MAIN-BELT ASTEROIDS OBSERVED FROM CS3: 2021 JULY-SEPTEMBER

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CCD photometric observations of 10 main-belt asteroids were obtained at the Center for Solar System Studies (CS3) from 2021 July-September.

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 a nearly full moon is too close to the family targets being studied, targets of opportunity amongst the main-belt families were selected.

Table I lists the telescopes and CCD cameras that were used to make the observations. Images were unbinned with no filter and had master flats and darks applied. The exposures depended upon various factors including magnitude of the target, sky motion, and Moon illumination.

Telescope	Camera
0.30-m f/6.3 Schmidt-Cass	SBIG 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.35-m f/9.1 Schmidt-Cass	FLI Microline 1001E
0.40-m f/10 Schmidt-Cass	FLI Proline 1001E
0.40-m f/10 Schmidt-Cass	FLI Proline 1001E
0.50-m F8.1 R-C	FLI Proline 1001E

Table I: List of CS3 telescope/CCD camera combinations.

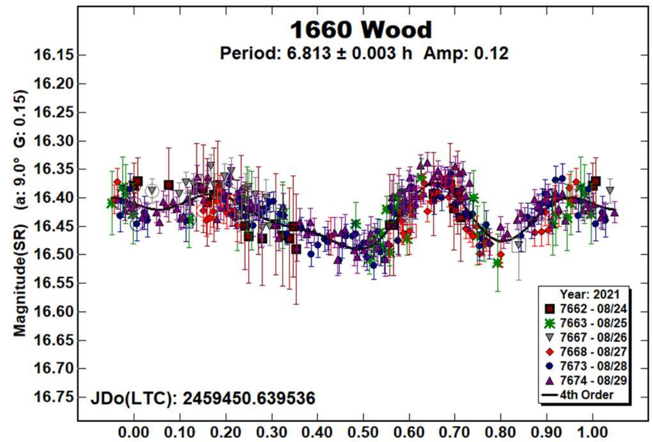
Image processing, measurement, and period analysis were done using *MPO Canopus* (Bdw Publishing), which incorporates the Fourier analysis algorithm (FALC) developed by Harris (Harris et al., 1989). The Comp Star Selector feature in *MPO Canopus* was used to limit the comparison stars to near solar color. 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.

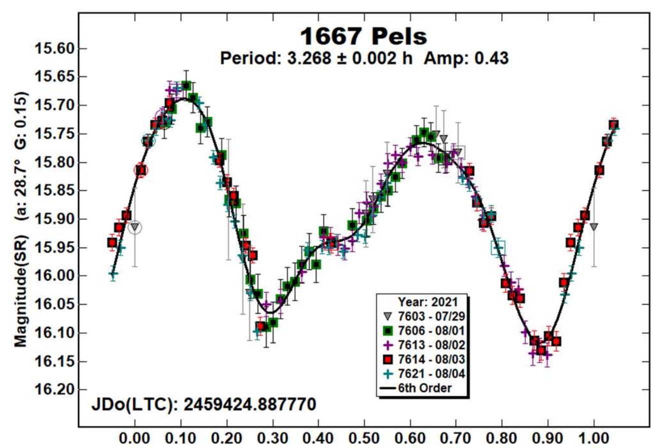
The X-axis shows rotational phase from –0.05 to 1.05. If the plot includes the amplitude, e.g., "Amp: 0.65", this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

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).

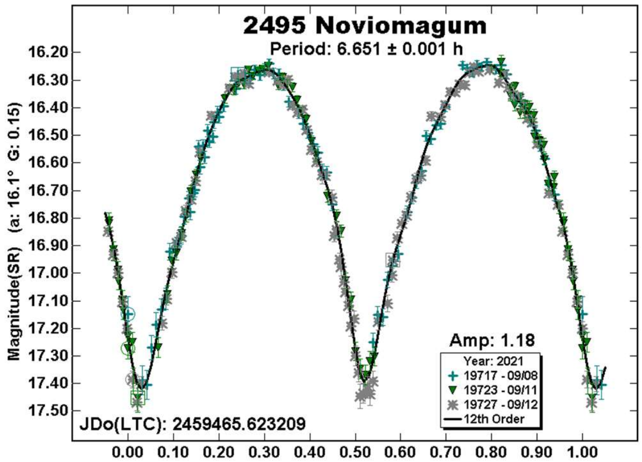
<u>1660 Wood</u>. This member of the Phocaea dynamical family has been observed three times in the past. Han et al. (2013), Hills (2012), and Oey & Alvarez (2012) all observed it in 2012 February finding periods near 6.809 h. Our results this year is in good agreement with those prior results.



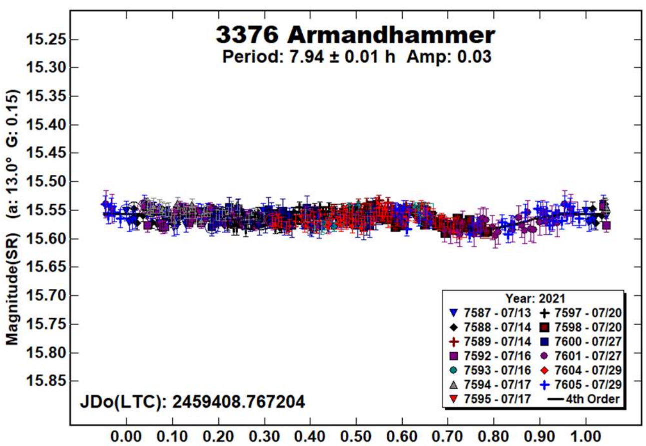
<u>1667 Pels</u>. This member of the Flora dynamical family has been observed several times in the past resulting in a pole/shape model (Stephens and Warner, 2020; and references therein). That model had a sideral period of 3.268280 h and two possible pole positions (182°, -53°, 3.268280 h) and (16°, -63°, 3.268280 h). This year's result is in good agreement with those prior findings.



<u>2495 Noviomagum</u>. Per the LCDB, this member of the Hungaria dynamical family has been observed once (Warner 2014), reporting a synodic period of 6.645 h. Hanuš et al. (2016) reported a spin axis model with (λ, β, *P*) = (15°, -57°) and a sidereal period of 6.65168 h. The result found this year is in good agreement with these prior periods.

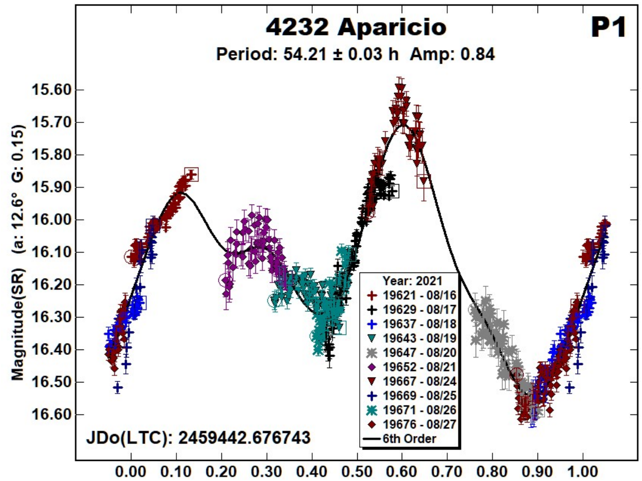


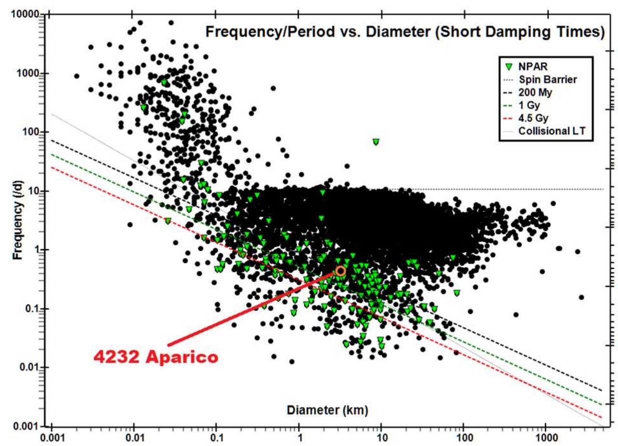
3376 Armandhammer. This member of the Flora dynamical family was observed by Pravec et al. (2009web) finding a period of 7.9184 h. and an amplitude of 0.04 mag. Using data from the Palomar Transient Factory, Waszczak et al. (2015) found a period of 9.480 h, which is a 5:6 alias of the Pravec period. Stephens (2016) found a period of 7.916 h and an amplitude of 0.27 mag. Even with the low amplitude of 0.03 mag., the result found this year is in good agreement with the prior Pravec and Stephens results.



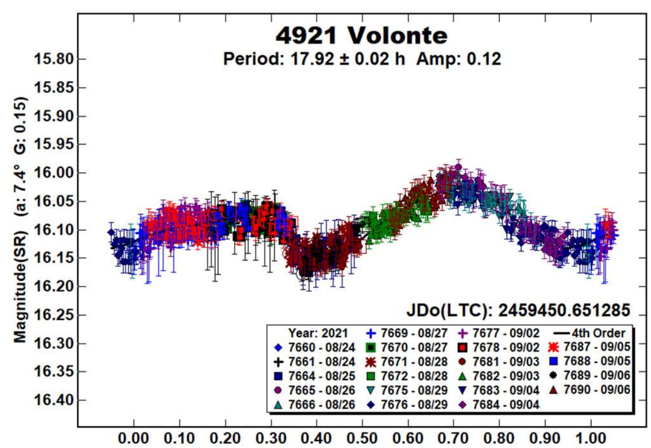
4232 Aparicio. This member of the Hungaria dynamical family is estimated to be 3.66 km in diameter. Warner (2006 and 2015) previously found a period near 54.3 h. Pravec et al. (2014) reported Aparicio to be in a tumbling state.

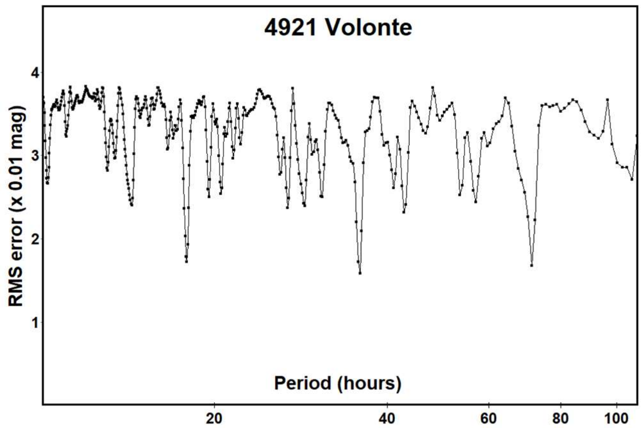
The data from 2021 also shows Aparicio to be tumbling. The tumbling frequencies cannot be confirmed from our data set alone, but we attempted to solve for the dominant period of the solution. The plot labeled "P1" is the dominant frequency, after subtracting one or more secondary frequencies, and is similar to dominant frequencies found in the past. The Frequency/Period vs. Diameter plot shows that Aparicio is near the 200 My damping line.



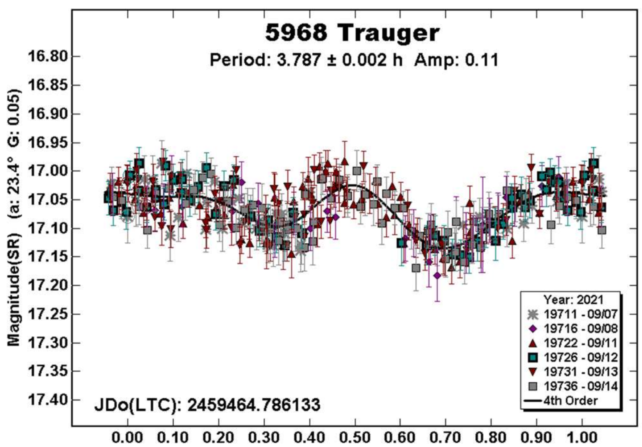


4921 Volonte. There are no previous results in the LCDB for this member of the Vestoid dynamical family. The Period Spectrum shows two plausible results for this year's data, 17.92 h and 35.78 h. We prefer the 17.92 h solution because it has an asymmetric bimodal lightcurve with maximums 0.5 phase apart. With this period being 2/3 commensurate with an Earth's day, the 35.78 h solution is fit-by-exclusion when viewed from a single longitude.

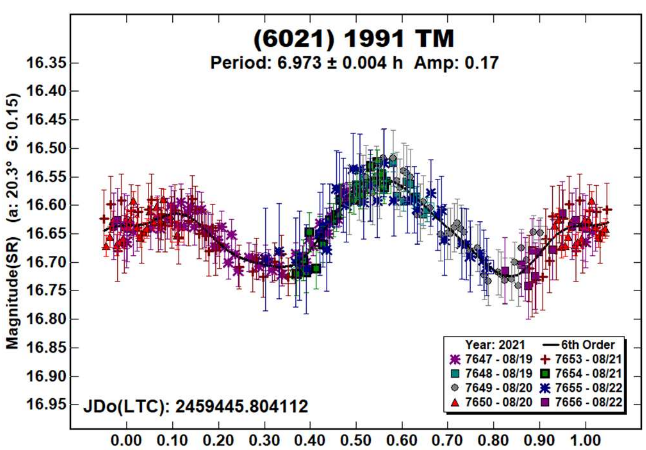




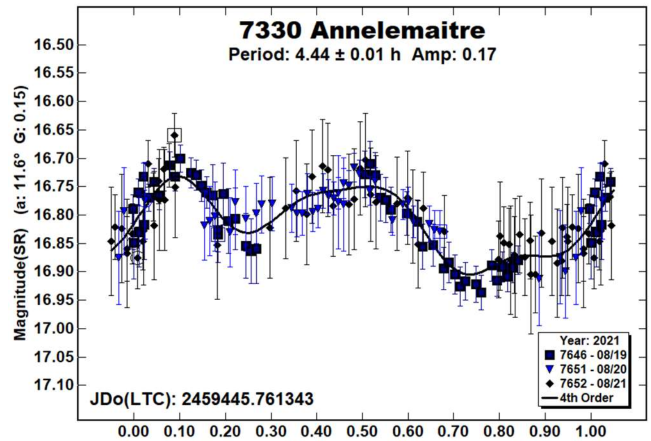
(5968) Trauger. The estimated diameter is 3.5 km for this member of the Hungaria dynamical family. It has been observed many times in the past (Warner, 2015; and references therein); most reporting a period near 3.748 h. The period found this year is in good agreement with those prior results.



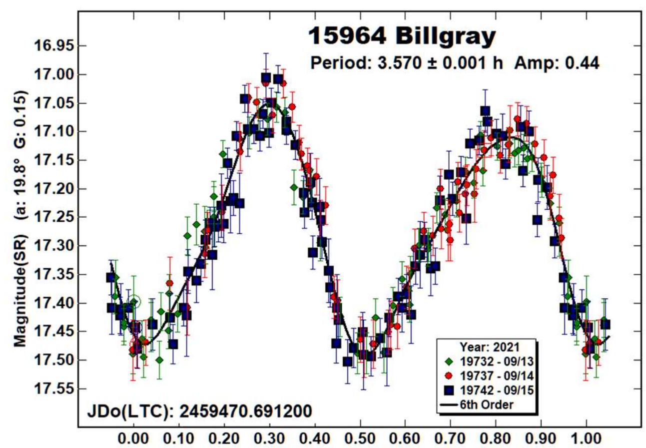
(6021) 1991 TM. Using data from the TESS spacecraft, Pál et al. (2020) found a period of 6.97081 h for this member of the Vestoid dynamical family. Our result this year is in good agreement with the Pál et al. result.



7330 Annelemaitre. This Mars-crosser has been observed three times in the past. Behrend (2014web) reported a period of 4.437 h. Stephens (2015) found a period of 4.438 h. Finally, using data from the TESS spacecraft, Pál et al. (2020) found a period of 4.43734 h. Our result this year is in good agreement with those prior results.



15964 Billgray. Periods for this member of the Hungaria dynamical family have been reported twice in the past. Warner (2011 and 2014) found periods near 3.57 h. Using data from the Palomar Transient Factory Survey, Waszczak et al. (2015) found a period of 3.570 h. The period found this year is in good agreement with the prior results.



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Number	Name	2021/mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.
1660	Wood	08/24-08/29	9.0,9.4	326	23	6.813	0.003	0.12	0.02
1667	Pels	07/29-08/04	28.7,28.2	16	-5	3.268	0.002	0.43	0.02
2495	Noviomagum	09/08-09/12	16.1,15.7	346	20	6.651	0.001	1.18	0.02
3376	Armandhammer	07/13-07/29	13.0,6.4	315	7	7.94	0.01	0.03	0.01
4232	Aparicio	08/16-08/27	*12.6,11.8	329	18	^{T}54.21	0.03	0.84	0.05
4921	Volonte	08/24-09/06	7.4,13.3	321	7	17.92	0.02	0.12	0.01
5968	Trauger	09/07-09/14	23.5,20.7	24	-2	3.787	0.002	0.11	0.02
6021	1991 TM	08/19-08/22	20.3,19.3	6	-5	6.973	0.004	0.17	0.02
7330	Annelemaitre	08/19-08/21	11.6,11.0	341	17	4.44	0.01	0.17	0.03
15964	Billgray	09/13-09/15	19.8,19.3	9	22	3.570	0.001	0.44	0.03

Table II. Observing circumstances and results. ^{T}Dominant frequency 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).

References

Behrend, R. (2014web). Observatoire de Geneve web site. *http://obswww.unige.ch/~behrend/page_cou.html*

Han, X.L.; Li, B.; Zhao, H. (2013). "Rotation Periods of 1660 Wood, 7173 Sepkoski, 12738 Satoshimiki and (23233) 2000 WM72." *Minor Planet Bull.* **40**, 14-15.

Hanuš, J.; Ďurech, J.; Oszkiewicz, D.A.; Behrend, R.; Carry, B.; Delbo, M.; Adam, O.; Afonina, V.; Anquetin, R.; Antonini, P.; Arnold, L.; Audejean, M.; Aurard, P.; Bachschmidt, M.; Baduel, B.; Barbotin, E.; Barroy, P.; Baudouin, P.; Berard, L.; Berger, N. (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.; Young, J.W.; Contreiras, L.; Dockweiler, T.; Belkora, L.; Salo, H.; Harris, W.D.; Bowell, E.; Poutanen, M.; Binzel, R.P.; Tholen, D.J.; Wang, S. (1989). "Phase relations of high albedo asteroids: The unusual opposition brightening of 44 Nysa and 64 Angelina." *Icarus* **81**, 365-374.

Hills, K. (2012). "Asteroid Lightcurve Analysis at Riverland Dingo Observatory: 1394 Algoa, 1660 Wood, 8882 Sakaetamura, and (15269) 1990 XF." *Minor Planet Bull.* **39**, 239-240.

Oey, J.; Alvarez, E.M. (2012). "Period Determination for 1660 Wood." *Minor Planet Bull*. **39**, 147-148.

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.* **247**, A26.

Pravec, P.; Wolf, M.; Sarounova, L. (2009web). *http://www.asu.cas.cz/~ppravec/neo.htm*

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. (2015). "Asteroids Observed from CS3: 2014 July - September." *Minor Planet Bull.* **42**, 70-74.

Stephens, R.D. (2016). "Asteroids Observed from CS3: 2016 January - March." *Minor Planet Bull.* **43**, 252-255.

Stephens, R.D.; Warner, B.D. (2020). "Main-Belt Asteroids Observed from CS3: 2020 April to June." *Minor Planet Bull*. **47**, 275-284.

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., (2006). "The lightcurve for the Hungaria asteroid 4232 Aparicio." *Minor Planet Bull*. **33**, 24-25.

Warner, B.D. (2011). "Lightcurve Analysis at the Palmer Divide Observatory: 2010 June-September." *Minor Planet Bull.* **38**, 25-31

Warner, B.D. (2014). "Asteroid Lightcurve Analysis at CS3-Palmer Divide Station: 2013 June - September." *Minor Planet Bull.* **41**, 27-32.

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

Warner, B.D.; Harris, A.W.; Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2021 May. *http://www.minorplanet.info/lightcurvedatabase.html*

Waszczak, A.; Chang, C.-K.; Ofek, E.O.; Laher, R.; Masci, F.; Levitan, D.; Surace, J.; Cheng, Y.-C.; Ip, W.-H.; Kinoshita, D.; Helou, G.; Prince, T.A.; Kulkarni, S. (2015). "Asteroid Light Curves from the Palomar Transient Factory Survey: Rotation Periods and Phase Functions from Sparse Photometry." *Astron. J.* **150**, A75.