

LIGHTCURVE ANALYSIS OF HILDA ASTEROIDS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2018 APRIL-JUNE

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Lightcurves for seven Hilda asteroids were obtained at the Center for Solar System Studies (CS3) from 2018 April-June: 1180 Rita, 1748 Mauderli, 1877 Marsden, (13035) 1989 UA6, (42237) 2001 EG21, and (60381) 2000 AX180. The previously reported period (Warner and Stephens, 2017) for 1180 Rita was revised following analysis of the 2018 data.

CCD photometric observations of seven Hilda asteroids were made at the Center for Solar System Studies (CS3) from 2018 April-June. 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.

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 and sky motion.

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.

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. Catalog magnitudes were usually taken from the APASS (Henden et al., 2009) or CMC-15 (Munos, 2017) catalogs.

The nightly zero points for the APASS and CMC-15 catalogs are generally consistent to about ± 0.05 mag or better, but occasionally reach >0.1 mag. There is a systematic offset between the two

catalogs so, whenever possible, the same catalog is used for all observations of a given asteroid. Period analysis is done with *MPO Canopus*, which implements the FALC algorithm by Harris (Harris et al., 1989).

In the plots below, the “Reduced Magnitude” is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying $-5 \log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid distances in AU. The magnitudes were normalized to the phase angle in the parentheses using $G = 0.15$, unless otherwise stated. The X-axis is the rotational phase ranging from -0.05 to 1.05 .

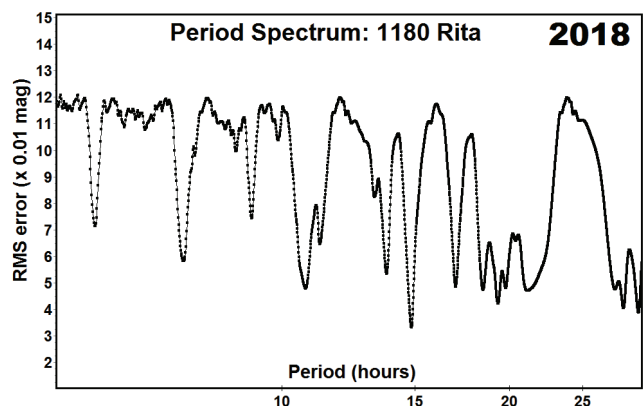
If the plot includes an amplitude, e.g., “Amp: 0.65”, this is the amplitude of the Fourier model curve and *not necessarily the adopted amplitude for the lightcurve*.

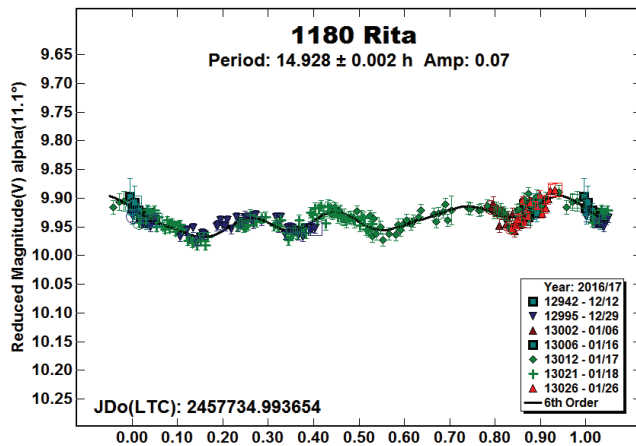
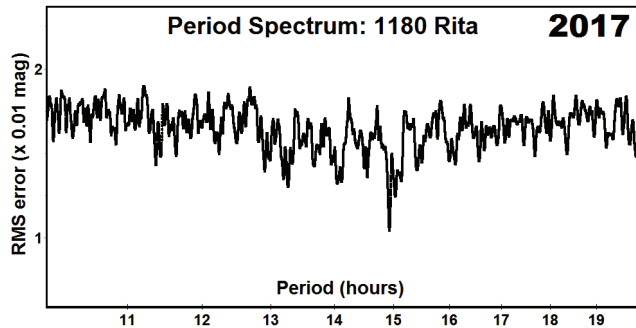
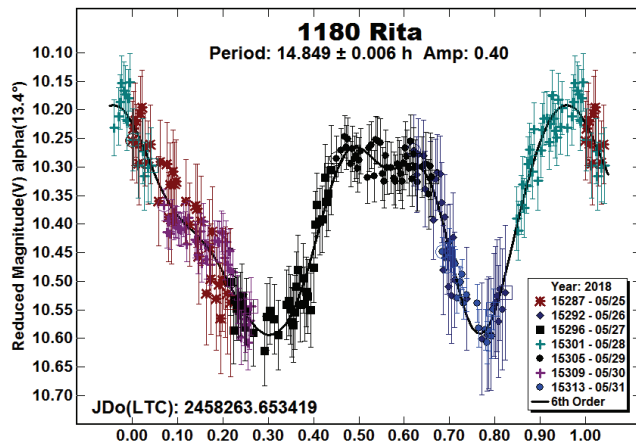
For the sake of brevity, only some of the previously reported results may be referenced in the discussions on specific asteroids. For a more complete listing, the reader is directed to the asteroid lightcurve database (LCDB; Warner et al., 2009). The on-line version at <http://www.minorplanet.info/lightcurvedatabase.html> allows direct queries that can be filtered a number of ways and the results saved to a text file. A set of text files of the main LCDB tables, including the references with Bibcode, is also available for download. Readers are strongly encouraged to obtain, when possible, the original references listed in the LCDB for their work.

1180 Rita. Several different periods have been reported for this 82-km Hilda: Gonano et al. (1991; 14.72 h), Dahlgren et al. (1998; 14.902 h), and Polishook (2012; 9.605 h), among others.

Our 2018 data led to what seems to be a convincing bimodal lightcurve with $P = 14.928 \pm 0.006$ h, $A = 0.40 \pm 0.03$ mag. This result is consistent with Dahlgren et al. (1998) but inconsistent with our results from 2017 (Warner and Stephens, 2017; 13.090 h). In his paper, Polishook (2012) phased his data to previously reported periods, all leading to improbable results.

We tried the same exercise using our data from 2018 and 2017 to force a solution between 9–10 hours. The best fit from the 2018 data was 9.130 h, but this required significant zero point shifts and some sessions being “too flat” for their position in the lightcurve. The amplitude of the 2017 data was only 0.04 mag, meaning the slightest zero point shifts could alter the solution. Even so, after many attempts, the best RMS fit, by far, was to a quadramodal lightcurve with a period of 14.849 h.



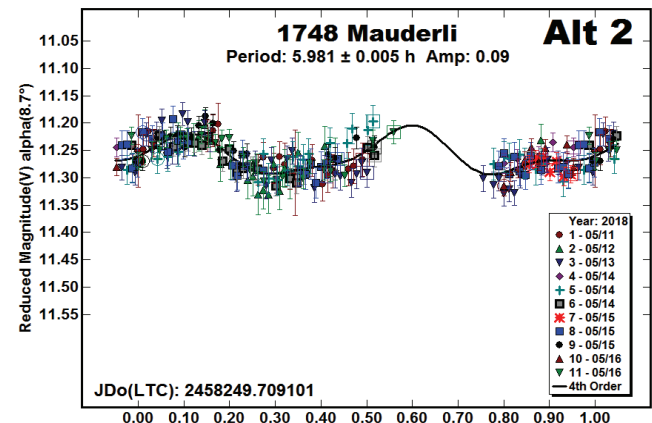
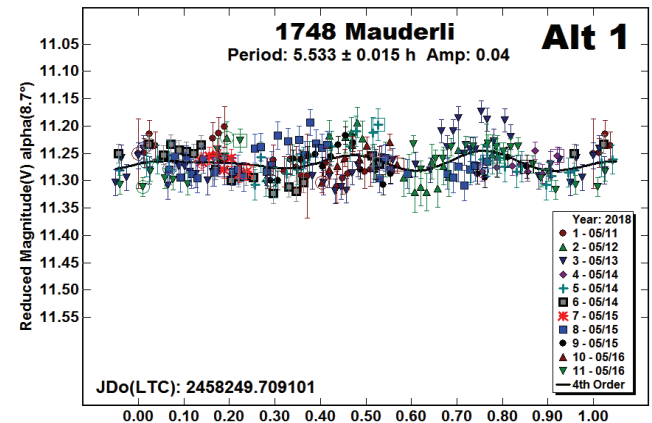
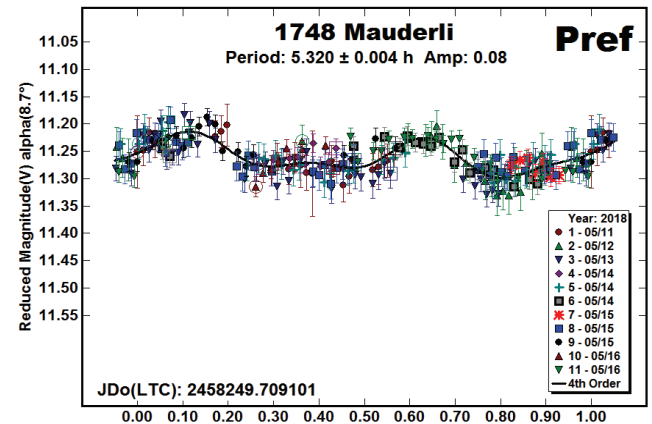
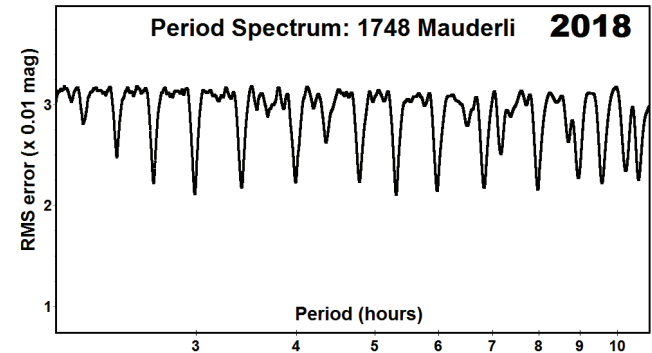


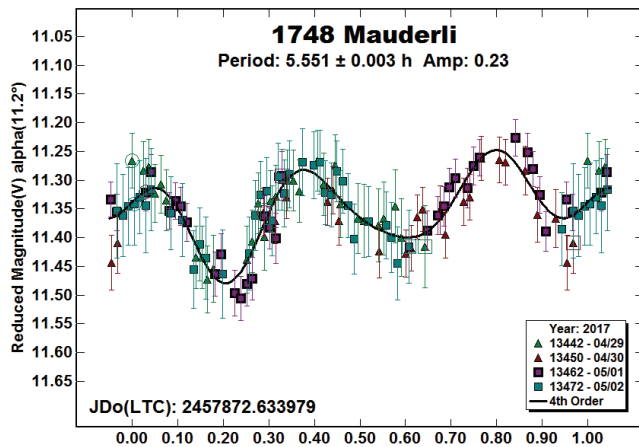
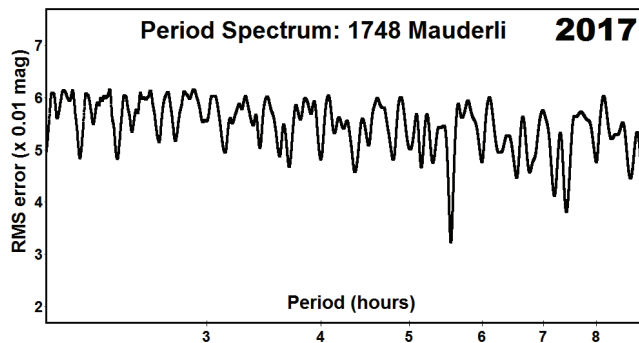
While we are confident in the 14.9-hour solution, especially given the fully-covered asymmetrical lightcurve with an amplitude of 0.4 mag (see Harris et al., 2014), we encourage additional observations at future apparitions.

1748 Mauderli. The estimated size of Mauderli is 40 km. Previous results include Gonano et al. (1991; 6.00 h), Dahlgren et al. (1998; 6.00 h) and Slyusarev et al. (2012; 6.001 h). Our previous observations (Warner and Stephens, 2017; 5.552 h) differed significantly and so we observed the asteroid again in 2018 to see if the ambiguities could be resolved.

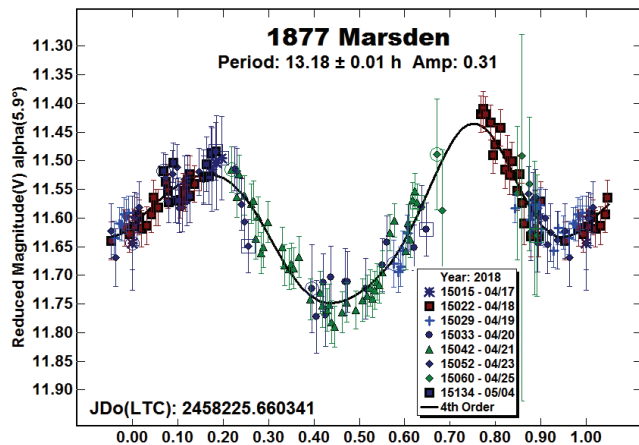
The 167 data points obtained on six consecutive nights led to a period of 5.320 h. However, as seen in the period spectrum, this was not a dominant solution and, in fact, one near 5.5 hours (our 2017 result) and 6 hours (other previous results) were also a possibility. We forced the data to fit near both of those periods. The solution at 5.981 h, in some ways, has a better fit to those parts of the curve that are filled in. However, the large gap could be the result of a “fit by exclusion”, which is when the Fourier

algorithm finds a local not global minimum in the RMS values. Given the uncertainty in the latest results, we double-checked those from the 2017 data. The period spectrum shows no doubt about the original period. Mauderli’s period remains a mystery.

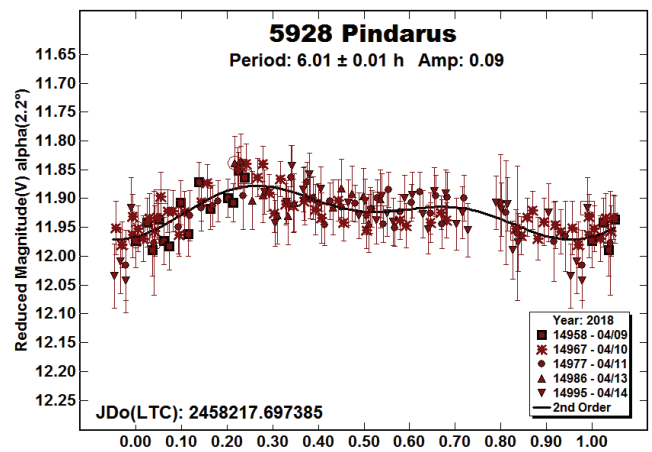
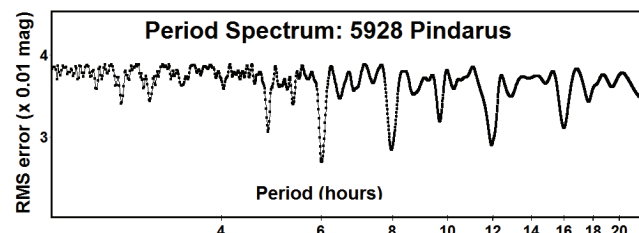




1877 Marsden. The only previous result in the LCDB was from Dahlgren et al. (1998), who found a period of 14.4 h. This was based on about 25 data points obtained from 1995 Mar 9-11 and a lightcurve with significant gaps. Our lightcurve is sufficiently covered, i.e., multiple sessions for most sections of the lightcurve, to give us high confidence in our result.

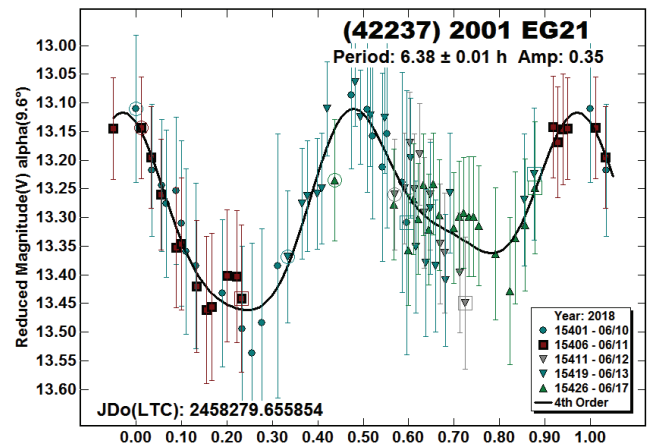
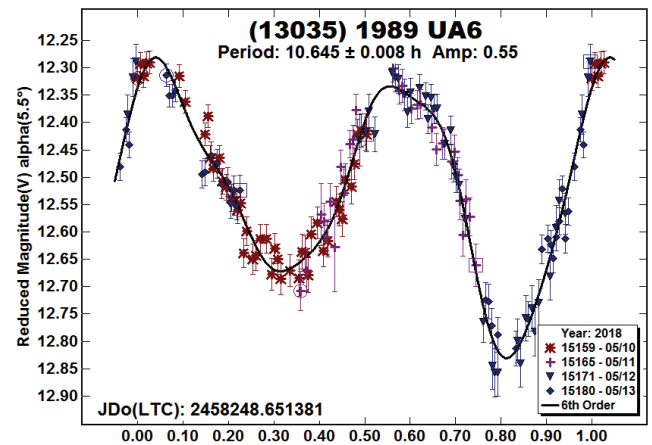


5928 Pindarus. This appears to be the first reported lightcurve. The low amplitude leaves room for doubt (see Harris et al., 2014).



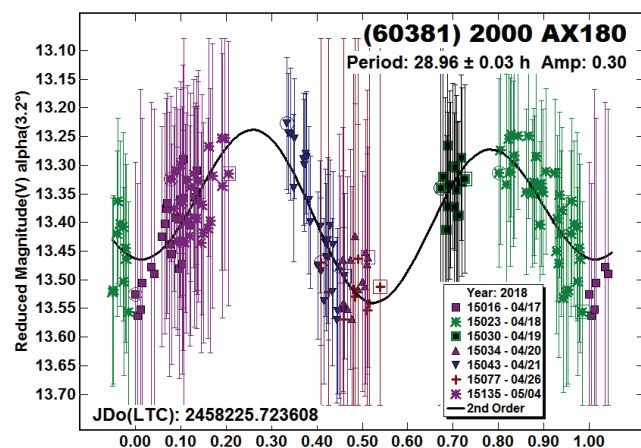
(13035) 1989 UA6, (42237) 2001 EG21, and (60381) 2000 AX180. There were no entries with periods in the LCDB for any of these Hilda asteroids. Mainzer et al. (2016) give estimated diameters of 28 km, 18 km, and 15 km for, respectively, 1989 UA6, 2001 EG21, and 2000 AX180.

The period of 10.645 h for 1989 UA6 is considered secure given the large amplitude, asymmetrical shape, and relatively good data. The period for 2001 EG21 is less than secure because the error bars almost rival the amplitude of the lightcurve in some cases. Even so, this is better than the result for 2000 AX180 where the error bars are even larger and all four of the extrema points are not covered.



Number	Name	2018/mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.
1180	Rita	05/25-05/31	254	13.5, 13.9	180	8	14.849	0.006	0.40	0.03
1180	Rita	²⁰¹⁶⁻¹⁷ 12/12-01/26	243	11.1, 3.2	139	6	14.93	0.01	0.07	0.01
1748	Mauderli	05/11-05/15	167	8.7, 9.5	194	4	5.320	0.004	0.08	0.01
1748	Mauderli	²⁰¹⁷ 04/29-05/02	125	11.2, 11.4	159	2	5.551	0.003	0.23	0.02
1877	Marsden	04/17-05/04	170	6.0, 9.8	186	-6	13.18	0.01	0.31	0.02
5928	Pindarus	04/09-04/14	143	2.2, 2.1, 2.2	202	7	6.01	0.01	0.09	0.01
13035	1989 UA6	05/10-05/14	174	5.5, 6.7	213	2	10.639	0.005	0.57	0.03
42237	2001 EG21	06/10-06/17	85	9.7, 11.1	225	5	6.38	0.01	0.35	0.03
60381	2000 AX180	04/17-05/04	156	3.2, 6.7	201	10	28.96	0.03	0.30	0.05

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



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