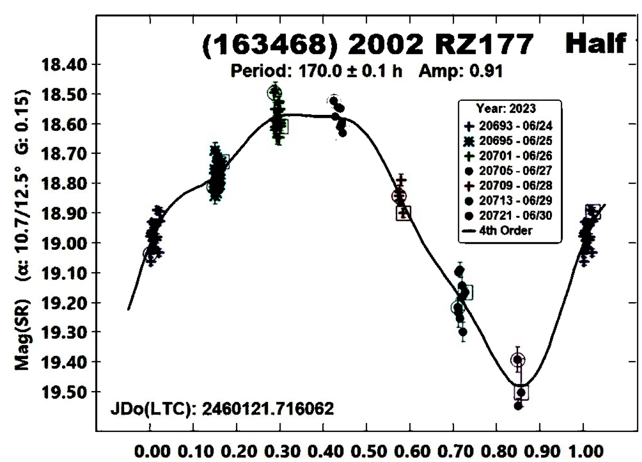
Warner et al. (2016) reported that the asteroid might be binary based on data obtained in 2016 June. A bimodal secondary period of 24.05 h and lightcurve amplitude of 0.08 mag were found but no mutual events were seen then or in the 2023 data.

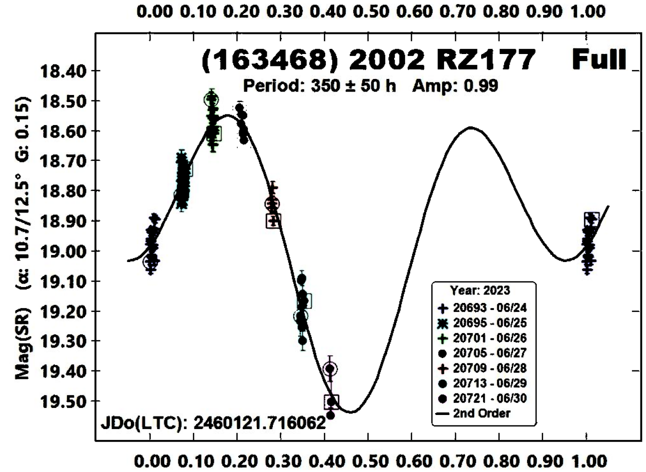
The phase angle bisector longitude (L_{PAB}) in 2016 was about 260°. The closest duplicate (or diametric opposite 80°) observations are from Aznar et al. (2018; 263°). They did not report signs of a satellite. As always with unexplained and/or unconfirmed results, additional observations are encouraged. The asteroid won't be V < 19 mag until 2030 August: V ~ 14.1, Dec +49°.



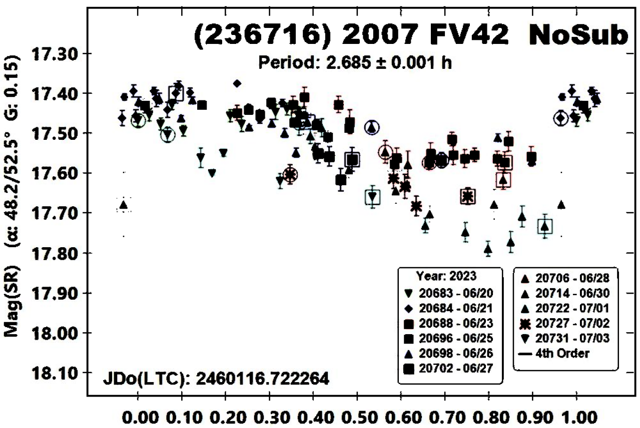
(163468) 2002 RZ177. There were no previously reported periods in the LCDB for this outer main-belt asteroid that kept pace in the field of another target, 1754 Cunningham. Circumstances did not allow long nightly runs nor a long campaign since the field was west of the meridian at the end of twilight.

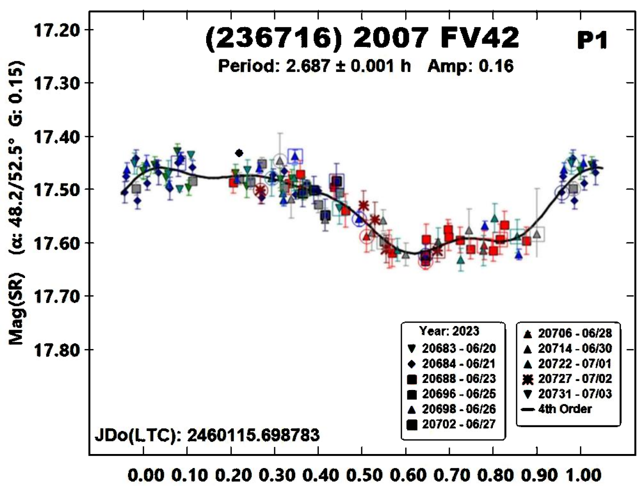
With a large amplitude and relatively low phase angle, the longer, bimodal lightcurve is far more likely correct given the dataset (Harris et al., 2014). The lack of coverage of the full lightcurve makes the solution a "good guess" for the time being. The brightest it will manage in the coming years will be V ~ 18.6 in 2034 May.

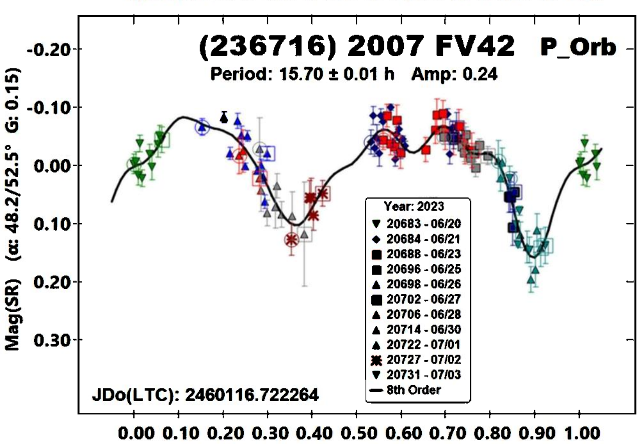




(236716) 2007 FV42. The only previous entry in the LCDB for this NEA is from Binzel et al. (2019), who determined its taxonomic type as S,Sr. The 2023 dataset is somewhat sparse, but it does provide enough information to say it's very possible that this NEA is a binary asteroid. Both periods and the effective diameter ratio, $Ds/Dp \geq 0.54 \pm 0.03$, are consistent with other binary asteroids (Pravec et al., 2018).



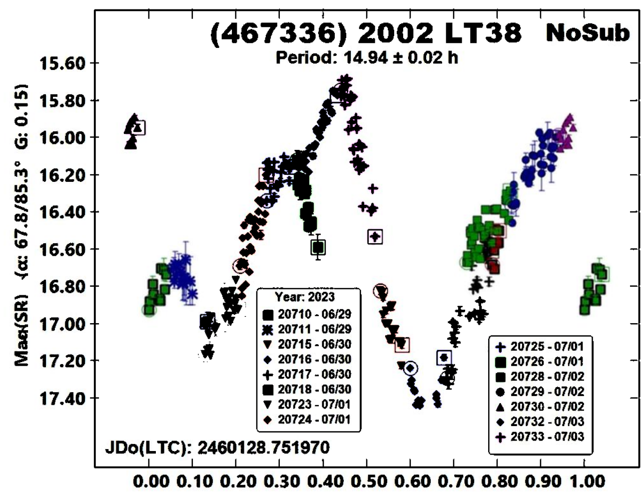


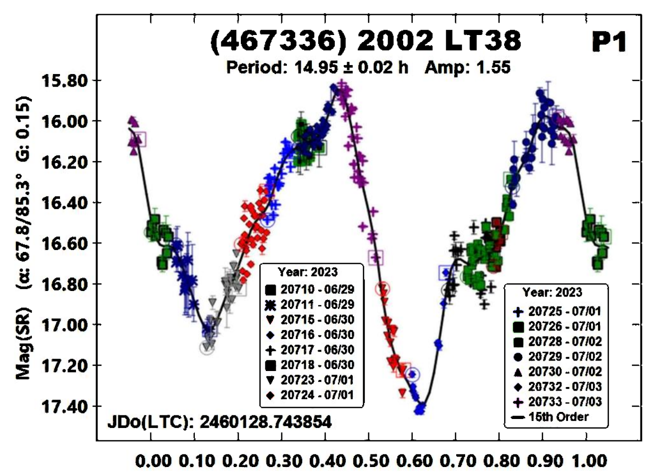


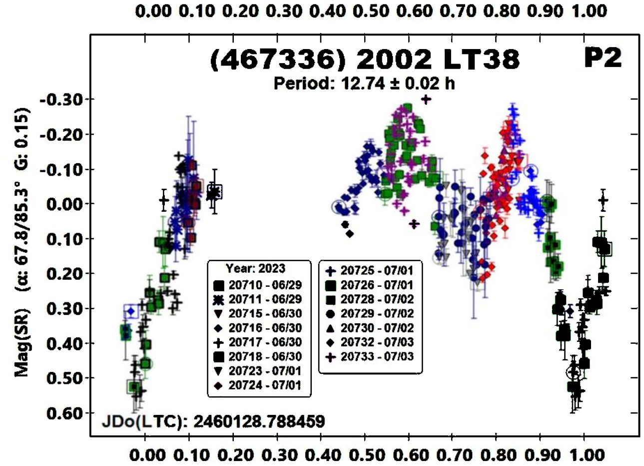
(467336) 2002 LT38. Warner (2017) reported this NEA as a possible tumbler with a dominant period of P = 21.80 h, A = 1.16 mag. A secondary period could not be determined, so the only evidence of tumbling was the shape of the single period lightcurve. The 2023 dataset was more supportive of tumbling (see Pravec et al., 2005; 2014).

The "NoSub" plot shows that a single period could not fit the data and that any secondary period would not be additive, e.g., due to a satellite. The dominant period was found to be 14.94 h. *MPO Canopus* does not handle non-additive periods correctly. Even so, it was used to extract a second period that would at least make for a reasonable dominant period lightcurve. The resulting secondary period of 12.74 h produces a poor lightcurve (at best) but does reach the goal for the dominant period lightcurve. *Neither* period should be considered the true periods of rotation and precession. They are constructs used to establish the strong possibly that the asteroid is tumbling.

The next good chance for observations is 2030 June when the asteroid will be V ~ 15.4 and Dec +21°.







Number	Name	2023/mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp Ds/Dp
1754	Cunningham	06/24-07/03	8.6,10.7	252	14	7.756	0.003	0.17	0.02	H
2272	Montezuma	05/15-05/24	30.2,31.3	252	14	8.186	0.001	1.36	0.03	H
2449	Kenos	05/10-05/24	23.9,29.5	210	26	[B]3.8463	0.0003	0.11	0.01	H
						15.812	0.003	0.05	0.01	0.13
3225	Hoag	06/05-06/16	26.0,25.5	271	37	2.3728	0.0001	0.13	0.01	H
						40.2	0.1	0.05	0.01	H
4232	Aparicio	05/12-05/15	20.3,21.4	202	15	[B]58.4	0.1	1.1	0.2	H
						9.99	0.02	0.08	0.01	
4483	Petofi	05/27-05/29	22.6,22.5	257	36	4.332	0.001	0.97	0.03	H
5390	Huichiming	05/09-05/15	25.2,26.2	188	28	110.8	0.4	0.89	0.05	H
5968	Trauger	05/30-06/02	20.8,20.9	250	31	[A]3.687	0.002	0.08	0.02	H
						7.376	0.007	0.08	0.02	
						7.376	0.007	0.08	0.01	
6087	Lupo	05/19-05/24	26.4,27.4	216	32	4.717	0.001	0.56	0.03	H
6249	Jennifer	05/30-05/31	14.8,15.3	225	8	4.94	0.01	0.46	0.03	H
7087	Lewotsky	05/09-05/14	10.9,8.7	243	8	3.934	0.002	0.37	0.03	H
15374	Teta	05/27-05/29	26.8,26.8	252	43	2.823	0.001	0.26	0.03	H
21261	1996 FF	05/27-05/29	22.8,23.5	209	9	3.271	0.002	0.35	0.03	H
26383	1999 MA2	05/27-05/29	22.5,22.3	249	32	[A]4.932	0.003	0.32	0.02	H
						5.204	0.003	0.33	0.03	
37378	2001 VU76	06/23-06/28	16.2,19.3	257	15	[A]5.951	0.002	0.15	0.02	H
						2.976	0.001	0.13	0.02	
53530	2000 AV200	06/18-06/23	12.7,12.6	266	20	3.942	0.003	0.28	0.03	H
		[2012]07/16-07/21	20.6,22.2	262	17	[C]3.936	0.003	0.23	0.04	
		[2014]01/03-01/06	20.8,19.4	136	4	[C]3.956	0.003	0.23	0.02	H
154244	2002 KL6	06/13-06/15	22.6,24.7	248	8	4.61	0.001	0.74	0.02	NEA
163468	2002 RZ177	06/24-06/30	10.7,12.5	254	14	350	50	0.95	0.05	MB-O
						[HP]170.0	0.1	0.91	0.05	
236716	2007 FV42	06/20-07/03	48.2,52.5	238	9	2.687	0.001	0.16	0.01	NEA
						15.70	0.01	0.24	0.02	0.54
467336	2002 LT38	06/29-07/03	68.1,85.5	245	25	[D]14.95 T	0.01	1.6	0.1	NEA
						12.74	0.02	0.70	0.06	

Table II. Observing circumstances and results. [A]Preferred period of an ambiguous solution. [B]Period of primary with one or more confirmed or suspected satellites. [D]Dominant period of an apparent tumbler. [HF]Half-period used to estimate actual period. If a suspected binary with mutual events, the second line gives the effective diameter ratio (*Ds/Dp*). 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).

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 author gratefully acknowledges a Shoemaker NEO Grants from the Planetary Society (2007). This was used to purchase some of the equipment used in this research.

References

Aznar, A.M.; Predatu, M.; Vaduvescu, O.; Oey, J. (2018). "EURONEAR - First Light Curves and Physical Properties of Near-Earth Asteroids." arXiv:1801.09420. *Romanian J. Phys.* **62**, 904.

Binzel, R.P.; DeMeo, F.E.; Turtelboom, E.V.; Bus, S.J.; Tokunaga, A.; Burbine, T.H.; Lantz, C.; Polishook, D. and 15 colleagues (2019). "Compositional distributions and evolutionary processes for the near-Earth object population: Results from the MIT-Hawaii Near-Earth Object Spectroscopic Survey (MITHNEOS)." *Icarus* **324**, 41-76.

Galad, A.; Kornos, L.; Vilagi, J. (2010). "An Ensemble of Lightcurves from Modra." *Minor Planet Bull*. **37**, 9-15.

Hanuš, J.; Ďurech, J.; Oszkiewicz, D.A.; Behrend, R.; Carry, B.; Delbo, M.; Adam, O.; Afonina, V.; Anquetin, R.; Antonini, P. and 159 colleagues (2016). "New and updated convex shape models of asteroids based on optical data from a large collaboration network." *Astron. Astrophys.* **586**, A108.

Harris, A.W.; Young, J.W.; Scaltriti, F.; Zappala, V. (1984). "Lightcurves and phase relations of the asteroids 82 Alkmene and 444 Gyptis." *Icarus* **57**, 251-258.

Harris, A.W.; Pravec, P.; Galad, A.; Skiff, B.A.; Warner, B.D.; Vilagi, J.; Gajdos, S.; Carbognani, A.; Hornoch, K.; Kusnirak, P.; Cooney, W.R.; Gross, J.; Terrell, D.; Higgins, D.; Bowell, E.; Koehn, B.W. (2014). "On the maximum amplitude of harmonics on an asteroid lightcurve." *Icarus* **235**, 55-59.

Nesvorny, D. (2015). "Nesvorny HCM Asteroids Families V3.0." NASA Planetary Data Systems, id. EAR-A-VARGBET-5-NESVORNYFAM-V3.0.

Nesvorny, D.; Broz, M.; Carruba, V. (2015). "Identification and Dynamical Properties of Asteroid Families." In *Asteroids IV* (P. Michel, F. DeMeo, W.F. Bottke, R. Binzel, Eds.). Univ. of Arizona Press, Tucson, also available on astro-ph.

Pravec, P.; Harris, A.W.; Scheirich, P.; Kušnirák, P.; Šarounová, L.; Hergenrother, C.W.; Mottola, S.; Hicks, M.D.; Masi, G.; Krugly, Yu.N.; Shevchenko, V.G.; Nolan, M.C.; Howell, E.S.; Kaasalainen, M.; Galád, A.; Brown, P.; Degraff, D.R.; Lambert, J.V.; Cooney, W.R.; Foglia, S. (2005). "Tumbling asteroids." *Icarus* **173**, 108-131.

Pravec, P.; Scheirich, P.; Kusnirák, P.; Sarounová, L.; Mottola, S.; Hahn, G.; Brown, P.; Esquerdo, G.; Kaiser, N.; Krzeminski, Z. and 47 colleagues (2006). "Photometric survey of binary near-Earth asteroids." *Icarus* **181**, 63-93.

Pravec, P.; Scheirich, P.; Durech, J.; Pollock, J.; Kusnirak, P.; Hornoch, K.; Galad, A.; Vokrouhlicky, D.; Harris, A.W.; Jehin, E.; Manfroid, J.; Opitom, C.; Gillon, M.; Colas, F.; Oey, J.; Vrastil, J.; Reichart, D.; Ivarsen, K.; Haislip, J.; LaCluyze, A. (2014). "The tumbling state of (99942) Apophis." *Icarus* **233**, 48-60.

Pravec, P.; Fatka, P.; Vokrouhlicky, D.; Scheeres, D.J.; Kusnirak, P.; Hornoch, K.; Galad, A.; Vrastil, J.; Pray, D.P.; Krugly, Yu.N.; Gaftonyuk, N.M.; Inasaridze, R.Ya.; Ayvazian, V.R.; Kvaratskhelia, O.I.; Zhuzhunadze, V.T.; Husarik, M.; Cooney, W.R.; Gross, J.; Terrell, D.; Világi, J. Kornos, L.; Gajdos, S.; Burkhonov, O.; Ehgamberdiev, Sh.A.; Donchev, Z.; Borisov, G.; Bonev, T.; Rumyantsev, V.V.; Molotov, I.E. (2018). "Asteroid clusters similar to asteroid pairs." *Icarus* **304**, 110-126.

Stephens, R.D. (2015). "Asteroids Observed from CS3: Results for 1754 Cunningham and 7023 Heiankyo." *Minor Planet Bull*. **42**, 279.

Stephens, R.D.; Warner, B.D. (2022). "Main-belt Asteroids Observed from CS3: 2021 September - 2022 January." *Minor Planet Bull*. **49**, 108-110.

Tonry, J.L.; Denneau, L.; Flewelling, H.; Heinze, A.N.; Onken, C.A.; Smartt, S.J.; Stalder, B.; Weiland, H.J.; Wolf, C. (2018). "The ATLAS All-Sky Stellar Reference Catalog." *Astrophys. J.* **867**, A105.

Warner, B.D. (2007a). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory - December 2006 - March 2007." *Minor Planet Bull*. **34**, 72-77.

Warner, B.D. (2007b). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory – March - May 2007." *Minor Planet Bull*. **34**, 104-107.

Warner, B.D. (2009). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2008 September - December." *Minor Planet Bull*. **36**, 70-73.

Warner, B.D. (2010). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2009 June - September." *Minor Planet Bull*. **37**, 24-27.

Warner, B.D. (2011). "Upon Further Review: VI. An Examination of Previous Lightcurve Analysis from the Palmer Divide Observatory." *Minor Planet Bull*. **38**, 96-101.

Warner, B.D. (2012a). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2011 December - 2012 March." *Minor Planet Bull*. **39**, 158-167.

Warner, B.D. (2012b). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2012 March - June." *Minor Planet Bull*. **39**, 245-252.

Warner, B.D. (2013). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2012 June - September." *Minor Planet Bull*. **40**, 26-29. (53530)

Warner, B.D. (2014a). "Binary Asteroid Lightcurve Analysis at the CS3-Palmer Divide Station: 2013 June - September." *Minor Planet Bull*. **41**, 54-57.

Warner, B.D. (2014b). "Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2014 January - March." *Minor Planet Bull*. **41**, 144-155.

Warner, B.D. (2015a). "Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2014 December - 2015 March." *Minor Planet Bull*. **42**, 167-172.

Warner, B.D. (2015b). "Three Unusual Hungaria Asteroids." *Minor Planet Bull*. **42**, 183-186.

Warner, B.D. (2015c). "Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2015 March - June." *Minor Planet Bull*. **42**, 267-276.

Warner, B.D. (2016). "Three Additional Candidates for the Group of Very Wide Binaries." *Minor Planet Bul.* **43**, 306-309. (Wide Binaries).

Warner, B.D. (2017). "Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2016 July - September." *Minor Planet Bull*. **44**, 22-36.

Warner, B.D. (2018). "Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2018 April - June." *Minor Planet Bull*. **45**, 380-386.

Warner, B.D. (2019). "Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2018 July - September." *Minor Planet Bull*. **46**, 46-51.

Warner, B.D.; Harris, A.W.; Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2023 March. *http://www.minorplanet.info/lightcurvedatabase.html*

Warner, B.D.; Benishek, V.; Ferrero, A.; Skiff, B.A. (2016). "Lightcurve Analysis of NEA (154244) 2002 KL6: A Potential New Binary Asteroid." *Minor Planet Bull*. **43**, 343-344.

Warner, B.D.; Stephens, R.D. (2018). "Lightcurve Analysis of Hilda Asteroids at the Center for Solar System Studies: 2017 July Through September." *Minor Planet Bull*. **45**, 35-39.

Warner, B.D.; Stephens, R.D. (2021). "Lightcurve Analysis of Hilda Asteroids at the Center for Solar System Studies: 2020 October - December." *Minor Planet Bull*. **48**, 164-165.

Warner, B.D.; Stephens, R.D. (2022). "On Confirmed and Suspected Binary Asteroids Observed at the Center for Solar System Studies." *Minor Planet Bull*. **49**, 22-29.

LIGHTCURVES AND ROTATION PERIODS OF 102 MIRIAM, 126 VELLEDA, 294 FELICIA, 547 PRAXEDIS, 716 BERKELEY, 1166 SAKUNTALA, AND 2535 HAMEENLINNA

Frederick Pilcher
Organ Mesa Observatory (G50)
4438 Organ Mesa Loop
Las Cruces, NM 88011 USA
fpilcher35@gmail.com

(Received: 2023 July 10)

Synodic rotation periods and lightcurve amplitudes at their year 2023 oppositions are found for 102 Miriam 23.618 ± 0.002 hours, 0.11 ± 0.01 magnitudes; 126 Velleda 5.3674 ± 0.0001 hours, 0.20 ± 0.01 magnitudes; 294 Felicia 10.426 ± 0.001 hours, 0.15 ± 0.01 magnitudes; 547 Praxedis 9.104 ± 0.002 hours, 0.06 ± 0.02 magnitudes; 716 Berkeley 15.580 ± 0.001 hours, 0.16 ± 0.02 magnitudes; 1166 Sakuntala 6.2912 ± 0.0002 hours, 0.21 ± 0.01 magnitudes; 2535 Hameenlinna 3.2312 ± 0.0002 hours, 0.10 ± 0.02 magnitudes. For 102 Miriam, V-R = 0.36, H = 9.32, G = 0.21. For 126 Velleda, V-R = 0.49, H = 9.40, G = 0.21.

The new observations to produce the results reported in this paper were made at the Organ Mesa Observatory with a Meade 35-cm LX200 GPS Schmidt-Cassegrain, SBIG STL-1001E CCD, 60 to 120 second exposures, unguided, clear filter. Image measurement and lightcurve construction were with *MPO Canopus* software with calibration star magnitudes for solar colored stars from the CMC15 catalog reduced to the Cousins R band. Zero-point adjustments of a few × 0.01 magnitude were made for best fit. To reduce the number of data points on the lightcurves and make them easier to read, data points have been binned in sets of 3 with maximum time difference 5 minutes.

<u>102 Miriam.</u> All early observations were made at oppositions near perihelion at longitude 358° and assumed the usual two maxima and minima per rotational cycle. These include Shevchenko et al. (1997), 15.789h; Riccioli et al. (2001), 15.853h; Johnson et al. (2008), 15.789 h; and a recent result by Behrend (2020web), 15.79h. This author (Pilcher, 2008), with observations extending for a much longer interval of two months near celestial longitude 21°, found a period of 23.613h with three unequal maxima and minima per rotational cycle that ruled out all periods near 15.8h. At a different celestial longitude of 117°, this author (Pilcher, 2013), again based on two months of observations, found a good fit to a period of 23.625h with a lightcurve including two unevenly spaced maxima and minima and smaller scale irregularities, again definitively ruling out a period approximately 2/3 as great. Franco et al. (2021) near celestial longitude 24° published a period of 23.63 hours. New observations on seven nights 2023 Mar. 27 - May 23 near celestial longitude 202° also provide a good fit to a lightcurve (Figure 1) with two asymmetric maxima, additional irregularities, a period of 23.618 ± 0.002 hours, and amplitude 0.11 ± 0.01 magnitudes. This period is compatible with the dense lightcurves of Pilcher (2008), Pilcher (2013), and Franco et al. (2021).

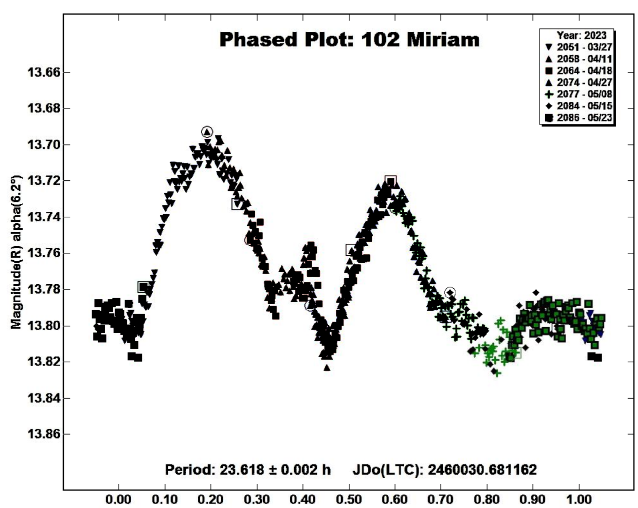


Figure 1. Phased lightcurve of 102 Miriam.

On 2023 Apr. 18, twenty images were obtained alternately with the R and V filters. Both image sets were measured with the same calibration stars. The method of extracting their R and V colors is explained by this author in Pilcher et al. (2016). The composite lightcurve (Figure 2) shows that V-R = 0.36. The calibrated R magnitudes found for each session were converted to V magnitudes by adding 0.36. An H-G plot in the V band (Figure 3) shows that at mid-light H = 9.323 ± 0.026, G = 0.212 ± 0.042.