LIGHTCURVE ANALYSIS OF HILDA ASTEROIDS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2019 NOVEMBER

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: 2020 January 9)

CCD photometric observations of three Hilda asteroids were made at the Center for Solar System Studies (CS3) in 2019 November to provide additional lightcurves for modeling.

CCD photometric observations of three Hilda asteroids were made at the Center for Solar System Studies (CS3) in 2019 November. This is another installment of an on-going series of papers on this group of asteroids, which is located between the outer main-belt and Jupiter Trojans in a 3:2 orbital resonance with Jupiter. The goal is to determine the spin rate statistics of the group and find pole and shape models when possible. We also look to examine the degree of influence that the YORP (Yarkovsky–O'Keefe–Radzievskii–Paddack) effect (Rubincam, 2000) has on distant objects and to compare the spin rate distribution against the Jupiter Trojans, which can provide evidence that the Hildas are more "comet-like" than main-belt asteroids.

Telescopes	Cameras
0.30-m *f*/6.3 Schmidt-Cass	FLI Microline 1001E
0.35-m *f*/9.1 Schmidt-Cass	FLI Proline 1001E
0.35-m *f*/11 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.

Table I lists the telescopes and CCD cameras that are 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. All lightcurve observations were unfiltered since a clear filter can result in a 0.1-0.3 magnitude loss. The exposures varied depending on the asteroid's brightness.

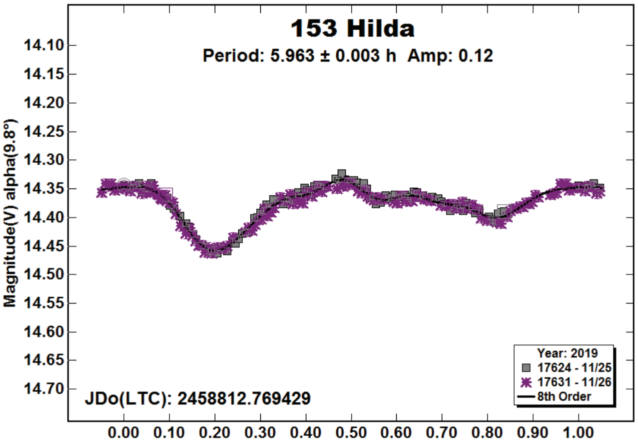
Measurements were made using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color for differential photometry. Comp star magnitudes were taken from ATLAS catalog (Tonry et al., 2018), which has Sloan griz magnitudes that were derived from the GAIA and Pan-STARR catalogs, among others. The authors state that systematic errors are generally no larger than 0.005 mag, although they can reach 0.02 mag in small areas near the Galactic plane. BVRI magnitudes were derived by Warner using formulae from Kostov and Bonev (2017). The overall errors for the BVRI magnitudes, when combining those in the ATLAS catalog and the conversion formulae, are on the order of 0.04-0.05 mag.

Period analysis was done with *MPO Canopus*, which implements the FALC algorithm by Harris (Harris et al*.*, 1989). The same algorithm is used in an iterative fashion when it appears there is more than one period. This works well for binary but not for tumbling asteroids.

In the plots below, the Y-axis gives the sky (catalog) magnitude of the asteroid (V is Johnson V, SR is Sloan r′). For plots of additional periods, the zero point is the average magnitude of the primary lightcurve. The magnitudes were normalized to the phase angle in parentheses using $G = 0.15$. The X-axis is the rotational phase ranging from –0.05 to 1.05. If the plot includes an amplitude, it is for the peak-to-peak Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

Our initial search for previous results started with the asteroid lightcurve database (LCDB; Warner et al., 2009), which is on-line at *http://www.minorplanet.info/lightcurvedatabase.html*. Readers are strongly encouraged to obtain, when possible, the original references listed in the LCDB.

153 Hilda. This is the largest member (170 km) of the Hilda group. Shevchenko et al. (2009) used data from 2002 observations to find a period of 5.9587 h. Our period of 5.963 h is in good agreement.

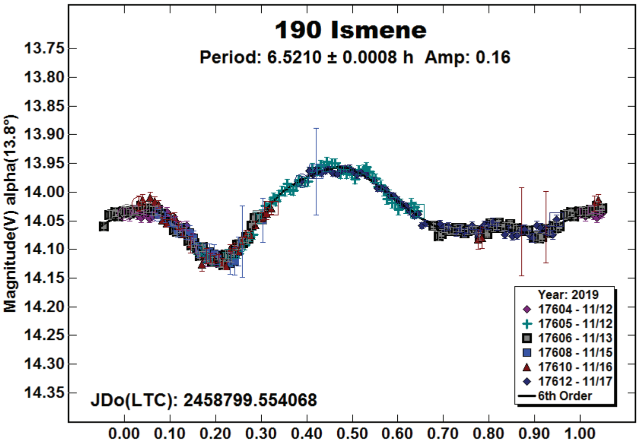


190 Ismene. Binzel and Sauter (1992) are the earliest entry in the LCDB with a result (6.51 h) that is near the adopted period of 6.5210 h given in the LCDB. Dahlgren et al. (1998) found a period of 6.52 h. Shevchenko et al. (2008) found a period of 6.5192 h using data from 1999. Since then, only two other references in the LCDB have a result near the adopted period: Dunckel (2011; a web posting) and this work.

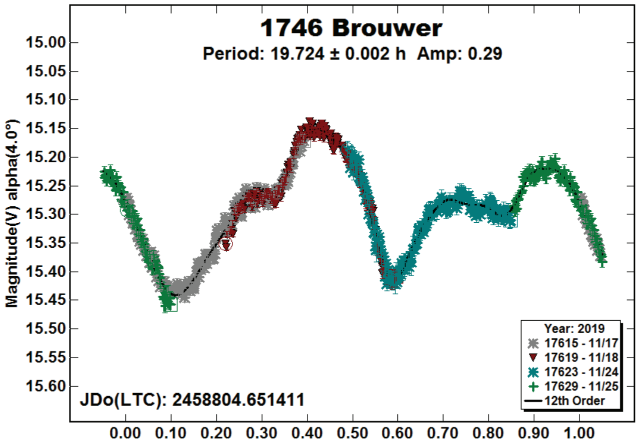
Number	Name	2019/mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.
153	Hilda	11/25-11/26	9.8,9.7	108	-7	5.963	0.003	0.12	0.01
190	Ismene	11/12-11/17	13.8,14.2	345	0	6.5210	0.0008	0.16	0.01
1746	Brouwer	11/17-11/25	4.0,3.5	60	10	19.724	0.002	0.29	0.02

Table II. Observing circumstances. The phase angle (α) is given at the start and end of each date range. L_{PAB} and B_{PAB} are the average phase angle bisector longitude and latitude (see Harris *et al*., 1984).

For the second largest member of the Hilda family (158 km) this seems a sparse sampling. It may be that observers seeing an accurate period and U = 3 in the LCDB believe that no other observations are required. It's a rare occasion when there are too many observations of an asteroid. In this case, the new data contributed to developing an accurate shape and spin axis model.



1746 Brouwer. Dahlgren et al. (1998) found P = 19.8 h for Brouwer. Hanus et al. (2016) derived a shape and spin axis model with two possible poles: (λ, β) = (21°, –67°) or (158°, –71°). The sidereal period was 19.7255 h for both models.



The result from the 2019 observations at CS3 led to an asymmetric bimodal lightcurve with a period of 19.724 h and amplitude of 0.29 mag.

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. 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.

References

Binzel, R.P.; Sauter, L.M. (1992). "Trojan, Hilda, and Cybele asteroids: New lightcurve observations and analysis." *Icarus* **95**, 222-238.

Dahlgren, M.; Lahulla, J.F.; Lagerkvist, C.-I.; Lagerros, J.; Mottola, S.; Erikson, A.; Gonano-Beurer, M.; Di Martino, M. (1998). "A Study of Hilda Asteroids. V. Lightcurves of 47 Hilda Asteroids." *Icarus* **133**, 247-285.

Dunckel, P.B. (2011). Posting on CALL site. *http://www.minorplanet.info/call.html*

Hanus, J.; Durech, J.; Oszkiewicz, D.A.; Behrend, R.; Carry, B.; Delbo, M.; Adam, O.; Afonina, V.; Anquetin, R.; Antonini, P.; and 159 coauthors (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.; 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.

Kostov, A.; Bonev, T. (2017). "Transformation of Pan-STARRS1 gri to Stetson BVRI magnitudes. Photometry of small bodies observations." *Bulgarian Astron. J.* **28**, 3 (AriXiv:1706.06147v2).

Rubincam, D.P. (2000). "Relative Spin-up and Spin-down of Small Asteroids." *Icarus* **148**, 2-11.

Shevchenko, V.G.; Chiorny, V.G.; Gaftonyuk, N.M.; Krugly, Y.N.; Belskaya, I.N.; Tereschenko, I.A.; Velichko, F.P. (2008). "Asteroid observations at low phase angles. III. Brightness behavior of dark asteroids." *Icarus* **196**, 601-611.

Shevchenko, V.G.; Tungalag, N.; Chiorny, V.G.; Gaftonyuk, N.M.; Krugly, Y.N.; Harris, A.W.; Young, J.W. (2009). "CCD-photometry and pole coordinates for eight asteroids." *Plan. Space Sci.* **57**, 1514-1520.

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 2019 July. *http://www.minorplanet.info/lightcurvedatabase.html*