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ASTEROID LIGHTCURVE ANALYSIS AT CS3-PALMER DIVIDE STATION: 2018 JANUARY-APRIL

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Lightcurves for six main-belt asteroids were obtained at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2018 January-April. Two of the asteroids were *targets of opportunity*, i.e., in the field of planned targets, which demonstrates a good reason for data mining images.

CCD photometric observations of six main-belt asteroids were made at the Center for Solar System Studies-Palmer Divide Station (CS3-PDS) from 2018 January-April. Table I lists the telescope/CCD camera combinations that were used. All the cameras use the KAF-1001E blue-enhanced CCD chip and so have essentially the same response. The pixel scales for the combinations range from 1.24-1.60 arcsec/pixel.

Desig	Telescope	Camera
Squirt	0.30-m f/6.3 Schmidt-Cass	ML-1001E
Borealis	0.35-m f/9.1 Schmidt-Cass	FLI-1001E
Eclipticalis	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Australius	0.35-m f/9.1 Schmidt-Cass	STL-1001E
Zephyr	0.50-m f/8.1 R-C	FLI-1001E

Table I. List of CS3-PDS telescope/CCD camera combinations.

All lightcurve observations were unfiltered since a clear filter can cause a 0.1-0.3 mag loss. The exposure duration varied depending on the asteroid's brightness and sky motion. Guiding on a field star sometimes resulted in a trailed image for the asteroid.

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 MPOSC3 catalog was used as a last resort. This catalog is based on the 2MASS catalog (<http://www.ipac.caltech.edu/2mass>) with magnitudes converted from J-K to BVRI (Warner, 2007b).

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 among all three 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).

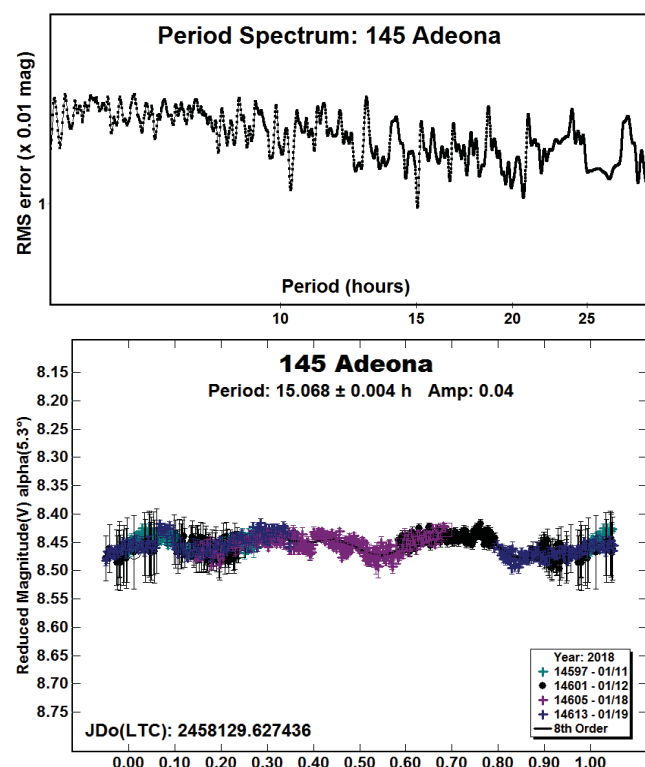
In the lightcurves below, the "Reduced Magnitude" is Johnson V as indicated in the Y-axis title. These are values that have been converted from sky magnitudes to unity distance by applying $-5 \cdot \log(r\Delta)$ to the measured sky magnitudes with r and Δ being, respectively, the Sun-asteroid and Earth-asteroid 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*.

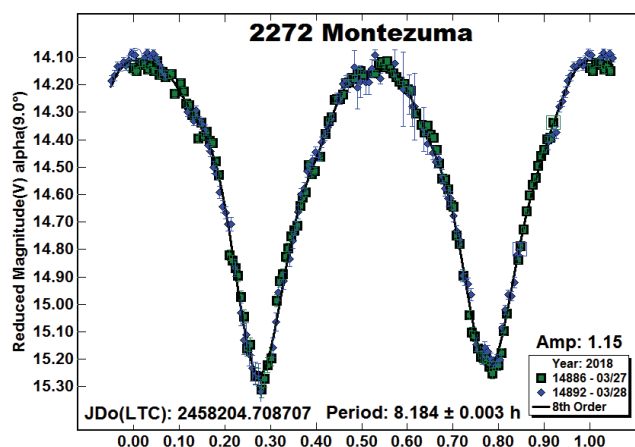
For the sake of brevity, only some of the previously reported results may be referenced in the discussions on specific asteroids. For a more complete listing, the reader is directed to the asteroid lightcurve database (LCDB; Warner et al., 2009). The on-line version at <http://www.minorplanet.info/lightcurvedatabase.html> 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, when possible, to cross-check with the original references listed in the LCDB.

145 Adeona is a 150 km member of the Eunomia group. The first reliable (LCDB $U > 1+$) rotation period was reported by Burchi et al. (1985), who found a period of 8.1 h. Behrend (2004) found a period of 8.301 h, but that was with a noisy data set and low amplitude lightcurve. Stephens (2009) and Pilcher (2010) found highly reliable results ($U = 3$) of 15.086 h and 15.017 h, respectively.

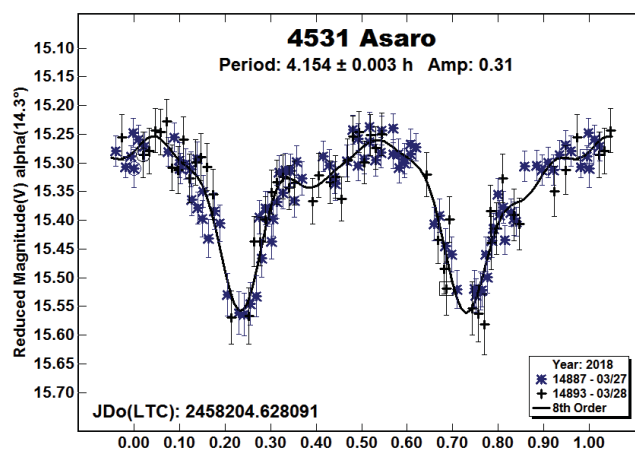
The observations at CS3-PDS were made at the request of Josef Hanus, who was updating a shape and spin axis model for the asteroid. The period of 15.068 h found from the CS3-PDS data is in good agreement with Stephens (2009) and Pilcher (2010).



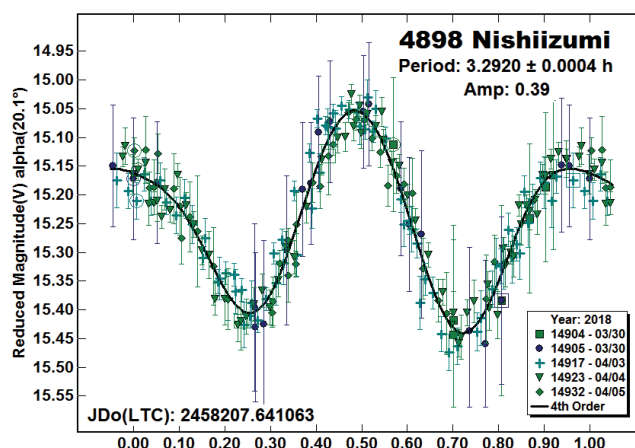
2272 Montezuma. This is a Hungaria asteroid that was observed at three previous apparitions by Stephens et al. (2014), Stephens (2017), and Warner (2012b), all of whom reported a period of 8.180-8.183 h. The period of 8.184 h found from the most recent CS3 data is in excellent agreement with those earlier findings.



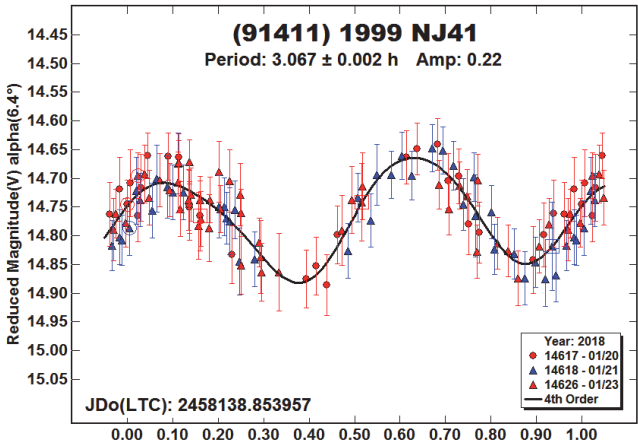
4531 Asaro. The data obtained in 2018 March was the fifth time that the Hungaria asteroid had been observed by the author. The previous results (Warner, 2013; 2015a; 2015b) ranged from 4.118-4.16 h. The period of 4.154 h reported here is in good agreement.



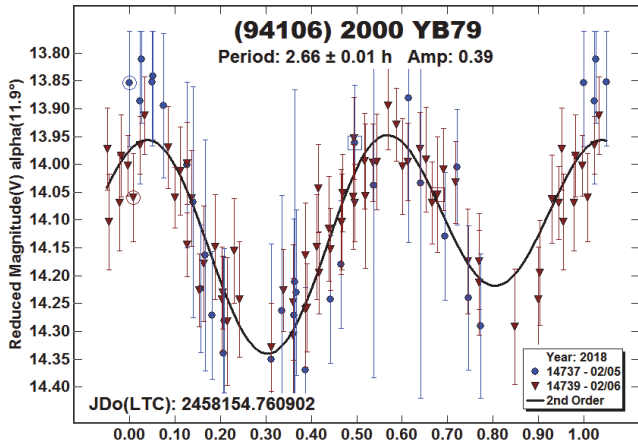
4898 Nishiizumi. This is another Hungaria member that was observed so that data could be used in lightcurve inversion to improve a previously found shape and spin axis. Previous results by the author, Warner (2007a; 2012b; 2015c), are in close agreement with the most recent result of 3.2920 h. The amplitude, $A = 0.39$ mag, was the largest by at least 0.1 mag, indicating the most equatorial view of the asteroid to-date.



(91411) 1999 JN41. This 4.4 km Eunomia asteroid was a *target of opportunity*, one that was in the same field as the planned target. There were no previous lightcurve results in the LCDB. The period of 3.067 h is considered secure.



(94106) 2000 YB79 is a 12 km outer main-belt asteroid that was serendipitously wandering through the field of a planned target. It was $V \sim 18$, so the SNR was low. However, it was possible to get a reliable solution because of the large amplitude.



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(<http://svo2.cab.inta-csic.es/vocats/cmc15/>).

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Number	Name	2018 mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Group
145	Adeona	01/11-01/19	1069	5.3, 6.8	112	10	15.068	0.004	0.04	0.01	EUN
2272	Montezuma	03/28-03/28	244	8.8, 8.8	193	11	8.184	0.003	1.15	0.02	H
4531	Asaro	03/28-03/28	142	14.7, 14.7	172	12	4.154	0.003	0.31	0.02	H
4898	Nishiizumi	03/30-04/05	209	20.1, 22.8	162	5	3.2920	0.0004	0.39	0.03	H
91411	1999 NJ41	01/20-01/23	111	6.4, 7.2	112	10	3.067	0.002	0.22	0.02	EUN
94106	2000 YB79	02/05-02/06	91	11.9, 11.6	166	13	2.66	0.01	0.39	0.04	MB-O

Table II. Observing circumstances and results. The phase angle (α) is given at the start and end of each date range. L_{PAB} and B_{PAB} are, respectively, the average phase angle bisector longitude and latitude (see Harris *et al.*, 1984). The Group column gives the orbital group to which the asteroid belongs. The definitions and values are those used in the LCDB (Warner *et al.*, 2009a). EUN: Eunomia; H: Hungaria; MB-O: outer main-belt.

Warner, B.D., Harris, A.W., Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2017 April. <http://www.minorplanet.info/lightcurvedatabase.html>

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2018 AJ: A TUMBLING NEAR-EARTH ASTEROID

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CCD photometric observations of the near-Earth asteroid 2018 AJ were made during its close approach (4.7 lunar distances) to Earth in 2018 January. Analysis of data obtained over three nights shows that the asteroid is in a state of non-principal axis rotation (NPAR, "tumbling") with possible periods of 0.6722 ± 0.0006 h and 0.986 ± 0.002 h. The lightcurve observations alone could not determine which period is that of rotation and the other of precession nor whether or not the corresponding rotation frequencies are the actual or a linear combination of the true values.

The near-Earth asteroid 2018 AJ was discovered by the Mt. Lemmon survey on 2018 Jan 5 (JPL, 2018). Shortly after, orbit calculations showed that the asteroid would approach the Earth at a minimum distance of about 4.7 lunar distances on Jan 23 around 12:23 UT.

The CCD photometric observations at CS3-PDS from Jan 22-24 were made using a 0.35-m *f*/9.1 Schmidt-Cassegrain and SBIG STL-1001E camera with a KAF blue-enhanced chip (1024x1024x24μ pixels). The resulting image scale was 1.5 arcsec/pixel. No filter was used given the 15-20 sec exposures that were required due to rapid sky motion.

Measurements were made using *MPO Canopus* using master dark and flat-field frames. 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 the APASS catalog (Henden et al., 2009). The session-to-session zero points for the catalog were generally consistent to ≤ 0.05 mag or better. The data were light-time corrected and adjusted for changing distances and geometry before period analysis.

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

Number	Name	2018 mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.
2018 AJ		01/22	114	24.5, 24.9	133	6	0.737	0.006	0.88	0.05
2018 AJ		01/23	672	32.8, 35.4	140	1	1.0081	0.0004	0.98	0.03
2018 AJ		01/24	226	44.2, 47.2	147	-4	1.0077	0.0008	1.15	0.05
2018 AJ		01/23	672	32.8, 35.4	140	1	0.6722	0.0002	1.09	0.05
2018 AJ		01/23					0.986	0.002		
2018 AJ		01/24	226	44.2, 47.2	147	-4	0.6725	0.0006	1.26	0.05
2018 AJ		01/24					0.982	0.005		

Table I. Observing circumstances. The phase angle (α) is given at the start and end of each date's observations. L_{PAB} and B_{PAB} are each the average phase angle bisector longitude and latitude (see Harris *et al.*, 1984). The results in normal text are by Warner using single-period analysis. The results in bold are by Pravec using software with a dual-period search feature capable of handling tumbling asteroids. In each case, the first line gives what is called P1 and the second line gives P2. See the text for more information.