Stephens, R.D. (2010). “Trojan Asteroids Observed from GMARS and Santana Observatories: 2009 October - December.” *Minor Planet Bull.* **37**, 47-48.

Stephens, R.D.; Coley, D.R.; Warner, B.D.; French, L.M. (2016). “Lightcurves of Jovian Trojan Asteroids from the Center for Solar System Studies: L4 Greek Camp and Spies.” *Minor Planet Bull*. **43**, 323-331.

Stephens, R.D.; Warner, B.D. (2020). “Lightcurve Analysis of L4 Trojan Asteroids at the Center for Solar System Studies: 2019 July To September.” *Minor Planet Bull*. **47**, 43-47.

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.; Harris, A.W.; Pravec, P. (2009). “The Asteroid Lightcurve Database.” *Icarus* **202**, 134-146. Updated 2020 Oct. *http://www.minorplanet.info/lightcurvedatabase.html*

CALL FOR OBSERVATIONS

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

Observers who have made visual, photographic, or CCD measurements of positions of minor planets in calendar year 2020 are encouraged to report them to this author on or before 2021 April 1. This will be the deadline for receipt of reports, for which results can be included in the “General Report of Position Observations for 2020,” to be published in *MPB* Vol. 48, No. 3.

NEAR-EARTH ASTEROID LIGHTCURVE ANALYSIS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2020 SEPTEMBER TO 2021 JANUARY

Brian D. Warner
Center for Solar System Studies / MoreData!
446 Sycamore Ave.
Eaton, CO 80615 USA
brian@MinorPlanetObserver.com

Robert D. Stephens
Center for Solar System Studies / MoreData!
Rancho Cucamonga, CA

(Received: 2021 Jan 10)

Lightcurves of 22 Near-Earth asteroids (NEAs) obtained at the Center for Solar System Studies (CS3) from 2020 October to early 2021 January were analyzed for rotation period, peak-to-peak amplitude, and signs of satellites or tumbling.

CCD photometric observations of 22 near-Earth asteroids (NEAs) were made at the Center for Solar System Studies (CS3) from 2020 September to early 2021 January. Table I lists the telescopes and CCD cameras that were combined to make observations.

Up to nine telescopes can be used for the campaign, although seven is more common. All the cameras use CCD chips from the KAF blue-enhanced family and so have essentially the same response. The pixel scales ranged from 1.24-1.60 arcsec/pixel.

Telescopes	Cameras
0.30-m *f*/6.3 Schmidt-Cass	FLI Microline 1001E
0.35-m *f*/9.1 Schmidt-Cass	FLI Proline 1001E
0.40-m *f*/10 Schmidt-Cass	SBIG STL-1001E
0.40-m *f*/10 Schmidt-Cass	
0.50-m *f*/8.1 Ritchey-Chrétien	

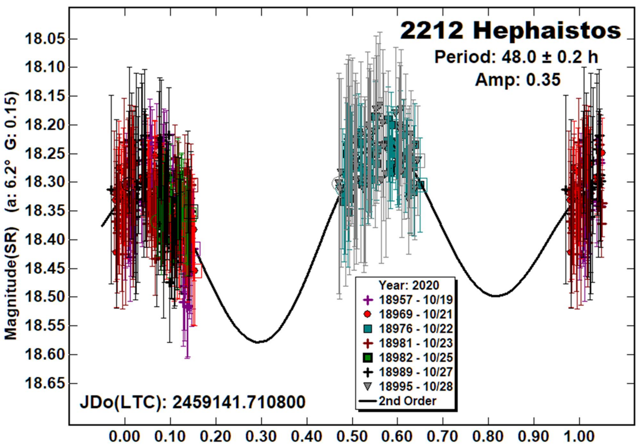
Table I. List of available telescopes and CCD cameras at CS3. The exact combination for each telescope/camera pair can vary due to maintenance or specific needs.

All lightcurve observations were unfiltered since a clear filter can cause a 0.1-0.3 mag loss. The exposure duration varied depending on the asteroid’s brightness and sky motion. Guiding on a field star sometimes resulted in a trailed image for the asteroid.

Measurements were made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. To reduce the number of times and amounts of adjusting nightly zero points, we use the ATLAS catalog r´ (SR) magnitudes (Tonry et al., 2018). 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. Another cause may be selecting what appears to be a single star but is actually an unresolved pair.

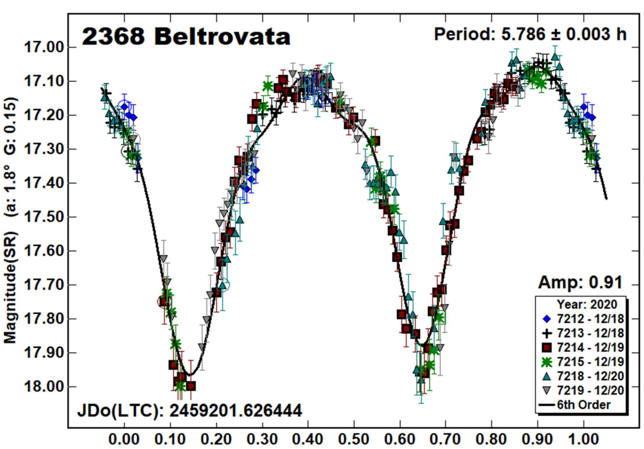
The Y-axis values are ATLAS SR “sky” (catalog) magnitudes. The two values in the parentheses are the phase angle (a) and the value of *G* used to normalize the data to the comparison stars used in the earliest session. This, in effect, had all the observations made at a single fixed date/time and phase 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*.

2212 Hephaistos. The estimated diameter for this NEA is 5.54 km (Mainzer et al., 2016). Pravec et al. (1997) reported a period of >20 h but the result was considered unreliable. Our data led to two probable results near 16 h and 48 h when using a second-order fit. We adopted a period of 48 h with a bimodal lightcurve based on the presumed amplitude of about 0.35 mag, which makes a bimodal lightcurve more likely than not (Harris et al., 2014) and because the slopes of the data agreed with the slopes of the Fourier model curve.

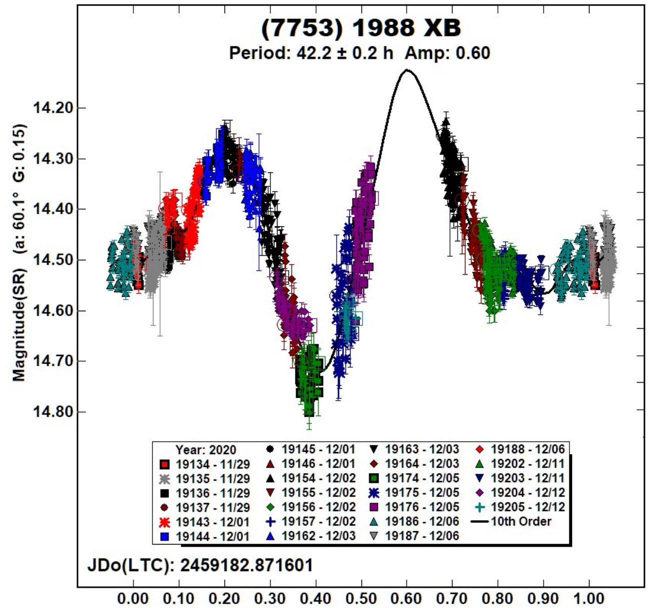


2368 Beltrovata. Pál et al. (2020) used TESS data to find a period of 5.793 h. Our result confirms their finding.

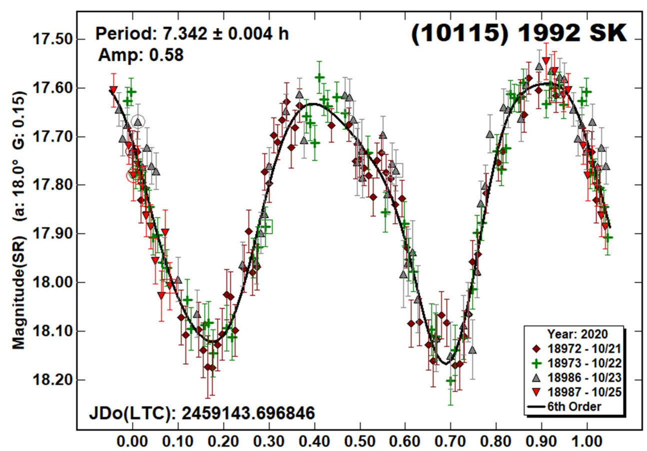
The 6th-order Fourier curve gave a good approximate peak-to-peak amplitude of 0.91 mag, but fell short of the bottom of the second minimum at 0.65 rotation phase by about 0.1 mag, giving a false impression of asymmetry in the lightcurve. In reality, the two minimums are actually close to the same depth. Lightcurves using higher order fits had too many artificial deviations from a smooth curve as the Fourier analysis locked onto noise.



(7753) 1988 XB. There were no previously reported periods in the LCDB for this 560-m NEA. The high phase angle helped produce a somewhat unusual shape. Despite that and the incomplete coverage, we have high confidence in the result.



(10115) 1992 SK. This 1-km NEA has been worked numerous times before, e.g., Pravec et al. (1999web, 7.328 h) and Polishook (2012, 7.31 h). The first time we observed 1992 SK was in 2013 November (Warner, 2014), which led to a period of 7.323 h. Our most recent result is in good agreement with the previous works.



(16834) 1997 WU22. Pravec et al. (2000web) found a period of 9.345 h using data from 2000 August. Vaduvescu et al. (2017) reported 9.36 h. This is the fourth time the asteroid has been observed at CS3. The three previous results were Stephens (2013web, 9.374 h), Warner (2017a, 9.343 h), and Warner and Stephens (2019, 9.348 h).

Source	α°	L_{PAB}	Amp	$Amp_{0°}$
Pravec et al. (2000web)	59	300	0.38	0.14
Stephens (2013web)	5	66	0.29	0.25
Vaduvescu et al. (2017)	58	300	0.48	0.18
Warner (2017a)	77	274	0.60	0.26
Warner and Stephens (2019)	27	21	0.63	0.35
This work	6	53	0.31	0.26

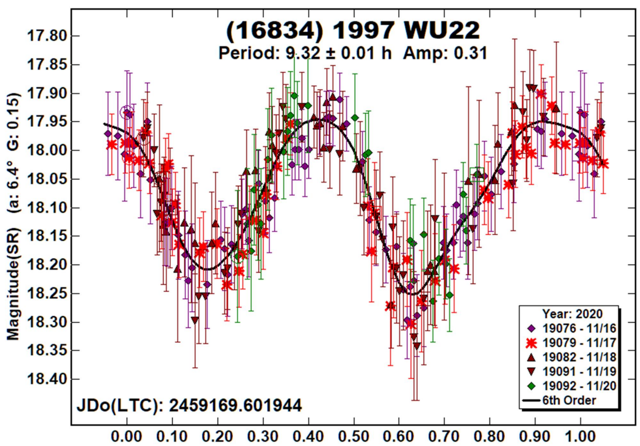
Table II. A comparison of amplitudes versus phase angle at different phase angle bisector longitudes for (16834). Amp is the measured amplitude of the lightcurve. $Amp_{0°}$ is the derived magnitude at 0° phase angle (Zappala et al., 1990).

An accurate comparison of amplitudes versus phase angle bisector longitude (L_{PAB}) requires reducing the amplitudes to a fixed phase angle, usually 0° by using the formula from Zappala et al. (1990):

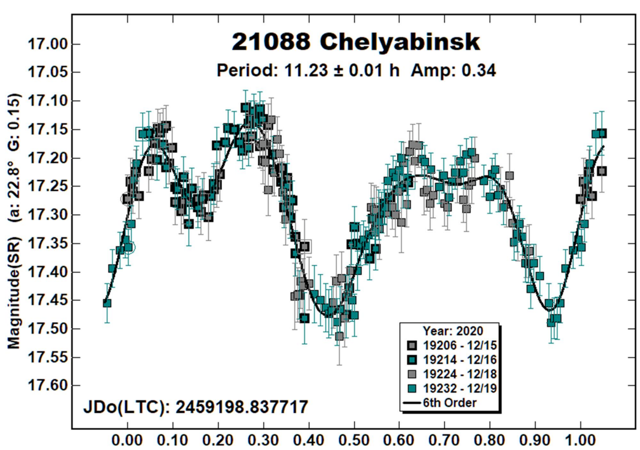
$$A_{0°} = A_{a}/(1 + ma)$$

Where α is the phase angle of the observations and *m* is a value based on taxonomic type. Assuming type S, the case for most NEAs, *m* = 0.030.

From Table II, a few suppositions can be made. The observations near L_{PAB} = 300° show the lowest adjusted amplitudes. From this, it can be assumed that the pole of the asteroid has an ecliptic longitude near 300° (or 120°). Since the adjusted amplitudes show a significant, though not extreme, range, the pole of the spin axis is moderately inclined from the ecliptic plane. Assuming the observations by Warner and Stephens (2019) were at a nearly equatorial view of the asteroid, then the *a/b* ratio of a smoothed triaxial ellipsoid is *a/b* ~ 1.38. Proper lightcurve inversion analysis is required to confirm the veracity of these results.



21088 Chelyabinsk. Pravec et al. (2002web) found a period of 22.49 h and *A* > 0.13 mag. They followed up in 2014 (Pravec et al., 2014), finding a period of 22.426 but could not put a firm cap on the amplitude.

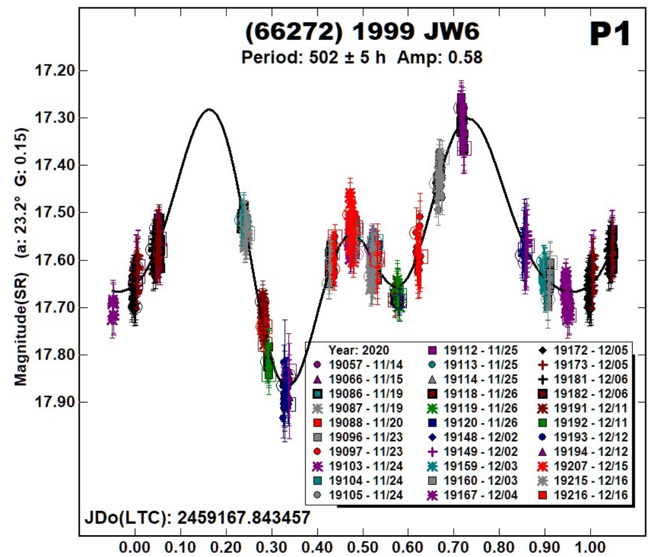


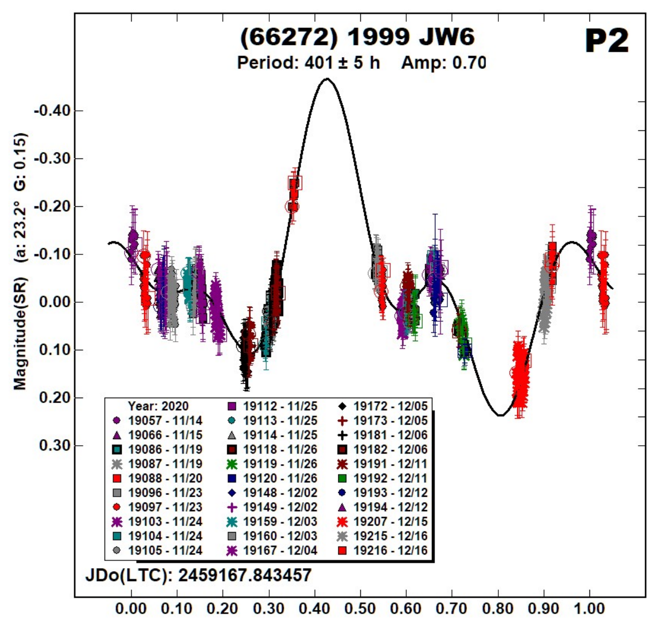
Our data from long nights in 2020 December allowed following the lightcurve for a large portion of its lightcurve, if adopting our period of 11.23 h. Given the amplitude and modest phase angle, the bimodal solution seems secure (Harris et al., 2014). More so, the asymmetry of the two halves of the lightcurve led us to reject the nearly double-period found by Pravec et al (2014).

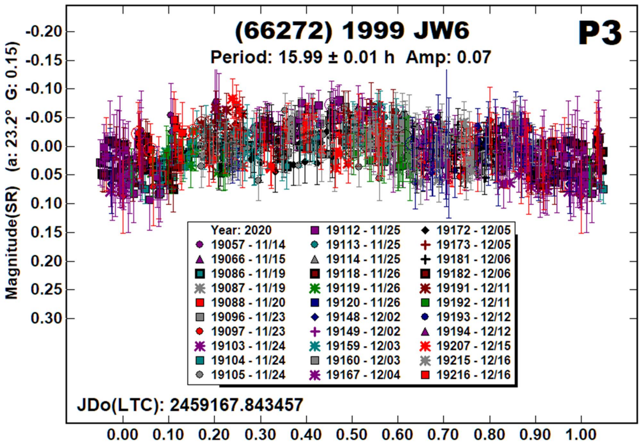
(66272) 1999 JW6. There were no previous rotation periods listed in the LCDB. Mainzer et al. (2016) estimated the effective diameter to be 750 ± 350 m. Using *H* = 17.1, they found an albedo of p_V = 0.453. This is unusually high for an NEA (Warner et al., 2009) but several other NEAs in the LCDB have similar values.

Initial analysis of the observations offered the possibility that the asteroid might be a member of the very wide binary asteroids (see Warner, 2016; and Jacobson et al., 2014). As more data became available, the more probable interpretation was that the asteroid was tumbling.

MPO Canopus is not able to handle tumbling asteroids correctly since it cannot perform a simultaneous dual-period search. The best it could do in this case was find the most dominant period in the data set and then, using an iterative dual-period search, find the dominant period after subtracting the first period. This led to finding periods of P_1 = 502 h and P_2 = 401 h.





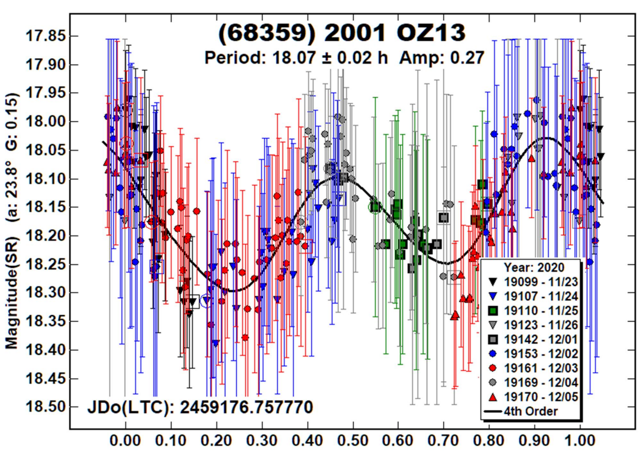


While not obvious from the lightcurves, the slope of the data in various sessions closely matches the slope of the Fourier curve; this lends at least some support for the derived periods. However, as with many tumbling asteroids, the two periods may not be the true periods of rotation and precession but are related to them by integral multiples of frequency, i.e., 1/*P*.

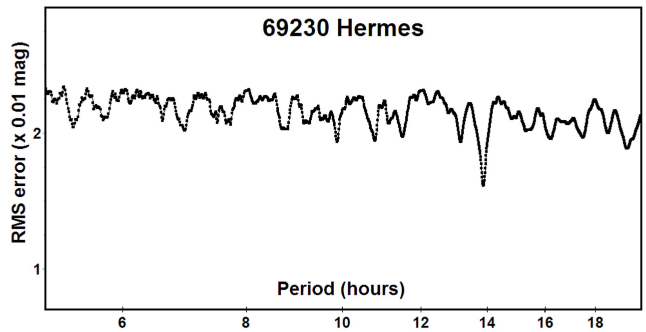
After find the two periods, there were still some residuals that led to a third period of 15.99 h. This is almost exactly 2/3 of an Earth day and could easily be the result of systematic errors and the sampling of the lightcurve at fixed intervals of about 24 hours.

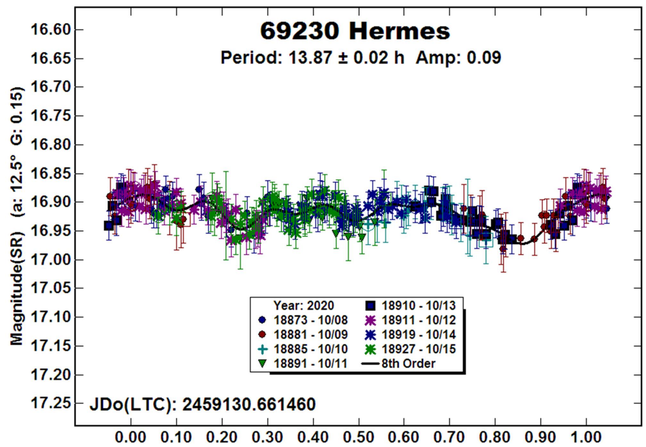
Using the rules of thumb for tumbling damping time (Pravec et al., 2014; 2005), the diameter and periods make this a good candidate for tumbling, which lends further support to the results.

<u>(68359) 2001 OZ13</u>. Pál et al. (2020) found a period of 2.9103 h. Our data were extremely noisy. Even so, we could not find a period near 2.9, as shown in the period spectrum. We do not have high confidence in the result. The next favorable apparition is in 2023 January when the asteroid will be V ~ 16.7 at +37° declination.



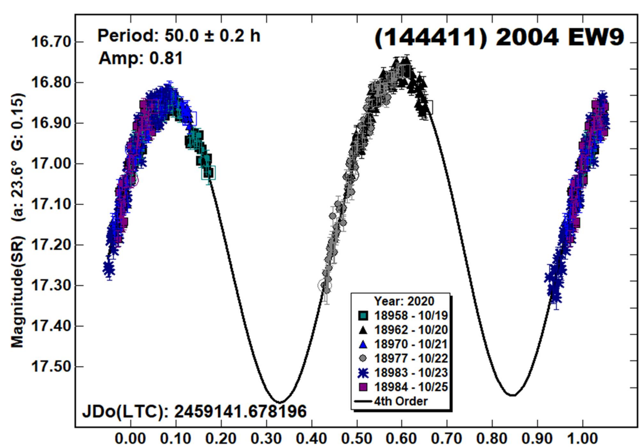
<u>69230 Hermes</u>. Pravec et al. (2003web) and Margot et al. (2003) reported this to be a binary asteroid. The radar observations by Margot et al. (2003) showed the asteroid to be "strongly bifurcated," being comprised to two bodies and "consistent with a rotating binary pair." They estimated the two bodies to have effective diameters of 300-450 m but they could not fully constrain the period (13-21 h). Pravec et al. (2003web) were able to find a period of 13.894 h. Those 2003 observations and results were the last to be reported in the LCDB for a rotation period.





Our observations some 17 years later confirm the original period and, as in 2003, a very low amplitude. This is not surprising since the 2003 and 2020 observations were at nearly the same viewing aspect (L_{PAB} = 10° ± 10°).

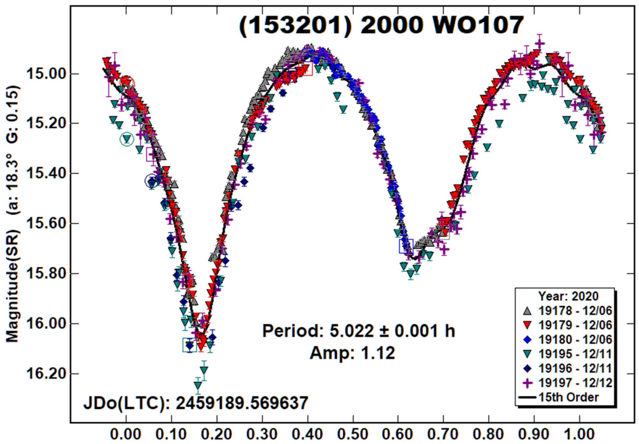
<u>(144411) 2004 EW9</u>. Pravec et al. (2004web) found a period of 49.94 h based on data from 2004 October. Behrend (2020web) found 51.150 h. Our result of 50.0 h, based on incomplete coverage, is in good agreement. We assumed a bimodal lightcurve because of the large amplitude and relatively low phase angle (Harris et al., 2014).

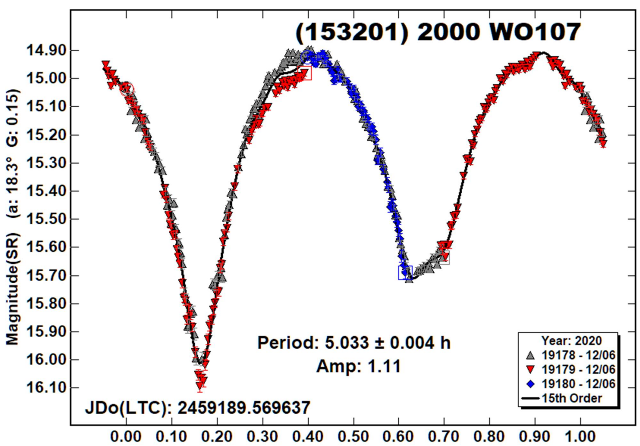


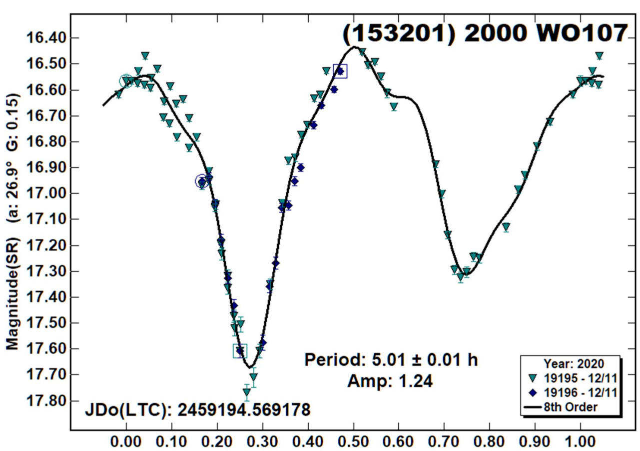
<u>(153201) 2000 WO107</u>. The lightcurve for this 400-m NEA changed significantly over the short time it was observed (2020 Dec 6-12). Analysis was best done by subdividing the data set.

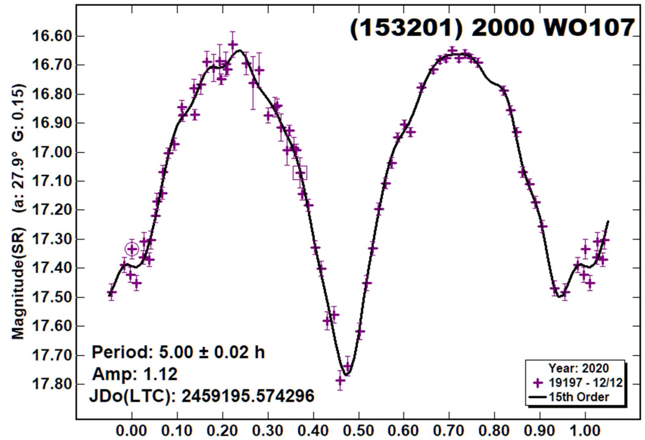
The combined lightcurve shows the derived period assuming a fixed synodic period. However, the individual lightcurves for Dec 6, 11, and 12 distinctly show how the shape and depth of the shallower minimum evolved and that the synodic period was not fixed. This is expected when the viewing aspect and and/or viewing aspect (L_{PAB}) change significantly over the range of the data set.

The high-order fits were required to get to the bottom of the deep minimum.

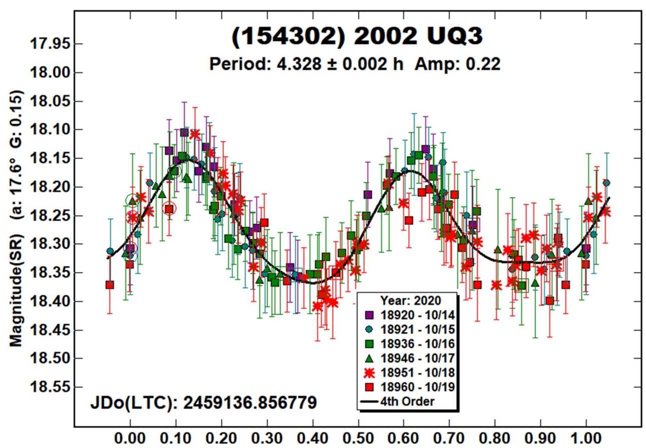




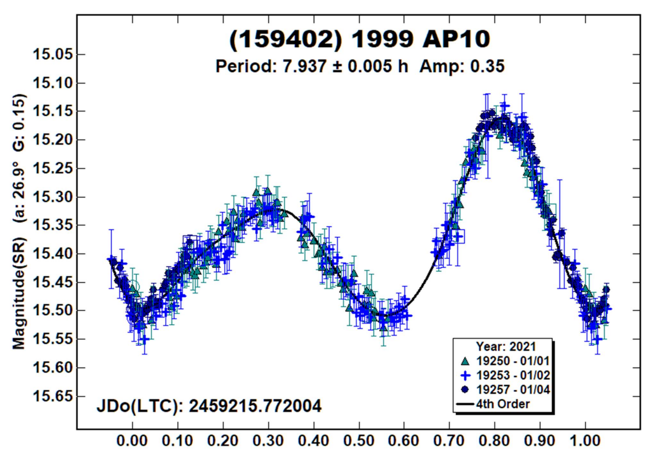


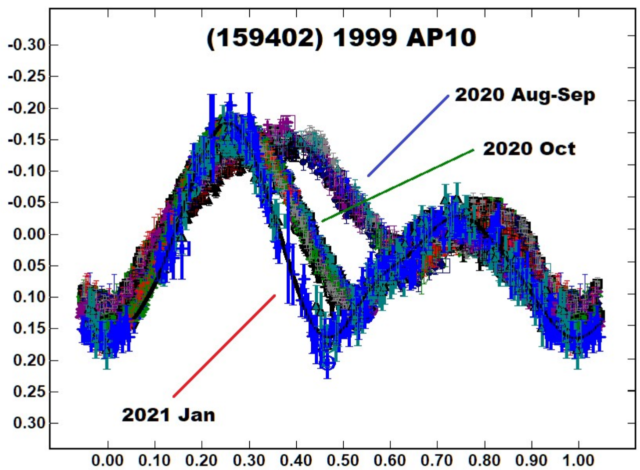


(154302) 2002 UQ3. Other than Binzel et al. (2019) reporting this 900-m NEA to be taxonomic class Sq, there were no previous entries in the LCDB. Assuming our adopted period of 4.328 h is correct, we were able to capture most of the lightcurve during each observing run. The amplitude and phase angle do not automatically preclude solutions other than a bimodal lightcurve (Harris et al., 2014). However, the very slight asymmetry in our result would seem to exclude a monomodal solution.



(159402) 1999 AP10. We (Warner and Stephens, 2021) previously reported the possibility that this asteroid is either binary or, at the least, has some physical trait that produces a second period beyond the dominant one near 7.9 h. The previous results are in Table III but their plots are not included here.



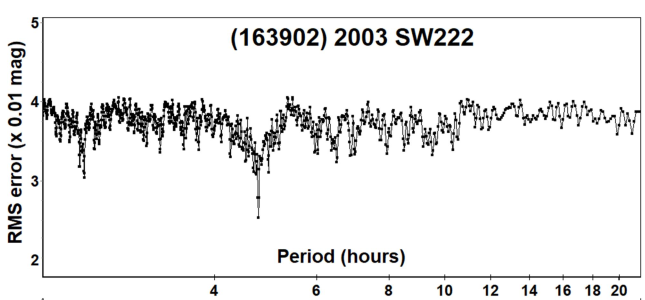


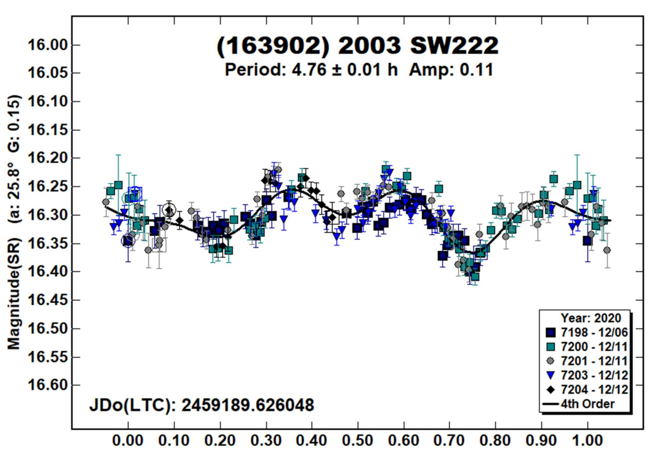
The main point of interest is that the amplitude of the secondary lightcurve diminished as the phase angle rose from 11° to 30° and, more important, the L_{PAB} changed by more than 30 degrees. The shape also changed, being much better defined in late August to early September than in early October.

Given this, when we reobserved the asteroid in early 2021 January, it was not surprising that any indications of a secondary period were not found, or were hidden within the noise. Our period (7.937 h) from the most recent observations closely agrees with the earlier results when accounting for changes in the synodic-sidereal difference over the span of the observations.

A composite of the three primary period solutions that forced the lowest minimum to 0° rotation phase provides a dramatic picture of the lightcurve evolution.

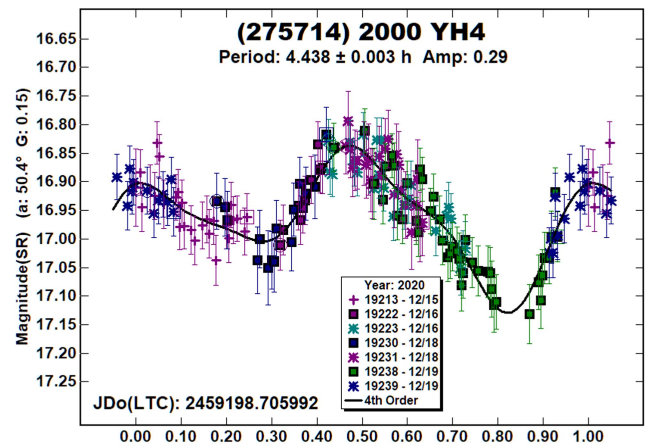
(163902) 2003 SW222. There were no previous reports of a period in the LCDB for this NEA with an estimated diameter of 1 km.





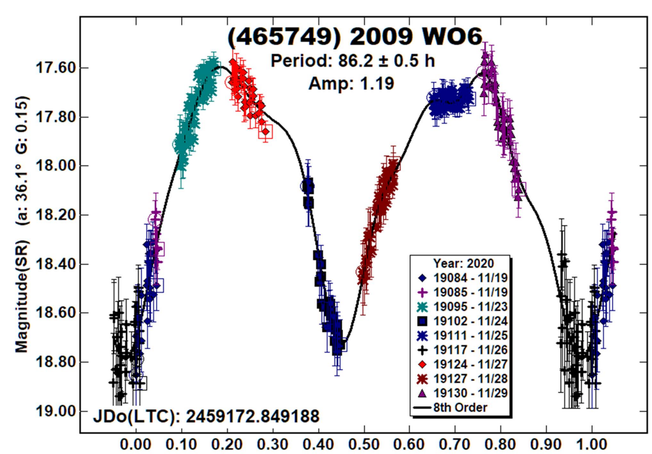
The Fourier analysis locked onto a seemingly clear solution of 4.76 h. However, the somewhat noisy data, especially compared to the low amplitude, makes this solution useable but hardly secure.

(275714) 2000 YH4. There were no previous entries in the LCDB of any kind for 2000 YH4, which has an effective diameter of 500-600 m. We consider the solution to be secure, but additional observations are encouraged. The 2022 June apparition (V ~ 18.5) is the only one with V < 19 until 2031.

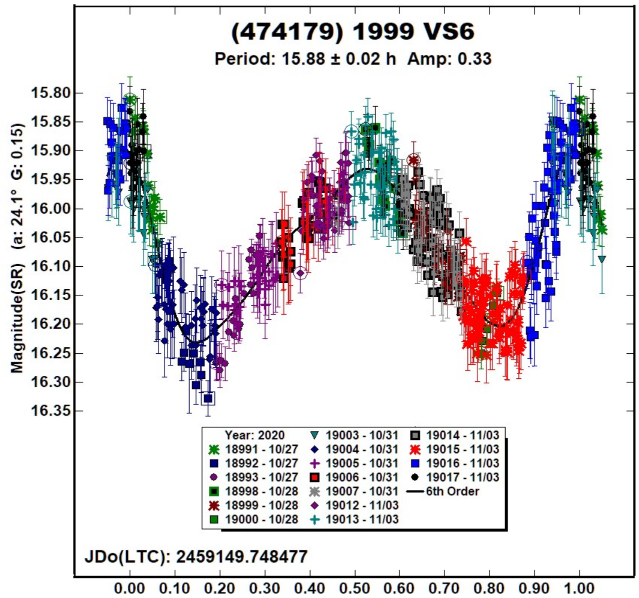


(465749) 2009 WO6. Mainzer et al. (2016) found this to be an usually low albedo object among the NEA population, p_V 0.034. Using H = 17.3, they found a diameter of 2.49 km. Our data set was obtained over 10 days in 2020 November but was not able to fully cover the presumed bimodal lightcurve with a period of 86.2 h. Based on Harris et al. (2014), a bimodal lightcurve is virtually assured.

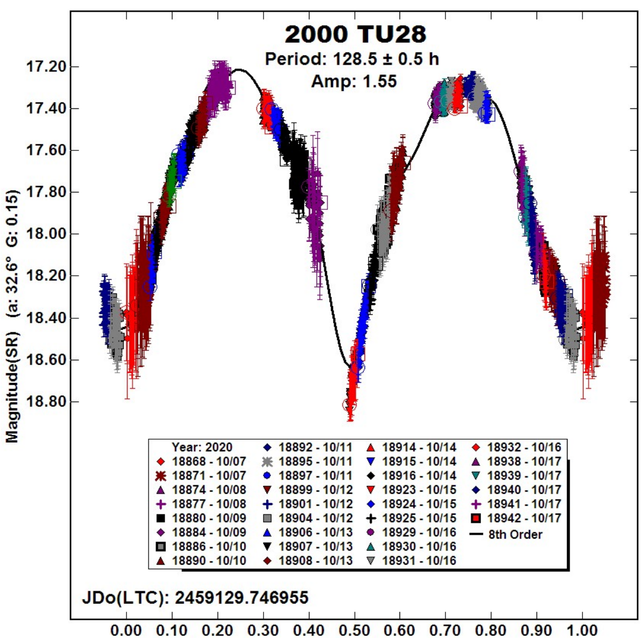
Using the rule of thumb for the damping time for a tumbling asteroid (Pravec et al., 2005; 2014), i.e., to go from tumbling to single axis rotation, the period leads to a time considerably greater than the age of the Solar System. The shape of the lightcurve, where the slope of some sessions doesn't match the slope of the Fourier model curve, would suggest that the asteroid is in a low-level tumbling state.



(474179) 1999 VS6. Warner (2017b) found a period of 16.91 h using data from 2017. Our 2020 data set led to a shorter period of 15.88 h, which we consider to be significantly more likely than the one from 2017 since that solution had large gaps in the lightcurve and the data had much higher noise.

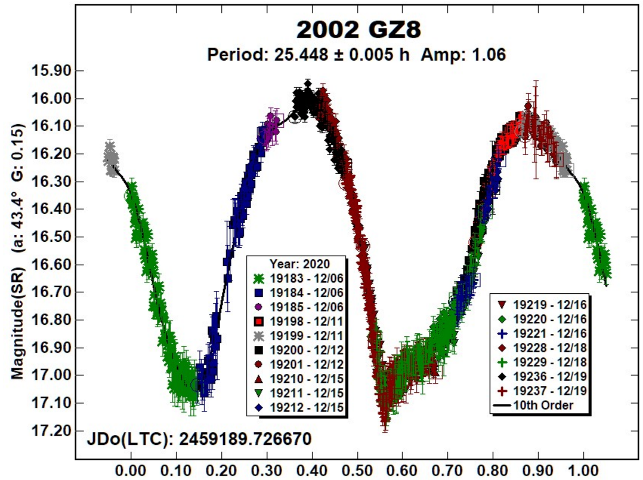


2000 TU28. There were no previous entries in the LCDB for 2000 TU28, which has an estimated diameter of 200 m. This is close to the approximate point of about 170 m when the rotation period can easily be < 2 h. This NEA is completely contrary in that regard. The large amplitude and phase angle assure a bimodal solution (Harris et al., 2014). The main issues were tying the sessions together over the period of ten days and the fact that each one covered only a short segment of the lightcurve. This is where the ATLAS catalog (Tonry et al., 2018) proved to be essential since the systematic errors are on the order of ±0.03 mag and less. This meant leaving the zero points alone (0.0 mag offset) and waiting until a good portion of the lightcurve was covered. In the end, all zero-point adjustments were ≤ ±0.03 mag.

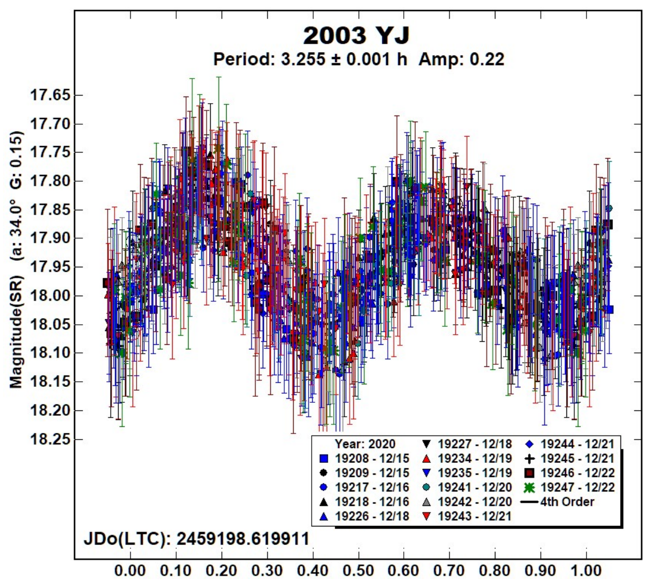


The shorter tumbling damping times in Pravec et al. (2014) would favor this being in a tumbling state. The longer times found in Pravec et al. (2005) allow for a damping time a little less than the age of the Solar System. There don't appear to be clear signs of even low-level tumbling but it cannot be formally excluded.

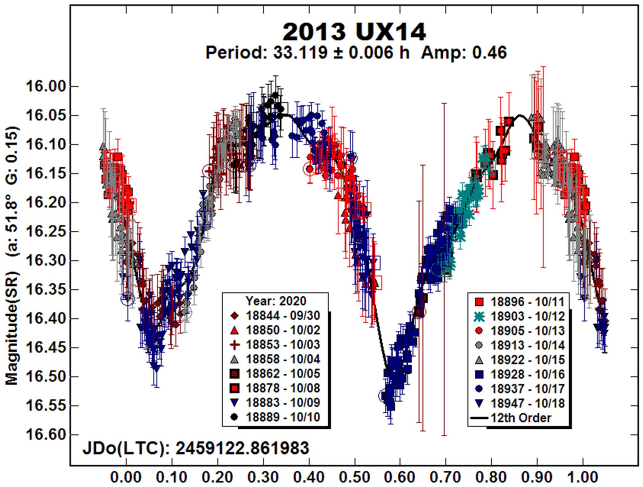
2002 GZ8. This was the first entry of any kind into the LCDB. The solution is considered secure and there don't appear to be any signs of tumbling, which fits the rule of thumb for longer damping times found in Pravec et al. (2005).



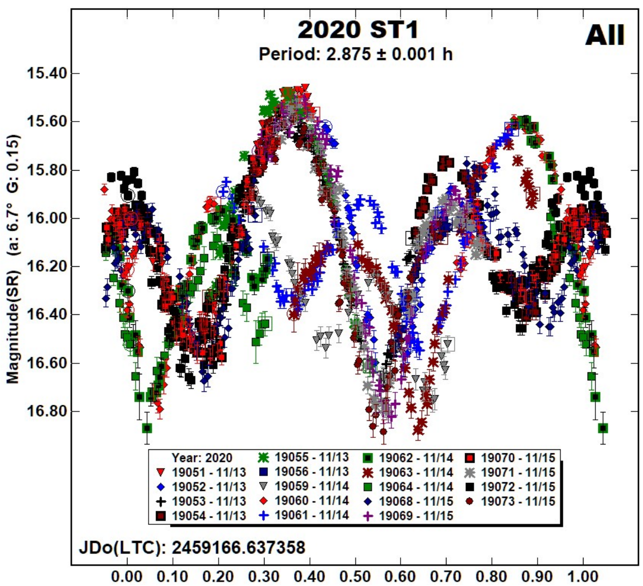
2003 YJ. This is good demonstration of "beating down the noise" to find a good solution in what might otherwise be a marginal data set. We consider the solution to be secure, but verification is warranted. A reasonable chance doesn't come again until 2029 December when the asteroid will be V ~ 16.4 and +28° declination.

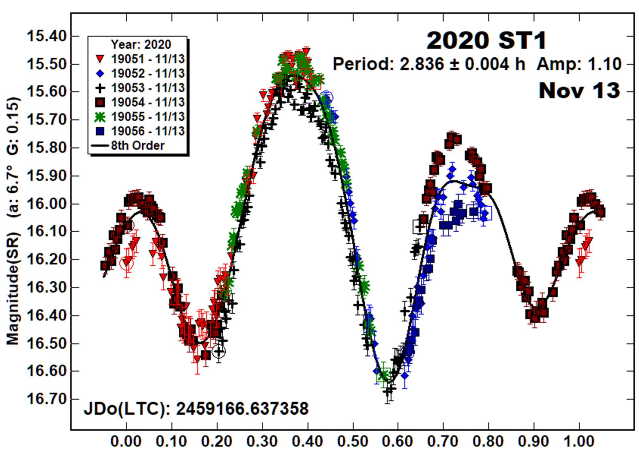


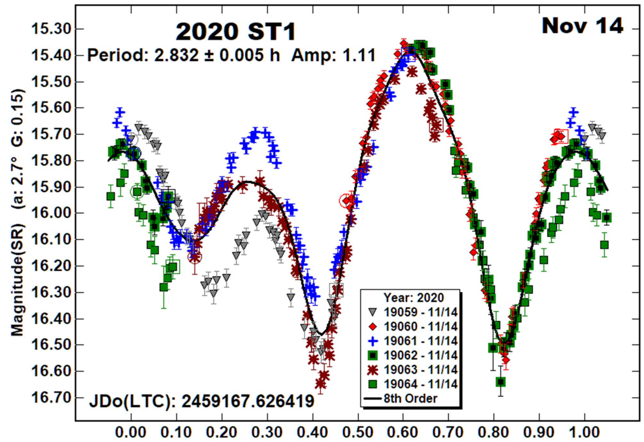
2013 UX14. There were no previous entries in the LCDB. The estimated diameter of this NEA is 650 m. There are gaps in the coverage and some of the data runs have noisy data, but we still consider the solution to be secure since no other period that was examined produced a plausible lightcurve shape.

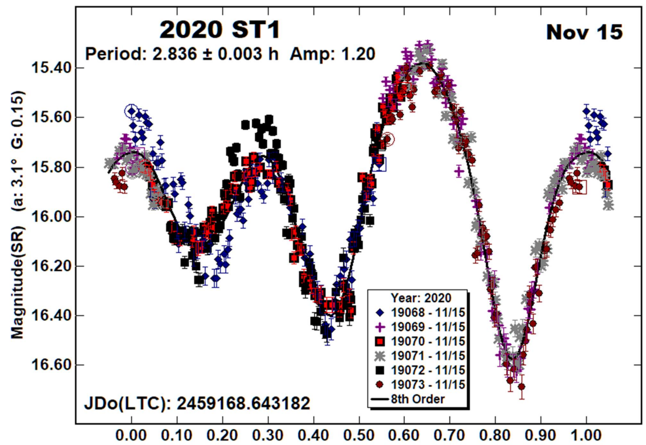


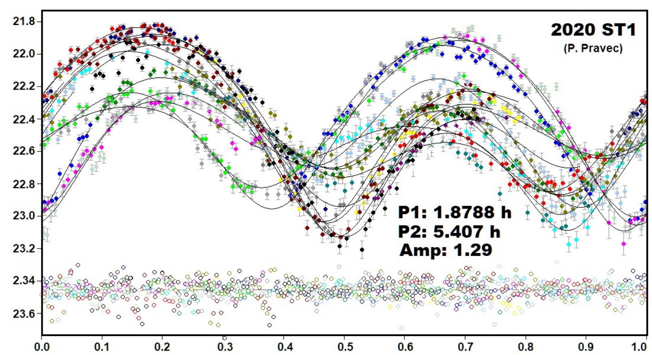
2020 ST1. If ever an asteroid showed clear signs of tumbling from the start of observations, 2020 ST1 was it. Each run covered more than what appeared to be a full cycle but the data could not be fit to a single period with a plausible lightcurve, even when using only one night's observations, as seen with the individual lightcurves for Nov 13-15.











The data from Nov 13 came the closes to fitting a single period but the lightcurve had three extrema pairs. Given the amplitude and low phase angle, this was highly unlikely (Harris et al, 2014). The Nov 14 data set led the worst fit to a single period while the set from Nov 15 almost fit a single, but implausible, period.

MPO Canopus cannot properly handle the data from a tumbling asteroid since it does not do a simultaneous search for two periods. To have any chance of finding the true periods of precession and rotation, the complete data set was sent to Petr Pravec for his analysis. He confirmed the tumbling state (private communications):

My full 2-period Fourier series analysis shows [the] following three periods with the highest signal: 1.879, 2.879 and 5.407 h. Two of the three are real periods of the tumbler, while a third one is related to them; note that 1/2.879 = 1/1.879 - 1/5.407. However, we cannot resolve which two of the three are the real ones based just on this analysis. … future physical modeling may reveal it.

His plot shows the two stronger periods of 1.879 h and 5.407 h and how confused lightcurves can be with a tumbling asteroid since the lightcurve almost never repeats itself. It can come close, as on Nov 13 and 15, but those are unlikely solutions, even though they are each close to the period of 2.879 h found by Pravec.

Acknowledgements

Funding for observations at CS3 and work on the asteroid lightcurve database (Warner et al., 2009) and ALCDEF database (*alcdef.org*) are supported by NASA grant 80NSSC18K0851.

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.

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.

References

References from web sites should be considered transitory, unless from an agency with a long lifetime expectancy. Sites run by private individuals, even if on an institutional web site, do not necessarily fall into this category.

Behrend, R. (2020web). Observatoire de Geneve web site. *http://obswww.unige.ch/~behrend/page_cou.html*

Binzel, R.P.; DeMeo, F.E.; Turtelboom, E.V.; Bus, S.J.; Tokunaga, A.; Burbine, T.H.; Lantz, C.; Polishook, D.; Carry, B.; Morbidelli, A.; Birlan, M.; Vernazza, P.; Burt, B.J.; Moskovitz, N.; Slivan, S.M.; Thomas, C.A.; Rivkin, A.S.; Hicks, M.D.; Dunn, T.; Reddy, V. (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.

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.

Jacobson, S.A., Scheeres, D.J., McMahon, J. (2014). "Formation of the Wide Asynchronous Binary Asteroid Population." *Ap. J.* **780,** A60.

Mainzer, A.K.; Bauer, J.M.; Cutri, R.M.; Grav, T.; Kramer, E.A.; Masiero, J.R.; Nugent, C.R.; Sonnett, S.M.; Stevenson, R.A.; Wright, E.L. (2016). "NEOWISE Diameters and Albedos V1.0." NASA Planetary Data System. EAR-A-COMPIL-5-NEOWISEDIAM-V1.0.

Margot, J.L.; Nolan, M.C.; Negron, V.; Hine, A.A.; Campbell, D.B.; Howell, E.S.; Benner, L.A.M.; Ostro, S.J.; Giorgini, J.D.; Marsden, B.G. (2003). "1937 UB (Hermes)." *IAUC* **8227**.

Pál, A.; Szakáts, R.; Kiss, C.; Bódi, A.; Bognár, Z.; Kalup, C.; Kiss, L.L.; Marton, G.; Molnár, L.; Plachy, E.; Sárneczky, K.; Szabó, G.M.; Szabó, R. (2020). "Solar System Objects Observed with TESS - First Data Release: Bright Main-belt and Trojan Asteroids from the Southern Survey." *Ap. J. Supl. Ser.* **247**, id.26.

Polishook, D. (2012). "Lightcurves and Spin Periods of Near-Earth Asteroids, The Wise Observatory, 2005 - 2010." *Minor Planet Bull.* **39**, 187-192.

Pravec, P.; Wolf, M.; Šarounová, L.; Mottola, S.; Erickson, A.; Hahn, G.; Harris, A.W.; Harris, A.W.; Young, J.W. (1997). "The Near-Earth Objects Follow-Up Program." *Icarus* **130**, 275-286.

Pravec, P.; Wolf, M.; Sarounova, L. (1999web; 2000web; 2002web; 2003web; 2004web). *http://www.asu.cas.cz/~ppravec/neo.htm*

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.; 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.

Stephens, R.D. (2013web). Center for Solar System Studies web site. *http://www.planetarysciences.org/PHP/CS3_Lightcurves.php*

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." *Ap. J.* **867**, A105.

Vaduvescu, O.; Macias, A.A; Tudor, V.; Predatu, M.; Galád, A.; Gajdoš, Š.; Világi, J.; Stevance, H.F.; Errmann, R.; Unda-Sanzana, E.; Char, F.; Peixinho, N.; Popescu, M.; Sonka, A.; Cornea, R.; Suciu, O.; Toma, R.; Santos-Sanz, P.; Sota, A.; Licandro, J. Serra-Ricart, M.; Morate, D.; Mocnik, T.; Diaz Alfaro, M.; Lopez-Martinez, F.; McCormac, J.; Humphries, N. (2017). "The EURONEAR Lightcurve Survey of Near-Earth Asteroids." *Earth, Moon, and Planets* **120**, 41-100.

Number	Name	2020 mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.
2212	Hephaistos	10/19-10/28	6.2,2.9	43	3	48	0.2	0.35	0.04
2368	Beltrovata	12/18-12/20	1.8,2.5	85	3	5.786	0.003	0.91	0.03
7753	1988 XB	11/29-12/12	60.5,18.2	96	1	42.2	0.2	0.65	0.05
10115	1992 SK	10/21-10/25	*18.0,15.8	36	9	7.342	0.004	0.58	0.04
16834	1997 WU22	11/16-11/20	6.4,6.9	53	10	9.32	0.01	0.31	0.03
21088	Chelyabinsk	12/15-12/19	22.8,21.1	124	5	11.23	0.01	0.34	0.03
66272	1999 JW6	11/14-12/20	*23.3,34.8	68	8	[T1]502	5	0.58	0.05
						[T2]401	5	0.4	0.1
						[3]15.99	0.01	0.07	0.02
68359	2001 OZ13	11/23-12/05	23.9,30.7	44	-13	18.07	0.02	0.27	0.04
69230	Hermes	10/08-10/15	12.5,22.1	4	-5	13.82	0.02	0.08	0.01
144411	2004 EW9	10/19-10/25	23.6,18.7	47	15	50	0.2	0.81	0.05
153201	2000 WO107	12/06-12/12	18.8,28.1	62	3	5.022	0.001	1.22	0.05
154302	2002 UQ3	10/14-10/19	17.7,14.5	36	13	4.328	0.002	0.22	0.03
159402	*1999 AP10*	*08/24-09/17*	**11.3,12.4*	*341*	*-5*	*[P]7.9219*	*0.0003*	*0.27*	*0.02*
						28.461	*0.006*	*0.06*	*0.01*
159402	*1999 AP10*	*10/02-10/07*	*26.3,32.9*	*356*	*9*	*[P]7.9186*	*0.0004*	*0.33*	*0.02*
						29.30	*0.01*	*0.04*	*0.01*
159402	1999 AP10	01/04-01/04	24.4	112	18	7.937	0.005	0.35	0.02
163902	2003 SW222	12/06-12/12	25.7,22.7	78	19	4.76	0.01	0.11	0.02
275714	2000 YH4	12/15-12/19	50.2,45.0	55	-10	4.438	0.003	0.29	0.03
465749	2009 WO6	11/19-11/29	36.1,34.4	97	4	86.2	0.5	1.19	0.06
474179	1999 VS6	10/27-11/03	24.0,32.9	49	10	15.88	0.02	0.33	0.04
	2000 TU28	10/07-10/18	*32.6,25.2	35	1	128.5	0.5	1.55	0.10
	2002 GZ8	12/06-12/19	43.4,61.3	110	19	25.448	0.005	1.06	0.03
	2003 YJ	12/15-12/22	34.1,39.0	66	-11	3.255	0.001	0.22	0.04
	2013 UX14	10/02-10/18	51.6,45.4	48	-8	33.119	0.006	0.46	0.03
	2020 ST1	11/13-11/15	*5.9,3.8	52	1	2.875	0.003	1.2	0.06

Table III. Observing circumstances. [P]Period of the primary in a binary system. [T1,2]Period associated with tumbling. [3]Third period in a solution. The phase angle (α) is given at the start and end of each date range. If there is an asterisk before the first phase value, the phase angle reached a maximum or minimum during the period. L_{PAB} and B_{PAB} are, respectively the average phase angle bisector longitude and latitude (see Harris et al.,1984). The results for 159402 in 2020 (in italics) are shown here for comparison (see Warner and Stephens, 2021).

Warner, B.D. (2014). "Near-Earth Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2013 September - December." *Minor Planet Bull.* **41**, 113-124.

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

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

Warner, B.D. (2017b). "Near-Earth Asteroid Lightcurve at CS3-Palmer Divide Station: 2017 April thru June." *Minor Planet Bull*. **44**, 335-344.

Warner, B.D.; Stephens, R.D. (2019). "Near-Earth Asteroid Lightcurve Analysis at the Center for Solar System Studies: 2018 July - September." *Minor Planet Bull*. **46**, 27-40.

Warner, B.D.; Stephens, R.D. (2021). "On Confirmed and Suspected Binary Asteroids Observed at the Center for Solar System Studies." *Minor Planet Bull.* **48**, 40-49.

Warner, B.D., Harris, A.W., Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2020 Sep. *http://www.minorplanet.info/lightcurvedatabase.html*

Zappala, V.; Cellini, A.; Barucci, A.M.; Fulchignoni, M.; Lupishko, D.E. (1990). "An anlaysis of the amplitude-phase relationship among asteroids." *Astron. Astrophys*. **231**, 548-560.