

**ON CONFIRMED AND SUSPECTED
BINARY ASTEROIDS OBSERVED AT
THE CENTER FOR SOLAR SYSTEM STUDIES:
2022 MARCH-JUNE**

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Analysis of CCD photometric observations of seven asteroids from 2022 March to June at the Center for Solar System Studies indicate that, by virtue of a suspected or distinct second period, they are either suspected or confirmed binary asteroids.

CCD photometric observations of five near-Earth and two inner main-belt asteroids were made at the Center for Solar System Studies from 2022 March to June. Each one is considered to be a suspected or confirmed binary asteroid. This is based on there being a sufficiently distinct secondary period, even if it might be a simple harmonic of the primary period.

The observations were made with a 0.35-m Schmidt-Cassegrain and either an FLI Proline or Microline CCD camera as well as a 0.40-m Schmidt-Cassegrain with FLI Proline CCD camera. All cameras use a KAF-1001E chip, which has a pixel array of $1024 \times 1024 \times 24\mu$. The field-of-view and image scale were about 26×26 arcminutes and 1.5 arcsec/pixel, respectively, for the 0.35-m telescopes. The 0.4-m values were 20×20 arcminutes and 1.2 arcsec/pixel.

All lightcurve observations were unfiltered or with a clear filter, even though the clear filter can cause a 0.1-0.3 mag loss. The exposures varied depending on the asteroid's brightness and sky motion. Whether guiding on a field star or not, sometimes the asteroid was trailed on the image.

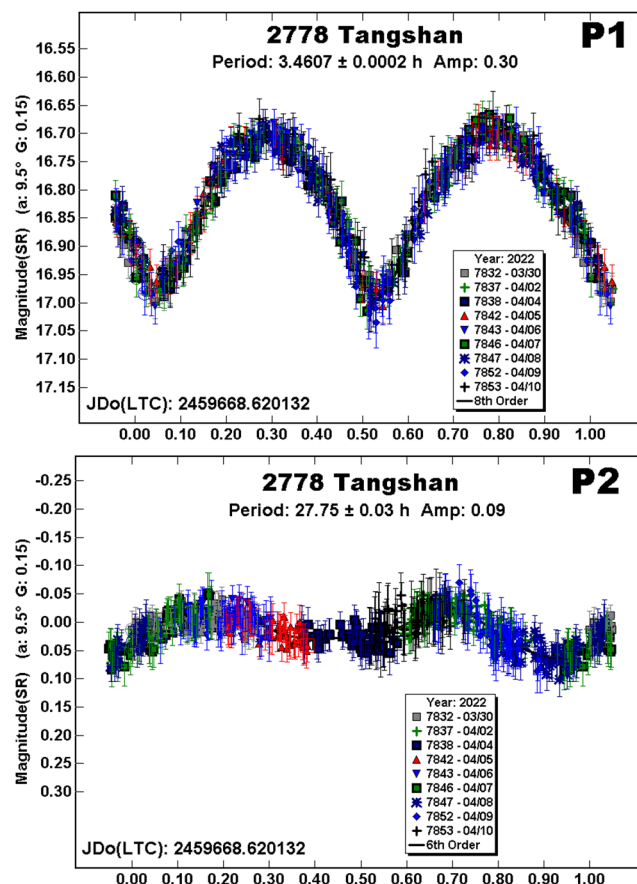
Measurements were made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. To reduce the number of adjusted nightly zero points and their amounts, the analysis of the data used the ATLAS catalog r' (SR) magnitudes (Tonry et al., 2018). The rare zero-point adjustments of $\geq \pm 0.03$ mag may be related to using unfiltered/clear observations, poor centroiding of the reference stars, not correcting for second-order extinction, or selecting a comp star that is 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, corrected all the observations to appear that they were made at a single fixed date/time and phase angle, presumably 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*.

References to previous works were taken from the asteroid lightcurve database (Warner et al., 2009), known as “LCDB” from here on. Since most listed rotation periods for the primary were very similar, only a few of the LCDB references have been used.

2778 Tangshan. We observed this inner main-belt asteroid twice before (Warner, 2004; Stephens and Warner, 2019). Behrend (2018web) found a period of 3.457 h, which is in good agreement with our earlier results of 3.461 h and 3.468 h, respectively.



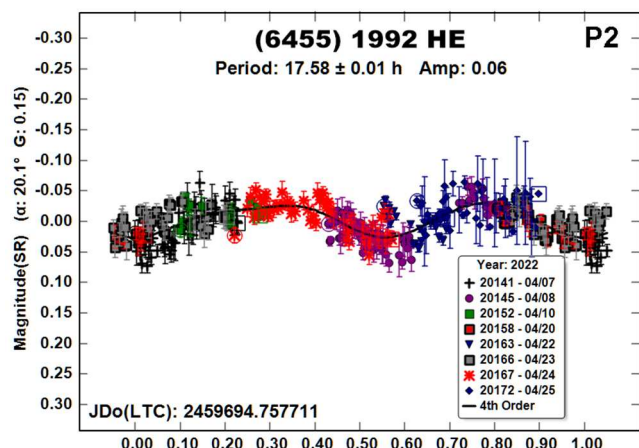
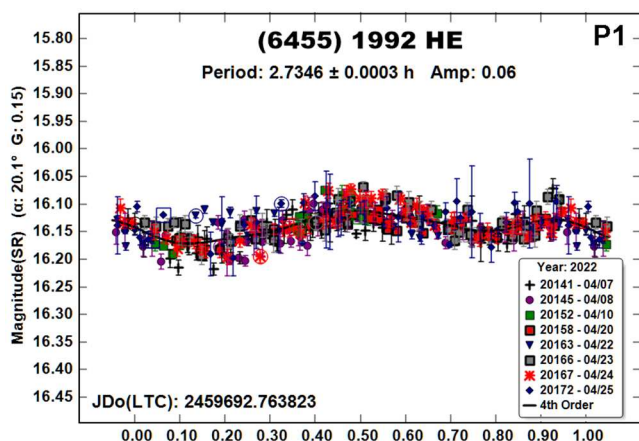
The 2020 observations led to a dominant period of 3.4607 h, in keeping with the previous results. However, unlike previous years, they also appeared to include a secondary period. This was extracted using the dual-period search of *MPO Canopus* and found to be a bimodal lightcurve with a period 27.75 h and amplitude of 0.09 mag. This is within the typical range of for the orbital period of the satellite in small asteroid binaries (Pravec et al., 2018).

There were no mutual events (occultation/eclipses) so it was not possible to determine the ratio of the effective diameters of the satellite versus the primary (D_s/D_p). However, the 0.09 mag amplitude indicates a nearly spheroidal object ($a/c = 1.09$) with its rotation period tidally-locked to the orbital period.

(6455) 1992 HE. The estimated diameter of this NEA is 4.6 km (Mainzer et al., 2019). Based on observations in 2002, Pravec et al. (2002web) found several synodic periods as the viewing aspect changed. The average period was about 5.48 h with amplitudes $A \leq 0.13$ mag. Observations made by Gaftonyuk and

Krugly (2004), led to period of 2.736 h, or half that of the Pravec et al. (2002web) period. Wolters et al. (2005) also observed in 2002 (late September) and found a similar half-period: 2.736 h. The amplitude of their lightcurve was 0.21 mag. Many other reports in the LCDB also indicate a period near 2.7 h, including ours from observations in 2019 (Warner and Stephens, 2020).

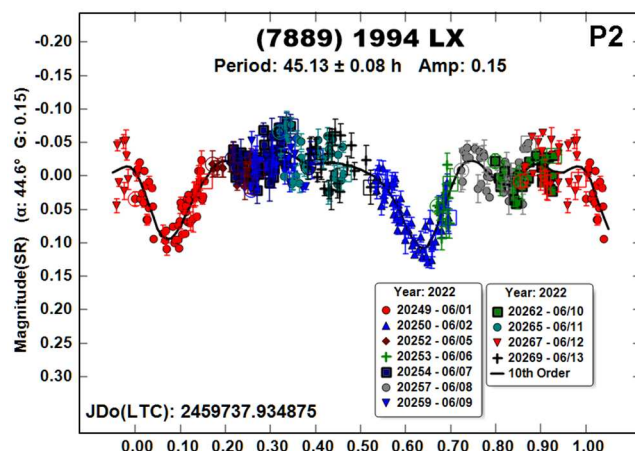
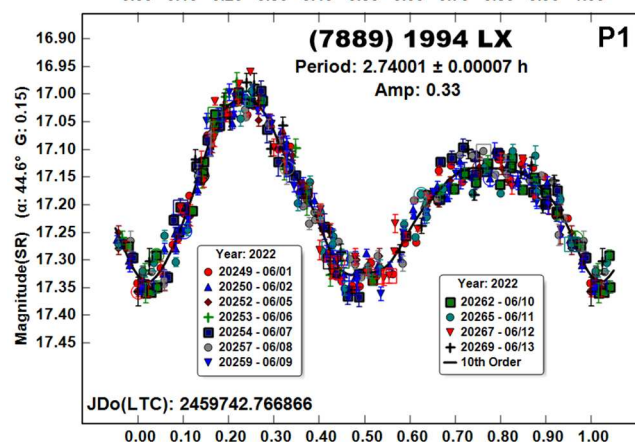
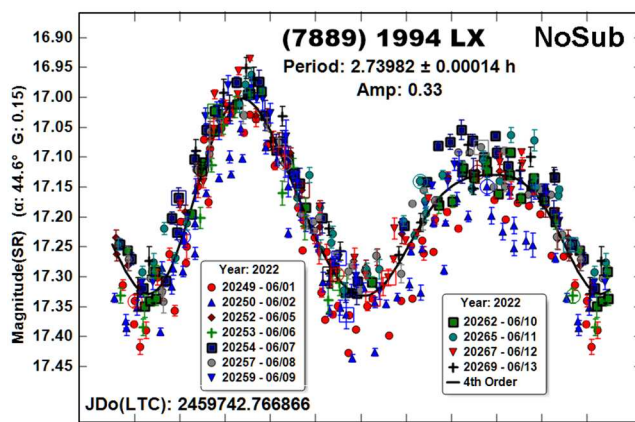
When low lightcurve amplitudes are involved, $A < 0.2$ mag and especially $A < 0.10$ mag, it should not be assumed that a lightcurve will be bimodal, i.e., two min/max pairs per rotation (Harris et al., 2014). Even with the larger amplitude from Wolters et al. (2005), the true period of the asteroid was at least somewhat ambiguous.



Our 2022 observations also produced a low amplitude primary lightcurve (0.06 mag). Using a liberal interpretation, our lightcurve is bimodal that is asymmetrical (minima at about 0.1 and 0.8 rotation phase). Even so, we found that looking for and finding a secondary period produced a much “cleaner” primary lightcurve.

The secondary lightcurve is noticeably asymmetrical, which casts some doubt about the solution since one explanation would be an unusually eccentric orbit for a satellite. However, the assumed orbital period is in keeping with those of other small binary asteroids (Pravec et al., 2018). As with 2778 Tangshan above, the low amplitude of the secondary lightcurve could imply a nearly spheroidal satellite and, as with all other asteroids included here, we highly recommend follow-up observations in the future.

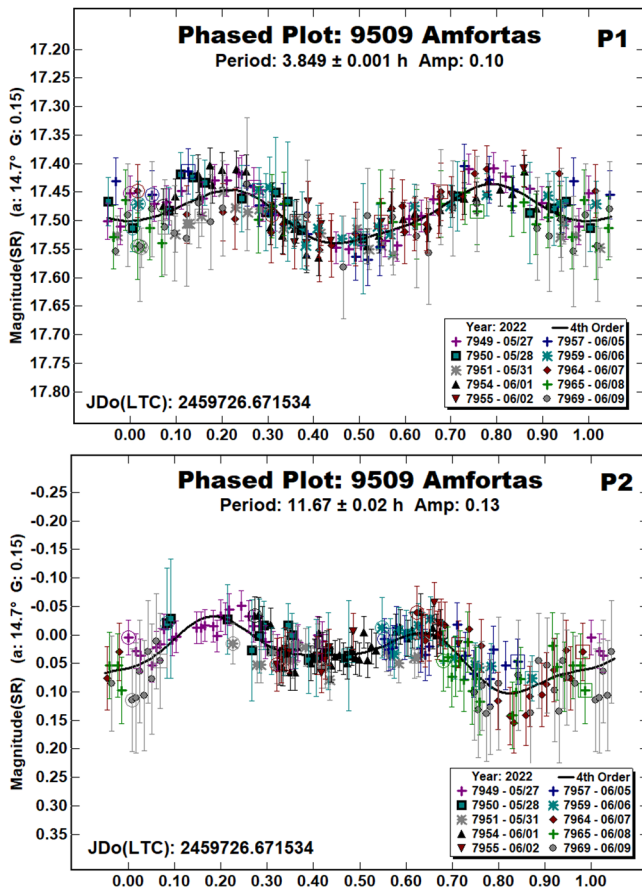
(7889) 1994 LX. The synodic rotation period for the primary of this NEA is well-established at about 2.74 h, e.g., Warner (2015).



Our 2022 observations clearly indicated a secondary period in the data (“NoSub” plot). No listing in the LCDB indicated that the asteroid is binary and a check with the Johnston binaries web site (Johnston, 2022web) seemed to confirm that ours are the first observations to confirm that the asteroid is binary.

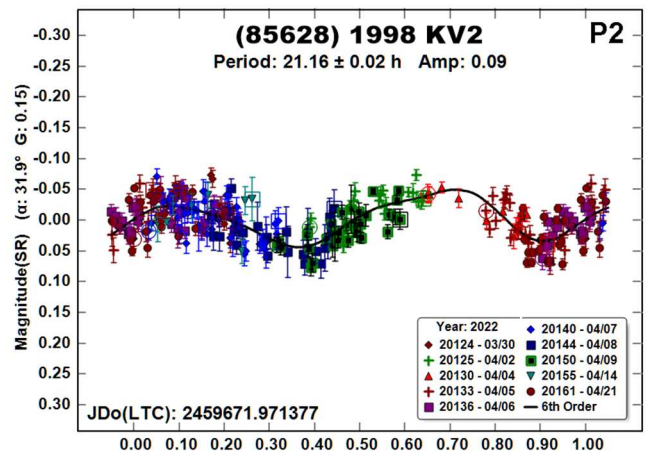
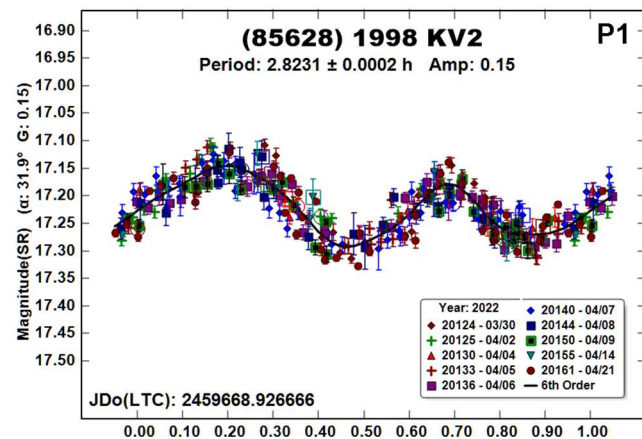
It took almost a fortnight to obtain the necessary data to establish that the asteroid is binary with an orbital period of 45.13 h. It seems to be comprised of two nearly equal-sized bodies, as indicated by the two mutual events differing by only 0.01 mag amplitude. The lesser amplitude of 0.11 mag gives an effective secondary-primary diameter ratio of $D_s/D_p \geq 0.33 \pm 0.02$.

9509 Amfortas. The only previous period listed in the LCDB was ours (Stephens and Warner, 2020), which was 3.996 h with a lightcurve amplitude of 0.07 mag. Our 2022 observations were of similar quality: error bars near the amplitude of the lightcurve. Our analysis found a dominant period of 3.849 h, significantly different from the previous result, as well as a secondary period.



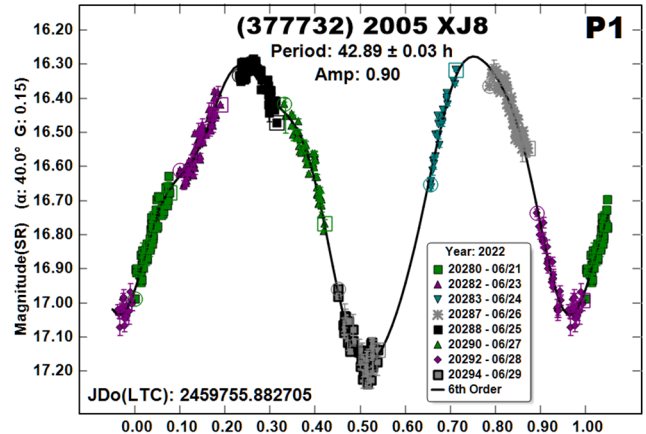
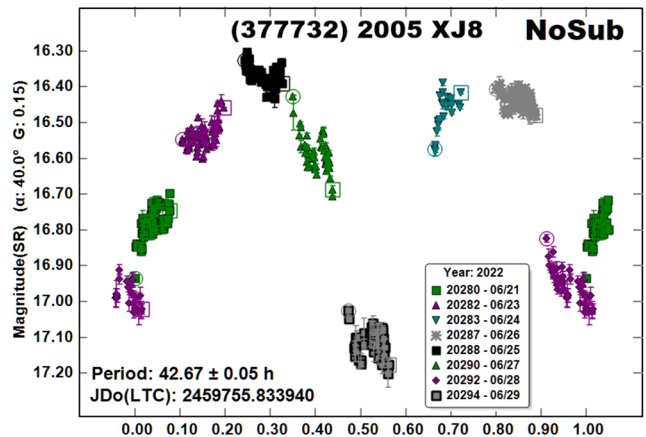
The signal for the secondary period is somewhat weak. The greatest concern is that $P2:P1 = 3.03$, or nearly an integral ratio. This is followed by the distinct asymmetry of the primary lightcurve. The true nature of this asteroid may be found only with additional observations at future apparitions at usefully different phase angle bisector longitudes and/or phase angles.

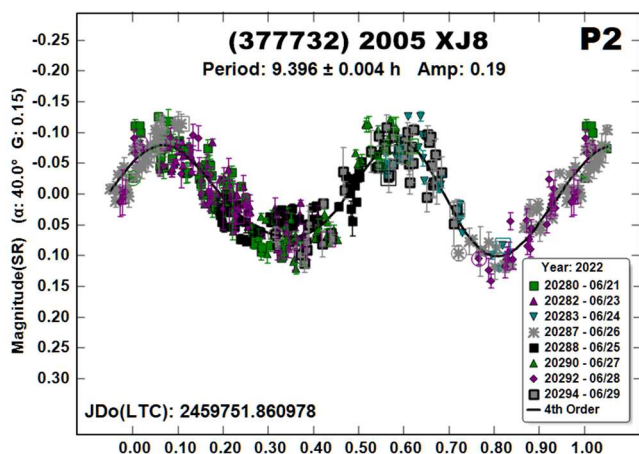
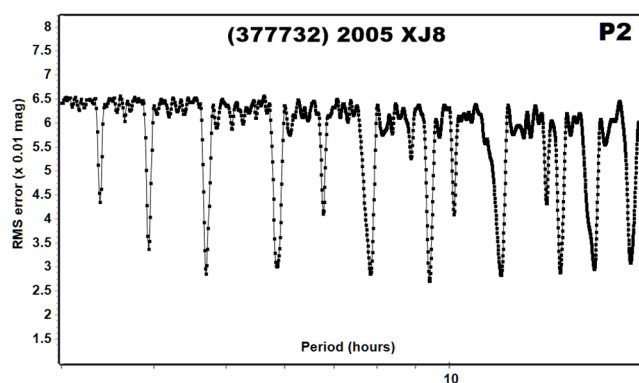
(85628) 1998 KV2. This is a known binary discovered at CS3 in 2020 (Warner et al., 2020a, 2020b; Pravec et al., 2020web).



Our 2020 observations indicated $Ds/Dp \geq 0.28 \pm 0.02$ based on event amplitudes of 0.08 and 0.13 mag. In 2022, they were 0.05 and 0.06 mag, giving $Ds/Dp \geq 0.22 \pm 0.02$ and indicating a significantly different viewing aspect of the binary orbit. The orbital periods derived from data analysis in 2020 and 2022 are statistically the same. The changes in the events should prove useful for modeling the system at some point.

(377732) 2005 XJ8. Vaduvescu et al. (2017) reported a very short period of 0.132 h (7.92 min). Keeping this mind, our initial exposures were kept short to avoid what can be called “rotational smearing,” as explained by Pravec et al. (2000). In short, exposures must be no longer than $0.185 * P$ (the rotational period). Otherwise, lightcurve features will blend into one another and so make it hard, if not impossible, to find the true period.





It became clear after the first session that a very short period was unlikely and so exposure times were increased. As more data were obtained, it was apparent that the period was tens of hours. Furthermore, the growing lightcurve showed distinct signs of a second period (“NoSub” plot).

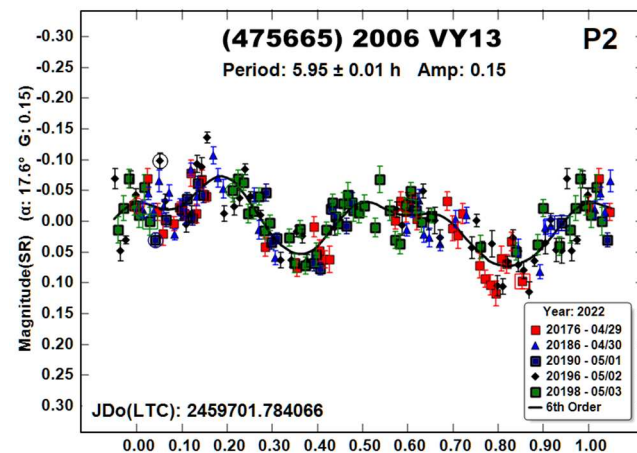
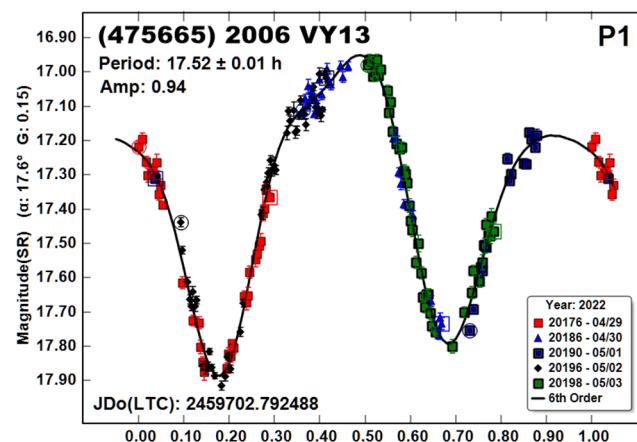
Our final data set covered nine out of ten nights from 2022 June 21 to 29. Dual-period analysis of the data with *MPO Canopus* found a primary period of $P_1 = 42.89$ h and a strong, but ambiguous, secondary period (“P2 period spectrum”). We have adopted $P_2 = 9.396$ h because 1) it is likely, but not certain, that the lightcurve should be bimodal (Harris et al., 2014) and 2) a split-halves plot (Harris et al., 2014) shows a distinct asymmetry of the halves at the adopted period and too much symmetry for the doubled period.

As to the physical cause of the second period, one possibility is that the asteroid is a *very wide binary* (Warner and Stephens, 2019; and references therein). This is a system where the primary has spun down to a long period as the secondary “stole” rotational angular momentum, converting it to orbital angular momentum to migrate outward. (Angular momentum is conserved.) Usually, the secondary period is in the range of 2–4 hours, but it can be much longer. The two periods here are within the ranges seen so far in very wide binary candidates.

(475665) 2006 VY13. Our previous observations in 2017 (Warner, 2017) were split into two sets: one centered on early April and the other on early June. The first set gave a synodic period $P = 17.507$ h and amplitude 1.39 mag at phase angle of 32° . The second set, at phase angle 14° , had a longer sidereal period (17.544 h) and smaller amplitude (0.89 mag). There were no signs of a satellite. Monteiro et al. (2018) found 17.545 h based on observations in 2012.

The decrease in amplitude in 2017 as the phase angle decreased is expected behavior (Zappala et al., 1990). In the meantime, the phase angle bisector longitude (Harris et al., 1984) in 2017 was *decreasing* as the asteroid approached opposition (minimum phase angle); this implies a retrograde rotation for the asteroid (Alan Harris, *private communications*).

The P_1 lightcurve was made considerably better (lower RMS) by finding and subtracting a second period. As with 9509 Amfortas, if the secondary lightcurve was more certain (and longer in this case), it would look similar to one of a satellite displaying mutual events. However, also as with 9509 Amfortas, the secondary period is very close to a 3:1 ratio with the primary period. Observations at future apparitions are needed to define the true nature of the asteroid.



Acknowledgements

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.

Number	Name	2022 mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp/Dr
2778	Tangshan	03/30-04/09	9.5, 13.4	176	5	3.4607 27.75	0.0002 0.03	0.30 0.09	0.01 0.01	MB-I UD
6455	1992 HE	04/06-04/25	19.8, 28.6	178	21	2.7346 17.58	0.0003 0.01	0.06 0.06	0.01 0.01	NEA UD
7889	1994 LX	06/01-06/13	44.6, 42.5	222	48	2.74001 45.13	0.00007 0.08	0.33 0.15	0.02 0.01	NEA 0.33
9509	Amfortas	05/27-06/08	14.8, 20.1	225	7	3.849 11.67	0.001 0.02	0.10 0.13	0.01 0.02	MB-I UD
85628	1998 KV2	03/30-04/21	31.9, 16.4	211	19	2.8231 21.16	0.0002 0.02	0.15 0.09	0.02 0.01	NEA 0.22
377732	2005 XJ8	06/24-06/29	34.3, 16.3	301	8	42.89 9.396	0.03 0.004	0.90 0.19	0.03 0.03	NEA UD
475665	2006 VY13	04/29-05/02	17.6, 15.3	234	9	17.52 5.95	0.01 0.01	0.94 0.15	0.03 0.02	NEA UD

Table II. Observing circumstances. The first line for an asteroid gives the primary or dominant period. The second line gives the secondary period. The phase angle (α) is given at the start and end of each date range. L_{PAB} and B_{PAB} are, respectively the average phase angle bisector longitude and latitude (see Harris et al., 1984). For the Grp/Dr column, the first line gives the group/family: MB-I: inner main-belt, PHO: Phocaea; NEA: near-Earth asteroid. The code "UD" on the second line in the Grp/Dr column means "undetermined," primarily because there were no mutual events. Otherwise, the value is the ratio of the secondary-to-primary effective diameters.

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LIGHTCURVES FOR THREE KORONIS FAMILY ASTEROIDS FROM THE UNION COLLEGE OBSERVATORY

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We present lightcurves for Koronis family asteroids (243) Ida, (321) Florentina, and (2713) Luxembourg. All had periods consistent with previously reported values and showed classic doubly-periodic lightcurves.

At the Union College Observatory we have undertaken a program to observe rotation lightcurves of Koronis family asteroids in support of determining spin vectors and shape models (Kaasalainen et al., 2001; Slivan et al., 2003). Members of this family (named for its lowest numbered member (158) Koronis) are believed to share a common progenitor which was broken up in a collision long ago; thus, they share similar orbits in the outer asteroid belt and similar S-type spectral characteristics. Long-term interaction with solar radiation via the YORP effect has modified members' spin properties (Slivan, 2002; Vokrouhlicky et al., 2003), and determination of spin vectors for a sufficiently large sample of Koronis members may shed light on YORP-driven evolution in the solar system.

We have obtained lightcurves for three Koronis Family asteroids using observations at the Union College Observatory during 2018-2019. This represents the first published asteroid data from the Union College Observatory. Target selection and ephemerides were based upon the Koronis family asteroids web tool (Slivan, 2003). The three selected objects for our first study were chosen because they have well-established short periods and large enough amplitudes. All observations were conducted at the 0.51-m Optical Guidance Systems f/8.1 Ritchey-Chrétien telescope using an SBIG STXL 11002 CCD camera, cooled to -30°C, with an Astrodon Bessel R filter. The detector has 4008×2672 μm square pixels. With 2×2 binning, the pixel scale is 0.93 "/pix and the field of view is $30' \times 20'$.

Bias, dark, flat field corrections and subsequent photometry were performed in *AstrolmageJ* software (Collins et al., 2017). We corrected for light travel time for all three targets using ephemerides from the NASA Horizons website.

(243) *Ida* has the distinction in that it is only the second asteroid to have been photographed at close range by a spacecraft. On 1993 Aug 28 NASA's Galileo flew by *Ida* at a distance of roughly 1,500 miles on its way to Jupiter. Its sidereal period was determined to be 4.633632 ± 0.000007 h (Binzel et al., 1993) using pre-Galileo observations. Because the pre-encounter analysis was based upon 9 years of observations and the flyby extended this by only three months, the Galileo spacecraft trajectory was not well-suited to

Number	Name	yyyy mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
243	Ida	2019 9/18	6.9	338	0	4.67	0.04	0.76	0.04	KOR
321	Florentina	2019 10/24-11/4	19.1, 17.0	86	2	2.8708	0.0003	0.35	0.03	KOR
2713	Luxembourg	2018 12/05-12/11	5.6, 7.9	59	2	3.581	0.002	0.53	0.05	KOR

Table I. Observing circumstances and results. The phase angle is given for the first and last date. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range. Grp is the asteroid family/group.