

LIGHTCURVE ANALYSIS OF L4 TROJAN ASTEROIDS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2021 OCTOBER TO DECEMBER

Robert D. Stephens
Center for Solar System Studies (CS3)
11355 Mount Johnson Ct., Rancho Cucamonga, CA 91737 USA
rstephens@foxandstephens.com

Brian D. Warner
Center for Solar System Studies (CS3)
Eaton, CO

(Received: 2022 January 12)

Lightcurves for five Jovian Trojan asteroids were obtained at the Center for Solar System Studies (CS3) from 2021 October to December.

For several years, the Center for Solar System Studies (CS3, MPC U81) has been conducting a study of Jovian Trojan asteroids. This paper reports CCD photometric observations of five Trojan asteroids from the L4 (Greek) Lagrange point from 2021 October to December.

All observations were made using a 0.4-m f/10 Schmidt-Cassegrain telescope and an FLI Proline 1001E CCD camera. Images were unbinned with no filter and had master flats and darks applied. The exposures were 180 seconds.

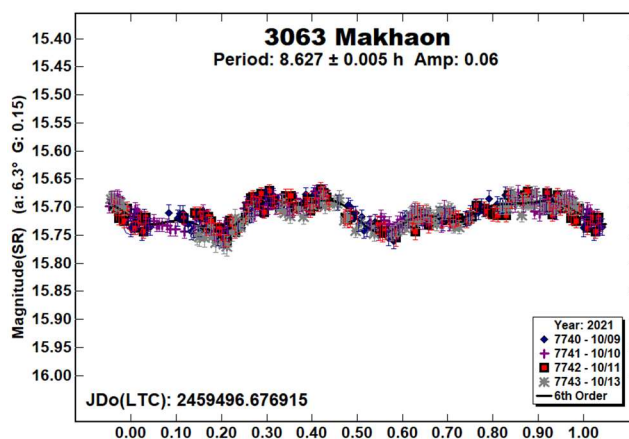
Image processing, measurement, and period analysis were done using *MPO Canopus* (Bdw Publishing), which incorporates the Fourier analysis algorithm (FALC) developed by Harris (Harris et al., 1989). The Comp Star Selector feature in *MPO Canopus* was used to limit the comparison stars to near solar color.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

The Y-axis of lightcurves gives ATLAS SR “sky” (catalog) magnitudes. During period analysis, the magnitudes were normalized to the phase angle and value for *G* given in the parentheses. The X-axis rotational phase ranges from -0.05 to 1.05.

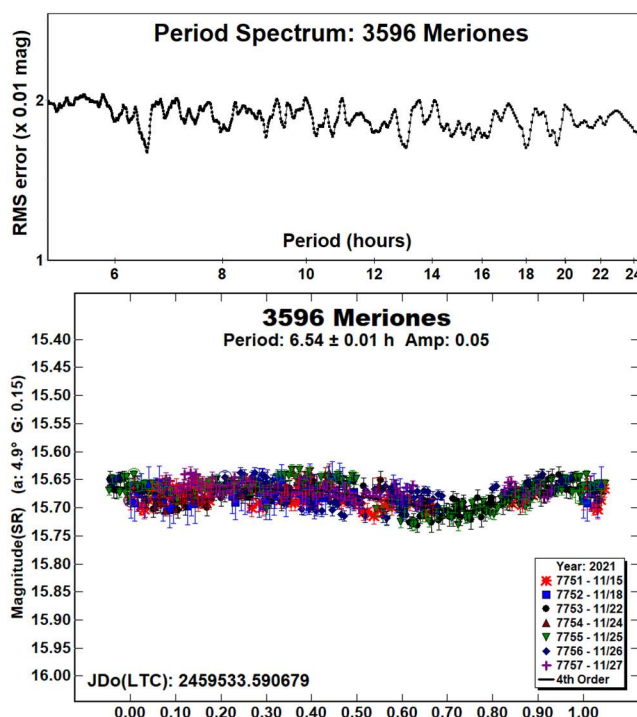
The amplitude indicated in the plots (e.g., Amp. 0.23) is the amplitude of the Fourier model curve and *not necessarily* the adopted amplitude of the lightcurve.

For brevity, only some of the previously reported rotational periods may be referenced. A complete list is available at the lightcurve database (LCDB; Warner et al., 2009).

3063 Makhaon. We observed this L4 Trojan five times in the past (Stephens et al., 2021; and references therein). Mottola et al. (2011) also observed it twice. The results this year are in good agreement with those prior findings.

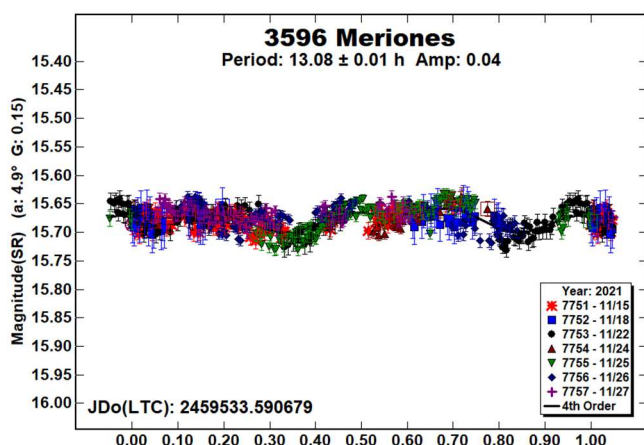


3596 Meriones. Periods for this L4 Trojan have been reported twice in the past. Gonano et al. (1991) found a period of 12.96 h. Using data from the TESS spacecraft, Pál et al. (2020) found a period of 6.4178 h, seemingly a 1:2 alias of the Gonano result. Both reported a 0.15 mag amplitude. The results this year did not break the tie. The amplitude we observed was only 0.04 - 0.05 mag. With such a low amplitude, one cannot assume a bimodal shape to the lightcurve (Harris et al., 2014). The period spectrum shows many possible periods, with ones around 6.5 h and 13 h barely above the noise. This dataset cannot differentiate between the two possible periods, but we prefer the 6.54 h solution because it produces a bimodal lightcurve with a much better fit to the Fourier curve.

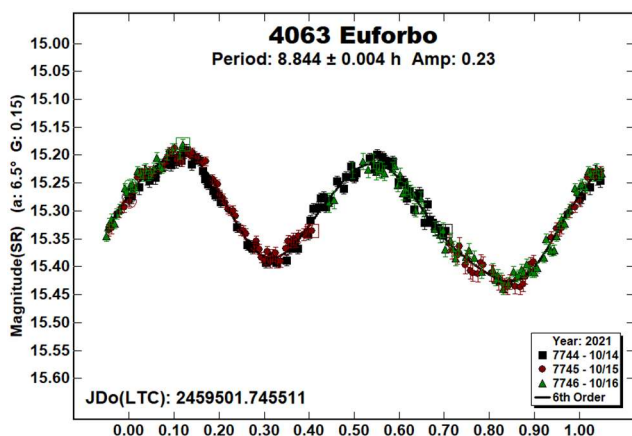


Number	Name	2021/mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.
3063	Makhaon	10/09-10/13	6.4, 5.7	46	12	8.627	0.005	0.06	0.01
3596	Meriones	11/15-11/27	4.9, 5.7	52	22	6.54 ^a 13.08	0.01 0.01	0.05 0.04	0.01 0.01
4063	Euforbo	10/14-10/16	6.6, 6.3	42	-21	8.844	0.004	0.23	0.01
4068	Menestheus	2019/08/30-09/06 12/01-12/06	3.9, 4.9 9.0, 9.5	320 18	12 -8	^r 14.319 14.301	0.003 0.007	0.52 0.28	0.02 0.02
4501	Eurypylos	11/28-11/30	2.3, 2.8	55	1	6.931	0.004	0.31	0.03

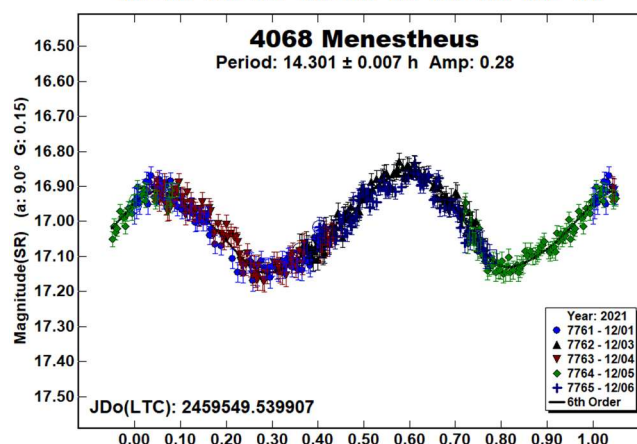
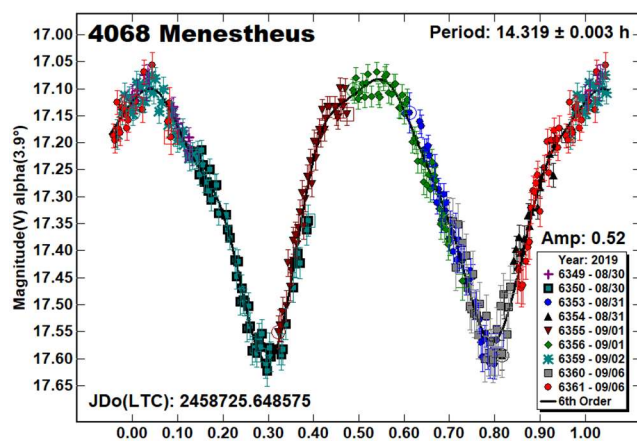
Table I. Observing circumstances and results. ^rRestated previous period. ^aAlternative period. The phase angle is given for the first and last dates. If preceded by an asterisk, the phase angle reached an extremum during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984).



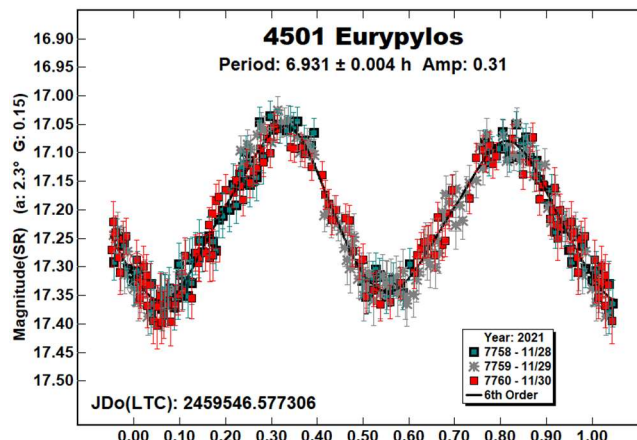
4063 Euforbo. This L4 Trojan is estimated to be 102 km in size. A period has been reported several times in the past (Stephens et al., 2016; and references therein), each time finding it rotated every 8.84 h. The result this year is in good agreement with the prior results.



4068 Menestheus. A period for this L4 Trojan has been reported several times in the past (e.g., Stephens and Warner, 2017), each time reporting a period near 14.3 h. In researching for this article, we found an unreported result of ours from 2019 September. The results from 2019 and 2021 are in good agreement with the prior findings.



4501 Eurypylos. A period for this Trojan has been reported twice in the past (Stephens and Warner, 2020; and references therein). The period found this year is in good agreement with those prior results.



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 purchase of a FLI-1001E CCD camera was made possible by a 2013 Gene Shoemaker NEO Grant from the Planetary Society.

References

- Gonano, M.; di Martino, M.; Mottola, S.; Neukum, G. (1991). "Physical study of outer belt asteroids." *Adv. in Space Research*. **11**, 197-200.
- 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.; Bowell, E.; Martin, L.J.; Millis, R.L.; Poutanen, M.; Scaltriti, F.; Zappala, V.; Schober, H.J.; Debehogne, H.; Zeigler, K.W. (1989). "Photoelectric Observations of Asteroids 3, 24, 60, 261, and 863." *Icarus* **77**, 171-186.
- 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.
- Mottola, S.; Di Martino, M.; Erikson, A.; Gonano-Beurer, M.; Carbognani, A.; Carsenty, U.; Hahn, G.; Schober, H.; Lahulla, F.; Delbò, M.; Lagerkvist, C. (2011). "Rotational Properties of Jupiter Trojans. I. Light Curves of 80 Objects." *Astron. J.* **141**, A170.
- 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.
- 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. (2017). "Lightcurve Analysis of L4 Trojan Asteroids at the Center for Solar System Studies 2017 April-June." *Minor Planet Bull.* **44**, 312-316.
- 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.
- Stephens, R.D.; Coley, D.R.; Warner, B.D. (2021). "Lightcurve Analysis of L4 Jovian Trojan Asteroids from the Center for Solar System Studies: 2020 October to December." *Minor Planet Bull.* **48**, 167-170.
- 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 2021 May. <http://www.minorplanet.info/lightcurvedatabase.html>