

LIGHTCURVE ANALYSIS FOR THIRTEEN MINOR PLANETS

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Photometric measurements were made for 13 main-belt asteroids, based on CCD observations made from 2021 March through 2021 May. Phased lightcurves were created for nine asteroids, while four did not yield a period solution. All the data have been submitted to the ALCDEF database.

CCD photometric observations of 13 main-belt asteroids were performed at Command Module Observatory (MPC V02) in Tempe, AZ. Images were taken using a 0.32-m f/6.7 Modified Dall-Kirkham telescope, SBIG STXL-6303 CCD camera, and a 'clear' glass filter. Exposure time for all the images was 2 minutes. The image scale after 2×2 binning was 1.76 arcsec/pixel. Table I shows the observing circumstances and results. All of the images for these asteroids were obtained between 2021 March and 2021 May.

Images were calibrated using a dozen bias, dark, and flat frames. Flat-field images were made using an electroluminescent panel. Image calibration and alignment was performed using *MaxIm DL* software.

The data reduction and period analysis were done using *MPO Canopus* (Warner, 2020). The 45'×30' field of the CCD typically enables the use of the same field center for three consecutive nights. In these fields, the asteroid and three to five comparison stars were measured. Comparison stars were selected with colors within the range of $0.5 < B-V < 0.95$ to correspond with color ranges of asteroids. In order to reduce the internal scatter in the data, the brightest stars of appropriate color that had peak ADU counts below the range where chip response becomes nonlinear were selected. *MPO Canopus* plots instrumental vs. catalog magnitudes for solar-colored stars, which is useful for selecting comp stars of suitable color and brightness.

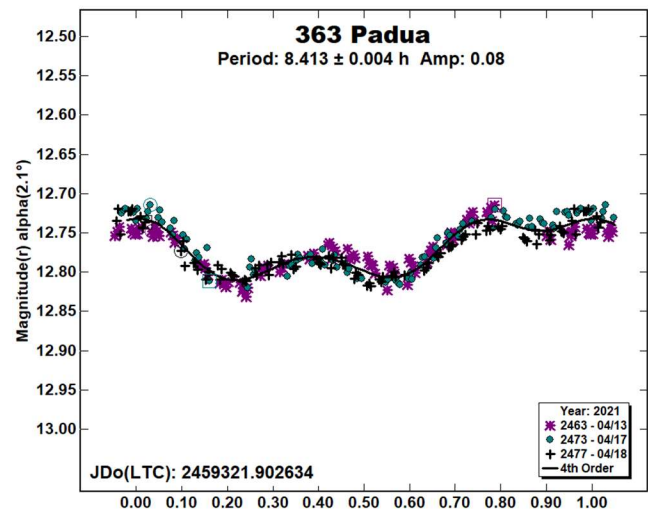
Since the sensitivity of the KAF-6303 chip peaks in the red, the clear-filtered images were reduced to Sloan r' to minimize error with respect to a color term. Comparison star magnitudes were obtained from the ATLAS catalog (Tonry et al., 2018), which is incorporated directly into *MPO Canopus*. The ATLAS catalog derives Sloan *griz* magnitudes using a number of available catalogs. The consistency of the ATLAS comp star magnitudes and color-indices allowed the separate nightly runs to be linked often with no zero-point offset required or shifts of only a few hundredths of a magnitude in a series.

A 9-pixel (16 arcsec) diameter measuring aperture was used for asteroids and comp stars. It was typically necessary to employ star subtraction to remove contamination by field stars. For the asteroids described here, I note the RMS scatter on the phased lightcurves, which gives an indication of the overall data quality including errors from the calibration of the frames, measurement of the comp stars, the asteroid itself, and the period-fit. Period determination was done using the *MPO Canopus* Fourier-type FALC fitting method (cf. Harris et al., 1989). Phased lightcurves show the maximum at phase

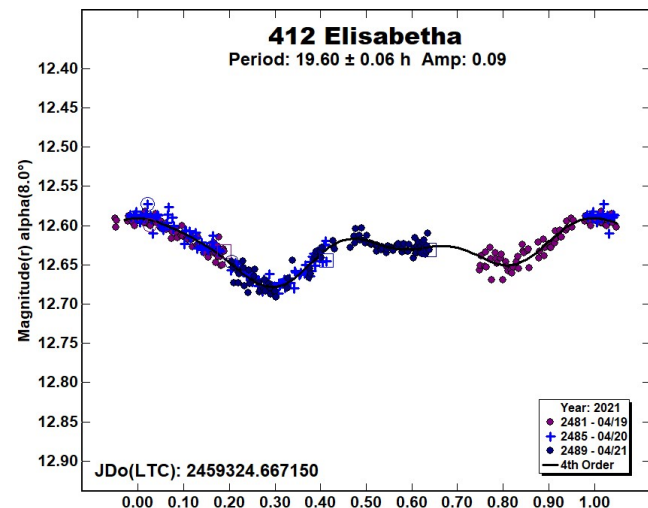
zero. Magnitudes in these plots are apparent and scaled by *MPO Canopus* to the first night. In cases where rotation periods could not be determined, raw lightcurves are presented, with "Raw" appearing in the upper right-hand corner of the plots.

Most asteroids were selected from the CALL website (Warner, 2011). In this set of observations, 3 of the 13 asteroids had no previous period analysis, 2 had $U=1$, 2 had $U=2$, and the remainder had $U=3$. The Asteroid Lightcurve Database (LCDB; Warner et al., 2009) was consulted to locate previously published results. All the new data for these asteroids can be found in the ALCDEF database.

363 Padua was discovered by Auguste Charlois at Nice in 1893. Koff (2006) computed a rotational period of 8.401 ± 0.001 h, and Pál et al. (2020) shows 8.40077 ± 0.00005 h. A total of 363 images were gathered over the course of three nights, yielding a period of 8.413 ± 0.004 h, agreeing with published values. The lightcurve has an amplitude of 0.08 mag. with an RMS error of 0.010 mag.



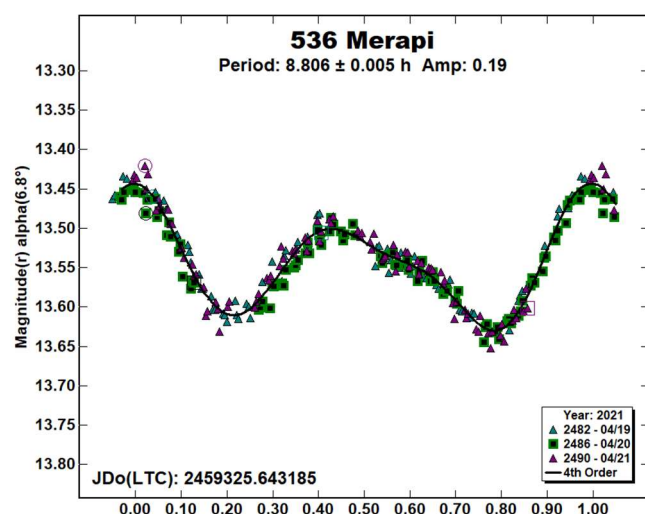
412 Elisabetha. This outer main-belt asteroid was discovered at Heidelberg in 1896 by Max Wolf. Two concurring period solutions are Cooney and Robinson (2002): 19.67 ± 0.1 h and Stephens (2012), 19.635 ± 0.005 h. Pál (2020) derived a period of 39.3269 ± 0.0005 h. During three nights, 323 images were taken, resulting in a period of 19.60 ± 0.06 h, with an amplitude of 0.09 ± 0.008 mag. This result agrees with Cooney's and Stephens's solutions.



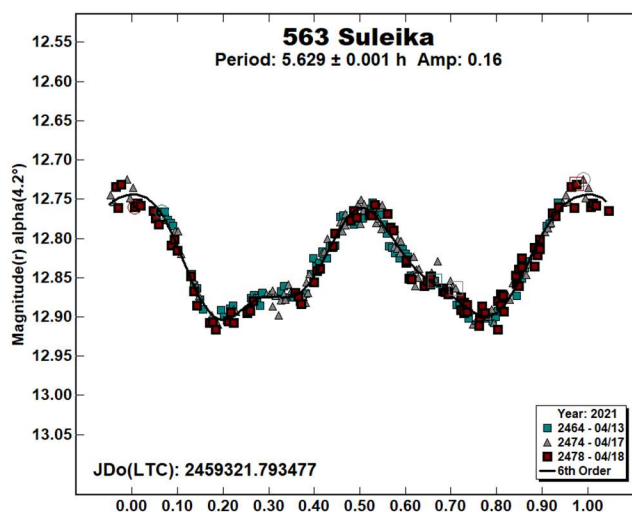
Number	Name	yy/mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
363	Padua	21/04/13-04/18	2.1, 3.1	202	5	8.413	0.004	0.08	0.01	MB-O
412	Elisabetha	21/04/19-04/21	8.0, 7.9	210	17	19.60	0.06	0.09	0.01	MB-O
536	Merapi	21/04/19-04/21	6.7, 7.1	193	16	8.806	0.005	0.19	0.01	MB-O
563	Suleika	21/04/13-04/18	*4.2, 4.2	205	11	5.629	0.001	0.16	0.01	MB-O
820	Adriana	21/03/17-03/22	2.6, 4.0	172	6	12.42	0.01	0.39	0.03	MB-O
1390	Abastumani	21/03/20-03/28	7.1, 8.7	164	16	26.49	0.07	0.13	0.02	MB-O
1458	Mineura	21/03/17-04/26	*1.3, 15.8	179	0	930.5	3.6	0.68	0.06	EUN
2326	Tololo	21/03/30-04/01	3.8, 4.1	188	10	9.60	0.05	0.11	0.05	MB-O
2521	Heidi	21/03/05-03/07	4.4, 4.5	165	-9	--	--	--	--	MB-O
2777	Shukshin	21/03/17-05/01	4.8, 22.4	171	4	1008.6	3.4	0.75	0.08	MB-I
3275	Oberndorfer	21/03/30-04/01	5.8, 6.4	185	8	--	--	--	--	MB-I
4133	Heureka	21/03/05-03/07	2.9, 3.5	163	-5	--	--	--	--	EUN
4238	Audrey	21/03/05-03/06	1.6, 1.1	167	1	--	--	--	--	MB-I

Table I. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema 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). Grp is the asteroid family/group (Warner et al., 2009).

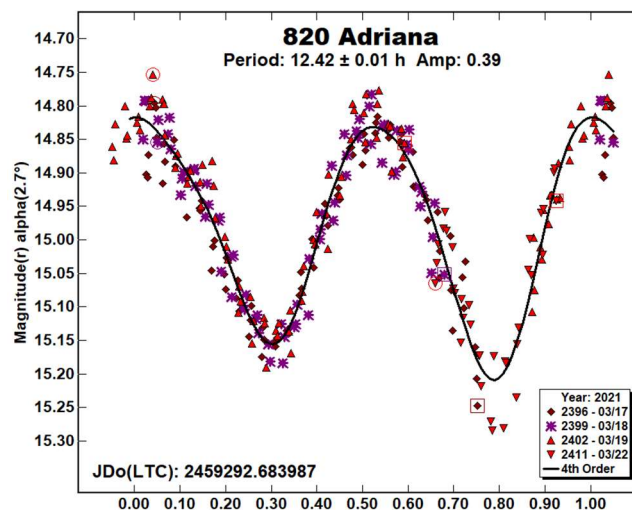
536 Merapi was discovered in Washington by George Henry Peters in 1904. Several consistent period solutions appear in the LCDB: Koff (2000), 8.78 ± 0.01 h; Ditteon and Hawkins (2007), 8.209 ± 0.008 h; and Behrend (2020web), 8.791 ± 0.001 h. A total of 277 data points were acquired in three nights, and the resulting period solution is 8.806 ± 0.005 h, which agrees with previous assessments. The amplitude and RMS error on the fit are 0.19 mag and 0.012 mag.



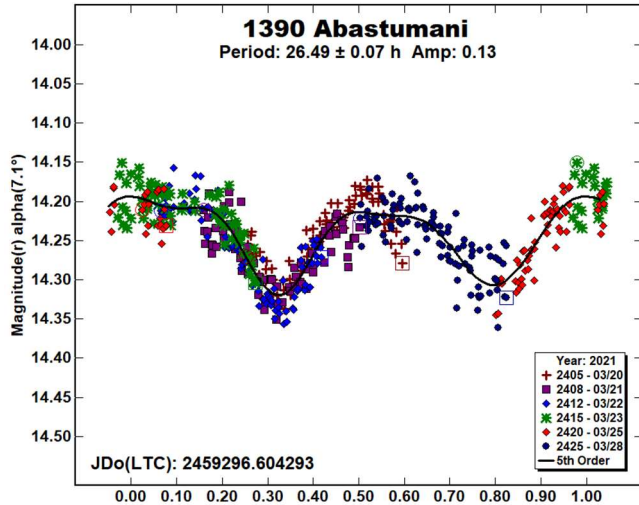
563 Suleika. This outer main-belt asteroid in a highly eccentric orbit was discovered by Paul Gotz at Heidelberg in 1905. The LCDB shows six similar period solutions. Two of the most recent are Ditteon and Hawkins (2007), 5.628 ± 0.002 h and Franco et al. (2020), 5.6656 ± 0.0004 h. During three nights, 270 images were taken. A 6th order fit produced a period solution of 5.629 ± 0.001 h, and an amplitude of 0.16 ± 0.010 mag.



820 Adriana, discovered in 1916, is another of Max Wolf's discoveries at Heidelberg. Only one rotational period appears in the LCDB, that of Ditteon et al. (2018), who computed 6.527 ± 0.006 h. During four nights, 272 images were gathered, producing a period solution of 12.42 ± 0.01 h, disagreeing with Ditteon's result. The amplitude of the lightcurve is 0.39 ± 0.034 mag.



1390 Abastumani. Grigory Shajn discovered this outer main-belt asteroid in an inclined orbit at Simeis in 1935. Gross (2003) published a period of 17.100 ± 0.005 h, and Durech et al. (2018) calculated 13.16482 ± 0.00002 h. Over the course of six nights, 502 images were obtained, yielding a synodic period of 26.49 ± 0.07 h, which is roughly double Durech's period. The amplitude is 0.13 mag., and the RMS error on the fit is 0.022 mag.



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LIGHTCURVE ANALYSIS OF L4 AND L5 TROJAN ASTEROIDS AT THE CENTER FOR SOLAR SYSTEM STUDIES: 2021 APRIL TO JUNE

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Lightcurves for two L5 Jovian Trojan asteroids were obtained at the Center for Solar System Studies (CS3) from 2021 April to June. In addition, recovered data from 2017 to 2019 allowed finding nine previously unreported periods and restating three previously reported Trojan rotational periods.

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 two Trojan asteroids from the L₅ (Trojan) Lagrange point from 2021. In addition, a substantial dataset was recovered with unpublished observations from both the L₄ and L₅ Lagrange points from 2017 to 2019. That recovered dataset also allowed us to reevaluate previous published results for (11395) 1998 XN77 for 2015, 2016, and 2017.

Table I lists the telescopes and CCD cameras that were used to make the observations. Images were unbinned with no filter and had master flats and darks applied. The exposures depended upon various factors including magnitude of the target, sky motion, and Moon illumination.

Telescope	Camera
0.40-m f/10 Schmidt-Cass	FLI Proline 1001E
0.40-m f/10 Schmidt-Cass	FLI Microline 1001E
0.35-m f/10 Schmidt-Cass	FLI Microline 1001E

Table I. List of telescopes and CCD cameras used at CS3.

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.