

LIGHTCURVE ANALYSIS OF HILDA ASTEROIDS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2020 AUGUST - SEPTEMBER

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New CCD photometric observations of four Hilda asteroid members were made from 2020 August through September: 499 Venusia, 1162 Larissa, 2760 Kacha, and (13035) 1989 UA6. One of them, 2760 Kacha, showed weak signs of a secondary period, but its origin may be only a harmonic artifact of Fourier analysis.

CCD photometric observations of Hilda asteroids are made at the Center for Solar System Studies (CS3) as part of an ongoing study of this family/group that 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 Hildas and to 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.

Table I lists the telescopes and CCD cameras that are combined to make observations. Up to seven telescopes are commonly used for observations. 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.

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	

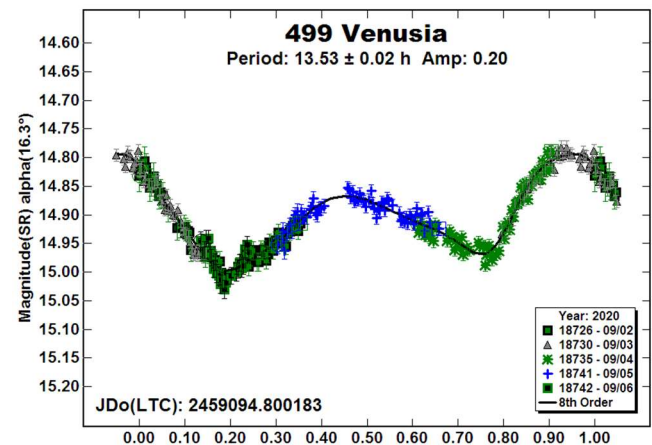
Table I. List of available telescopes and CCD cameras at CS3. The exact combination for each telescope/camera pair can vary due to maintenance or specific needs.

To reduce the number of times and amounts of adjusting nightly zero points, we use the ATLAS catalog r' (SR) magnitudes (Tonry et al., 2018). Those adjustments are usually $\leq \pm 0.03$ 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. Another cause may be selecting what appears to be a single star but is actually an unresolved pair.

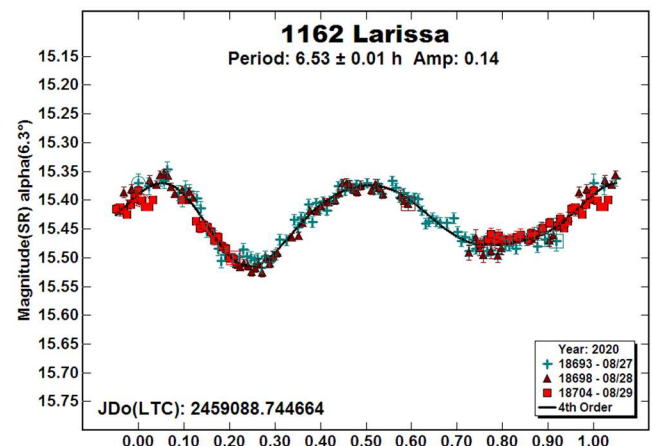
The Y-axis values are ATLAS SR “sky” (catalog) magnitudes. During period analysis, the magnitudes were normalized to the comparison stars used in the earliest session and to the phase angle given in parentheses using $G = 0.15$. The X-axis shows rotational phase from -0.05 to 1.05 . If the plot includes 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*.

Our initial search for previous results started with the asteroid lightcurve database (LCDB; Warner et al., 2009) found on-line at <http://www.minorplanet.info/lightcurvedatabase.html>. Readers are strongly encouraged to obtain, when possible, the original references listed in the LCDB. From here on, we’ll use only “LCDB” to reference the paper by Warner et al. (2009).

499 Venusia. Two previous rotational periods listed in the LCDB are from Dahlgren et al. (1998, 13.48h) and Behrend (2006web, 13.486 h). Hanuš et al. (2011) used a combination of dense and sparse data sets to find a sidereal period of 13.4871 h and a pole with J2000 ecliptic coordinates of $(\lambda, \beta) = (37^\circ, 50^\circ)$ or $(212^\circ, 46^\circ)$. Our synodic period of 13.53 h is more than one-sigma from the previous results, more than might be expected from the sidereal-synodic difference. A larger data set, one that filled in the entire lightcurve may have moved the result closer to the others.



1162 Larissa. Pligge et al. (2011) found a period of 6.520 h for this 44-km Hilda. Warner and Stephens (2017) found a similar result of 6.514 based on 2017 observations. Our results from 2020 are in reasonably good agreement.

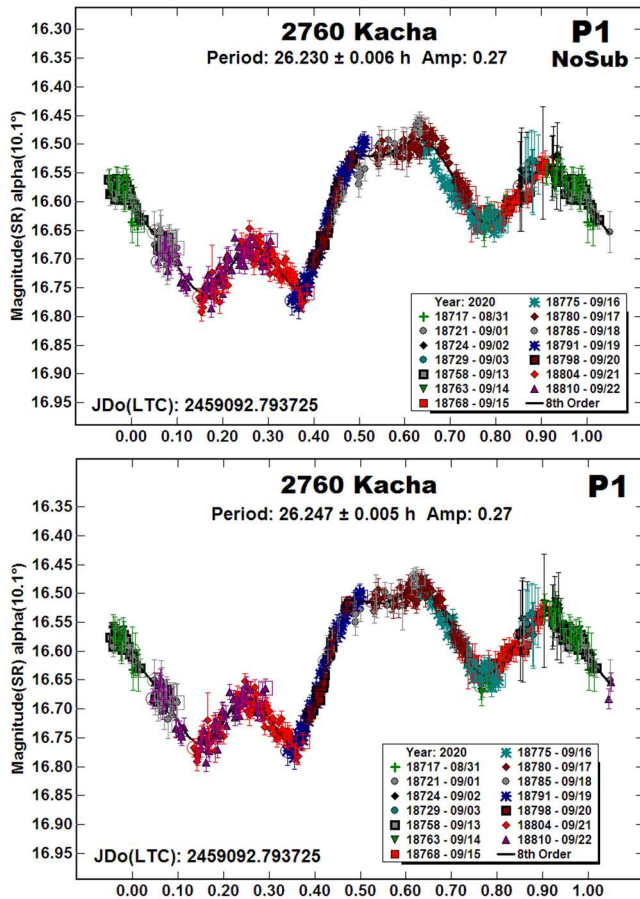


Number	Name	20yy/mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.
499	Venusia	09/02–09/06	16.3, 15.8	38	2	13.53	0.02	0.20	0.01
1162	Larissa	08/27–08/29	6.3, 5.8	357	–2	6.53	0.01	0.14	0.01
2760	Kacha	08/31–09/22	10.1, 5.7	20	6	26.247 15.63	0.005 0.02	0.27 0.04	0.02 0.01
13035	1989 UA6	08/30–09/09	5.3, 2.5	354	–4	10.647	0.003	0.40	0.03

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).

2760 Kacha. Dahlgren *et al.* (1998) reported a period of 13.0 h for the 58-km Larissa. Āurech *et al.* (2018b) used lightcurve inversion to find a sidereal period of 53.040 h and pole with J2000 ecliptic coordinates of $(\lambda, \beta) = (101^\circ, -30^\circ)$. Our synodic period is almost exactly one-half that found by Āurech *et al.* (2018b).

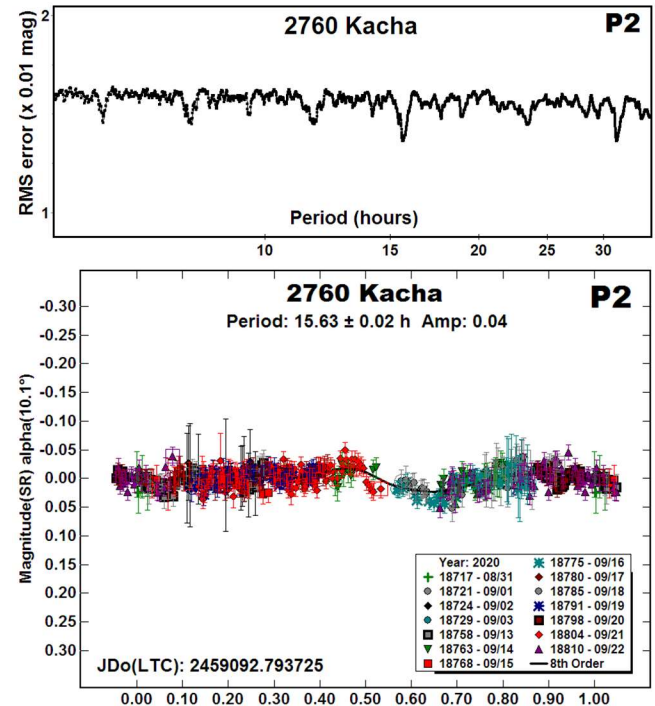
Trying to fit our data to near 53 h produced a very ragged lightcurve. To get it close to a reasonable fit would have required unacceptably large zero-point offsets. Also, given the apparent lightcurve amplitude of 0.27 mag, it was not likely that even an ill-fitting result near 53 h was correct (Harris *et al.*, 2014).



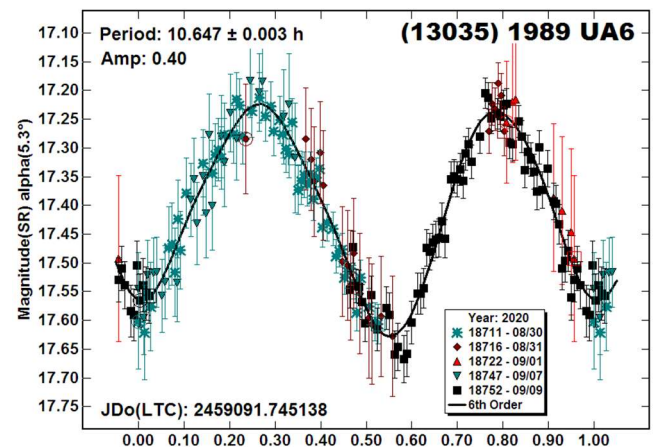
Even after getting a close fit to 26.230 h, parts of the lightcurve did not quite line-up. We used the dual-period search feature of *MPO Canopus* to see if a second period was present.

The period spectrum shows several possible, but relatively weak, possibilities with the lowest RMS at about 15.6 h. Refinement of the two periods led to a final result of $P_2 = 15.63$ h which, when subtracted from the full data set, produced a cleaner lightcurve for $P_1 = 26.230$ h. A search for a secondary period that would improve the results for a period of 53 h was unsuccessful.

Tumbling is unlikely given the period and diameter (Pravec *et al.*, 2014), so it's doubtful that the P_2 lightcurve has a physical origin. Given that P_2 is almost an exact 3:2 ratio with an Earth day and is also very close to being a 5:3 ratio with P_1 , it's more likely that P_2 is the result of a harmonic artifact from the Fourier analysis and acts as a “noise filter” for the data set.



(13035) 1989 UA6. Āurech *et al.* (2018a) used lightcurve inversion to find a sidereal period $P_{\text{sidereal}} = 10.65696$ h and a pole with J2000 ecliptic coordinates of $(\lambda, \beta) = (142^\circ, 46^\circ)$ or $(323^\circ, 37^\circ)$. We (Warner and Stephens, 2018) observed the 24-km asteroid in 2018 and found a synodic period of 10.639 h. Our result from the 2020 observations is in very good agreement.



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