# MAIN-BELT ASTEROIDS OBSERVED FROM CS3: 2022 JULY-SEPTEMBER

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(Received: 2022 October 6 Revised: 2022 November 19)

CCD photometric observations of seven main-belt asteroids were obtained at the Center for Solar System Studies (CS3) from 2022 July-September. Two revised periods from observations obtained in 2003 and 2018 are also reported. 4429 Chinmoy appears to be in non-principal axis rotation ("tumbling"). Our analysis found an additional, unexpected short period, low amplitude lightcurve. (101465) 1998 WL12 also appears to be tumbling. It was not possible to establish the true periods of rotation and precession for either asteroid.

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 |
|---|---|
| 0.35-m f/10 Schmidt-Cass | FLI Microline 1001E |
| 0.35-m f/10 Schmidt-Cass | FLI Proline 1001E |
| 0.40-m f/10 Schmidt-Cass | FLI Proline 1001E |
| 0.50-m F/8.1 R-C | QHY600 CMOS |

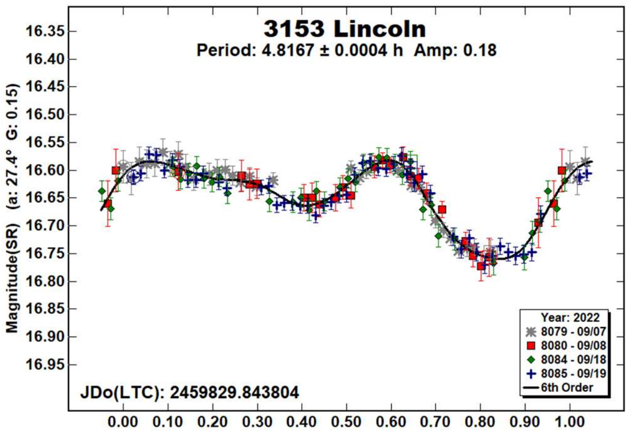
Table I: List of CS3 telescope/CCD camera.

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 (a) 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).

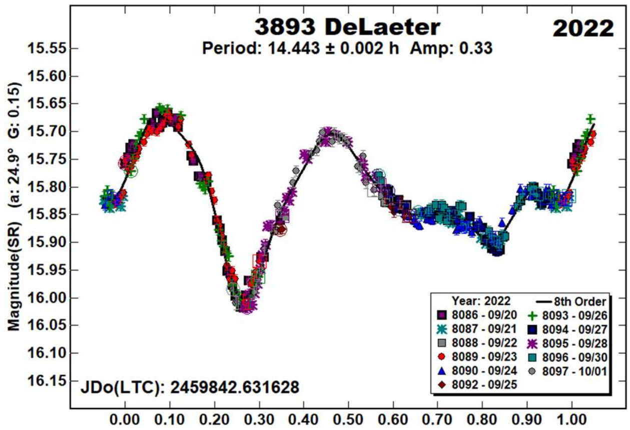
3153 Lincoln. Periods have been reported for this Vestoid using survey data. Using dense TESS data, Pál et al. (2020) reported a period of 4.81947 h. Using sparse ATLAS data, Erasmus et al. (2020) reported a period of 15.997 h, close to a 3:1 alias of the Pál et al. result. Our result this year confirmed the Pál et al. period and illustrates the issue of using sparse data while assuming a bimodal lightcurve.

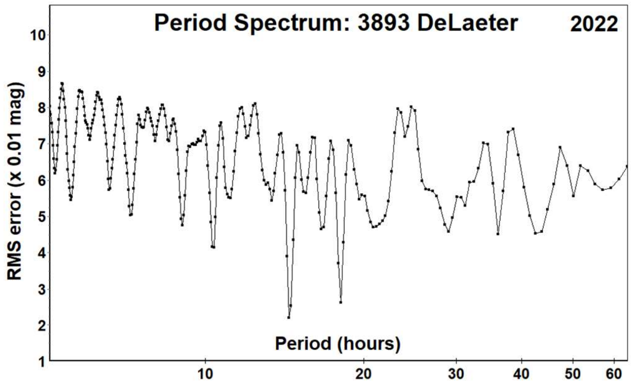


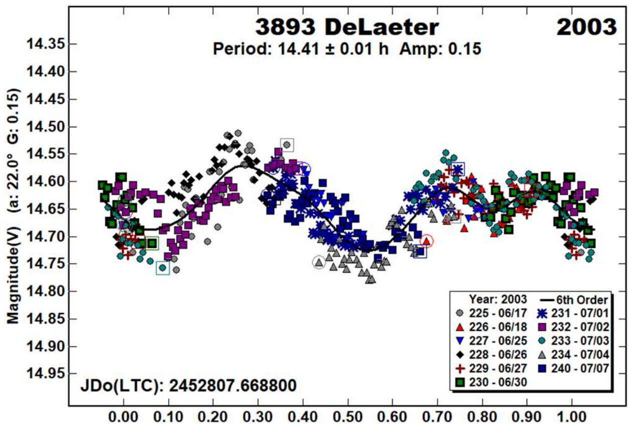

3893 DeLaeter. Finding a reliable period for this inner main-belt asteroid has been difficult in the past due to the asymmetric shape of its lightcurve and low-quality data. We observed it three times before with varying results (Stephens, 2004, 9.73 h; Warner, 2014, 5.633 h; Stephens, 2019, 9.61 h). This year we were able to obtain a high-quality dataset covering the entire phased lightcurve three times. The period spectrum suggests only two possibilities: near 14 h and 18 h. Upon inspection, the 18 h period is not plausible.

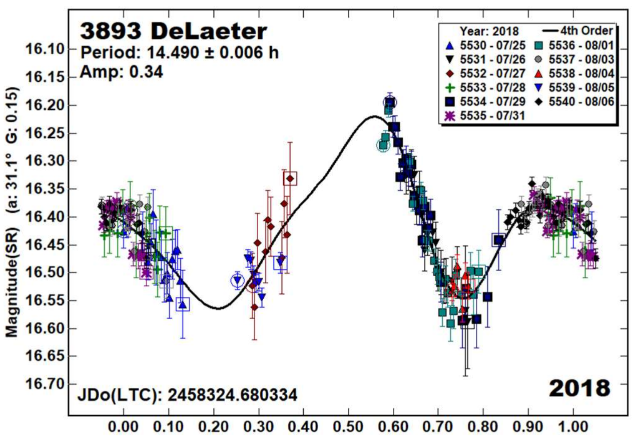
The original 2003 images no longer exist, but we were able to rephase that lightcurve to a period near 14.41 h resulting in a low amplitude lightcurve. With such a low amplitude, it is possible that a lightcurve could have a single minimum/maximum pair, or three or more pairs (Harris et al., 2014). The 2014 data were of too low a quality to rephase to a useful lightcurve, but we remeasured the 2018 data using ATLAS SR magnitudes and were able to find a 14.490 h period with an asymmetric lightcurve.

We think we can pronounce 'case closed' for 3893 DeLaeter. The next opportunities to observe it are in 2025, and particularly in 2026 when it will be mag 15.1.

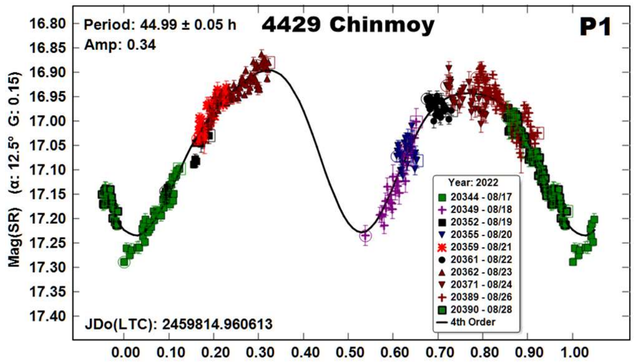


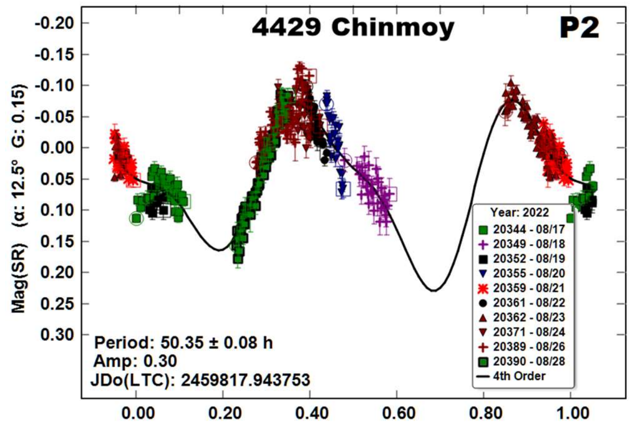



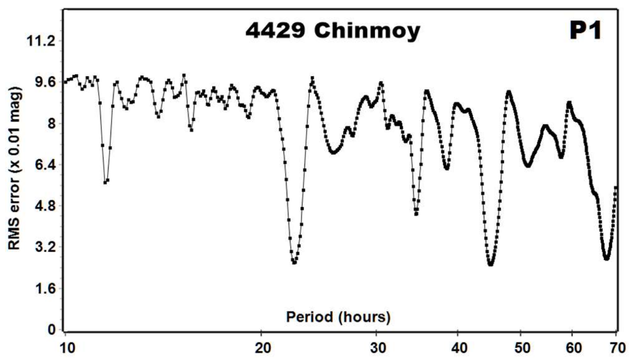



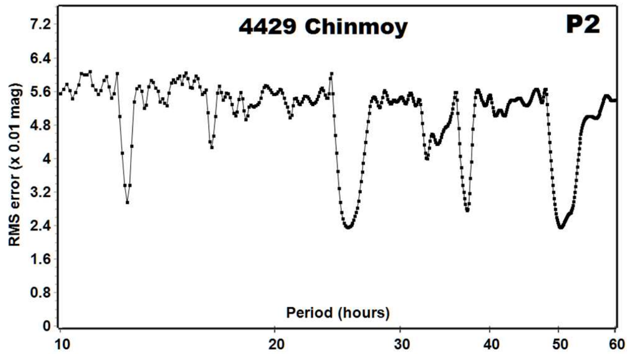




<u>4429 Chinmoy</u>. There are no previous periods reported in the LCDB for this member of the Hertha dynamical family (Nesvorny et al., 2015; Nesvorny, 2015). We were requested to observe it by Szabolcs Nyari. It was apparent from our first night of observations that Chinmoy had a long period. Deviations in the period suggested it to be tumbling, which *MPO Canopus* cannot properly analyze. Even so, we used it to extract the dominant period and another that, when subtracted from the full data set, allowed a good fit to a bimodal lightcurve with $P_1$ = 44.99 h. The other period, $P_2$ = 50.35 h, is likely an integral ratio (1/P) of the true frequency, an artifact of holding the first period constant while searching for a second and insufficient data. Proper analysis would have the two periods solved simultaneously. The periods are long enough to suspect that the asteroid has been in a tumbling state for some time. Based on a general rule of thumb (Pravec et al., 2005, 2014), the damping time for the asteroid, given its size and periods, would be slightly more than 1 Gyr.

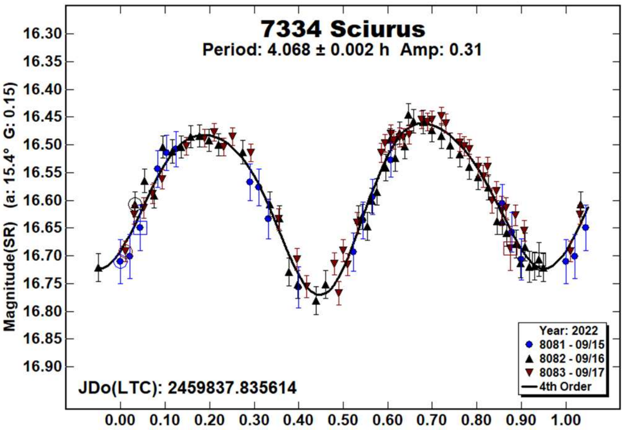


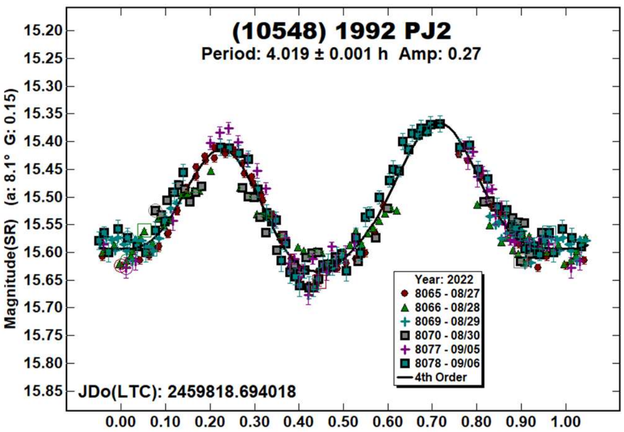





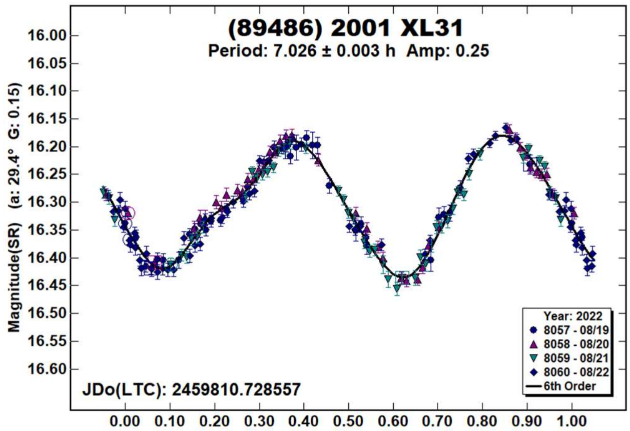

7334 Sciurus. This Vestoid has been observed twice in the past. Pravec (2011web) observed it finding a period of 4.0659 h. Using Gaia data (DR2), Colazo et al. (2021) reported a period of 4.067 h. Our result this year is in good agreement with those prior findings.



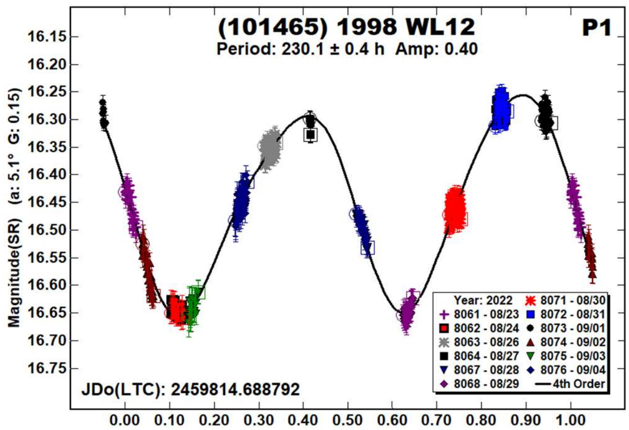

(10548) 1992 PJ2. As part of the Photometric Survey of Binary Near-Earth Asteroids (Pravec et al., 2006; Pravec et al., 2007web) reported a period of 4.01838 h for this Mars-crosser. Our period of 4.068 h this year is in good agreement with that prior result.

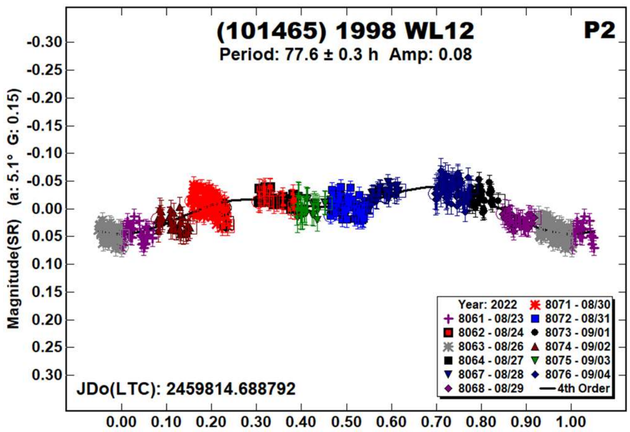



(89486) 2001 XL31. There are no previous entries in the LCDB for this Mars-crosser. The result of 7.026 h is assured since each of the four sequential nights covered the complete lightcurve.




(101465) 1998 WL12. There are no previous periods reported in the LCDB for this Mars-crosser. From the first night of observations, it was apparent that it had a long period. It seems likely from the period and diameter of 1.9 km that this is a tumbler (Pravec et al. 2005). *MPO Canopus* cannot fully analyze this type of object. Even so, we were 200able to extract a dominant period of 230.1 h. Subtracting that dominant period allowed us to find a secondary period of 77.6 h. Given that this has a 3:1 integral ratio with $P_1$ suggests the idea of $P_2$ being a harmonic artifact of the Fourier analysis.



| Number | Name | 2022/mm/dd | Phase | $L_{PAB}$ | $B_{PAB}$ | Period(h) | P.E. | Amp | A.E. |
|---|---|---|---|---|---|---|---|---|---|
| 3153 | Lincoln | 09/07-09/19 | 27.4,25.5 | 46 | -1 | 4.8167 | 0.0004 | 0.18 | 0.01 |
| 3893 | DeLaeter | 09/20-10/01 | 24.9,26.8 | 327 | 21 | 14.443 | 0.002 | 0.33 | 0.02 |
| | | 2003/06/17-07/07 | 22.0, 25.2 | 266 | 33 | $^{R}$14.41 | 0.01 | 0.15 | 0.05 |
| | | 2018/07/25-08/06 | 31.1, 32.8 | 256 | 29 | $^{R}$14.490 | 0.006 | 0.34 | 0.05 |
| 4429 | Chinmoy | 08/17-08/28 | 12.4,6.6 | 344 | 0 | $^{T}$44.99 | 0.05 | 0.37 | 0.05 |
| | | | | | | 50.35 | 0.08 | 0.30 | 0.05 |
| 7334 | Sciurus | 09/15-09/17 | 15.4,14.5 | 18 | -5 | 4.068 | 0.002 | 0.31 | 0.02 |
| 10548 | 1992 PJ2 | 08/27-09/06 | 8.1,12.0 | 306 | 7 | 4.019 | 0.001 | 0.27 | 0.02 |
| 89486 | 2001 XL31 | 08/19-08/22 | 29.4,29.2 | 345 | 29 | 7.026 | 0.003 | 0.25 | 0.01 |
| 101465 | 1998 WL12 | 08/23-09/04 | 5.1,11.5 | 329 | 5 | $^{T}$230.1 | 0.4 | 0.40 | 0.05 |
| | | | | | | 77.6 | 0.3 | 0.08 | 0.02 |

Table II. Observing circumstances and results. $^{R}$Revised period. $^{T}$Dominant 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.

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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