

LIGHTCURVE ANALYSIS FOR SEVEN MAIN-BELT MINOR PLANETS

Tom Polakis
 Command Module Observatory
 121 W. Alameda Dr.
 Tempe, AZ 85282 USA
 tpolakis@cox.net

(Received: 2018 October 12)

Synodic rotation periods were determined for seven main-belt asteroids: 831 Stateira, 860.7 ± 7.1 h; 983 Gunila, 16.633 ± 0.023 h; 1006 Lagrangea, 19.497 ± 0.024 h; 1149 Volga, 27.262 ± 0.049 h; 1409 Isko, 11.639 ± 0.004 h; 1539 Borrelly, 15.922 ± 0.007 h; and 2406 Orelskaya, 6.109 ± 0.001 h. All the data have been submitted to the ALCDEF database.

CCD photometric observations of seven main-belt asteroids were performed at Command Module Observatory (MPC V02) in Tempe. Images at V02 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 2x2 binning was 1.76 arcsec/pixel. Table I shows the observing circumstances and results. All of the images for these seven asteroids were obtained during 2018 September and October.

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, 2017). The $45' \times 30'$ 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. The *MPO Canopus* internal star catalogue was useful in selecting comp stars of suitable color and brightness.

Comp star magnitudes were derived from a combination of CMC15 (Muñoz et al. 2014), APASS DR9 (Munari et al. 2015), and GAIA2 G (Sloan $r' = G$ for stars of asteroidal color) catalogues to set the zero-points each night. In most regions the Sloan r' data sources for brighter stars yielded very similar magnitudes (within about 0.05 mag total range), so mean values rounded to 0.01 mag precision were used.

This careful adjustment of the 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

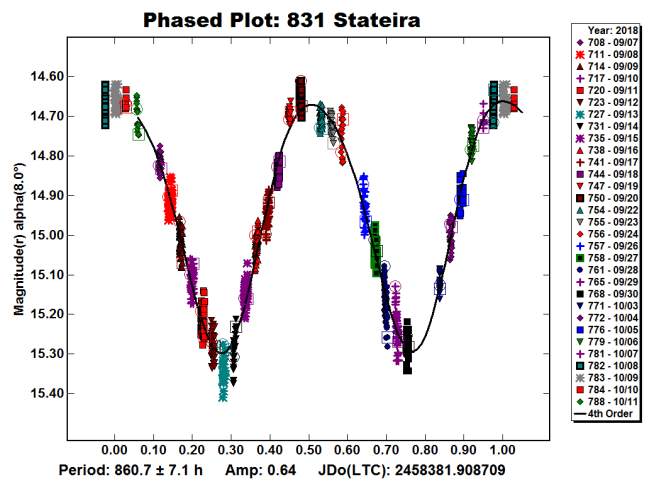
determination was done using the *MPO Canopus* Fourier-type FALC fitting method (cf. Harris et al., 1989). Phased lightcurves show the maximum at phase zero. Magnitudes in these plots are apparent, and scaled by *MPO Canopus* to the first night.

In most cases, asteroids were selected from the CALL website (Warner, 2011) using the criteria of magnitude greater than 15.0 and quality of results, U, less than 3-.

The Asteroid Lightcurve Database (LCDB; Warner et al., 2009) was consulted to locate previously published results. All the new data for these seven asteroids may be found in the ALCDEF database.

831 Stateira is a Flora-family asteroid discovered by Max Wolf at Heidelberg in 1916. The only rotation period in the LCDB is that of Behrend (2008), whose sparse data yielded >4 h.

During the course of 31 nights, 1209 data points were gathered. Nearly one rotation of 831 Stateira was covered during the 34-night observing interval. A fourth-order fit produced a period solution of 860.7 ± 7.1 h, disagreeing with Behrend's result, and placing it among the 30 longest known rotation periods. Despite its long period, the lightcurve exhibits no evidence of tumbling. The amplitude is 0.64 ± 0.03 mag, and the RMS scatter on the fit shown in the phased plot is 0.033 mag.

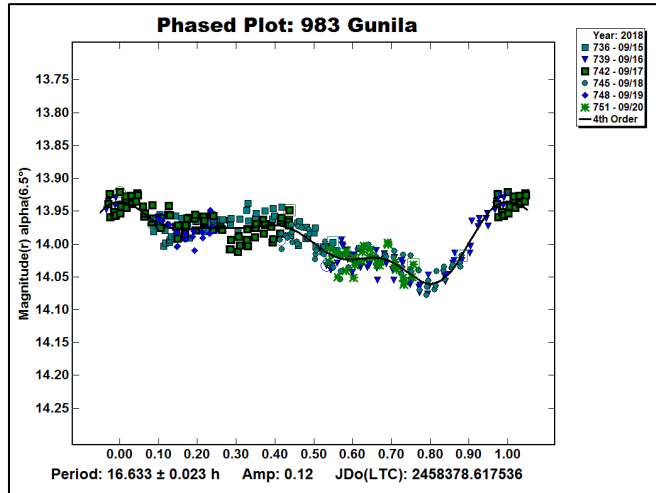


983 Gunila. This outer-belt asteroid was discovered at Heidelberg in 1922 by Karl Reinmuth. Hayes-Gehrke (2014) published a period of 8.37 ± 0.12 h.

During six nights, 329 images were gathered, yielding a period solution of 16.633 ± 0.023 h. This double-mode result is roughly twice that of Hayes-Gehrke. The amplitude is 0.12 ± 0.02 mag. The RMS scatter on the fit is 0.015 mag.

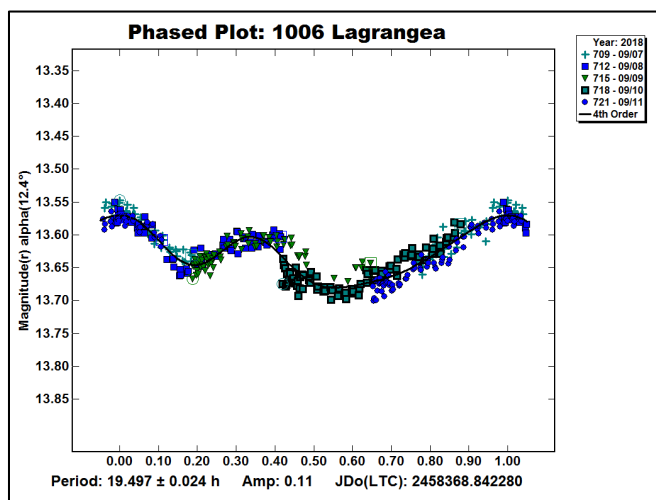
Number	Name	2018/mm/dd	Pts	Phase	L_{PAB}	B_{PAB}	Period (h)	P.E.	Amp	A.E.	Grp
831	Stateira	09/07-10/11	1209	8.0, 0.0, 12.8	357	0	860.7	7.1	0.64	0.03	FLOR
983	Gunila	09/15-09/20	329	6.5, 6.9	349	18	16.633	0.023	0.12	0.02	MB-O
1006	Lagrangea	09/07-09/11	400	12.4, 11.2	359	14	19.497	0.024	0.11	0.01	MB-O
1149	Volga	09/15-09/21	427	7.7, 9.1	344	15	27.262	0.049	0.14	0.02	MB-O
1409	Isko	09/27-10/06	371	1.9, 6.1	0	-1	11.639	0.004	0.14	0.03	MB-M
1539	Borrelly	09/07-09/11	314	6.3, 4.6	358	-1	15.922	0.007	0.54	0.04	MB-O
2406	Orelskaya	09/27-10/05	363	10.0, 14.7	351	-1	6.109	0.001	0.37	0.04	FLOR

Table I. Observing circumstances and results. The phase angle (α) is given at the start and end of each date range, unless it reached a minimum or maximum, which is then the second of three values. L_{PAB} and B_{PAB} are each the average phase angle bisector longitude and latitude (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009).



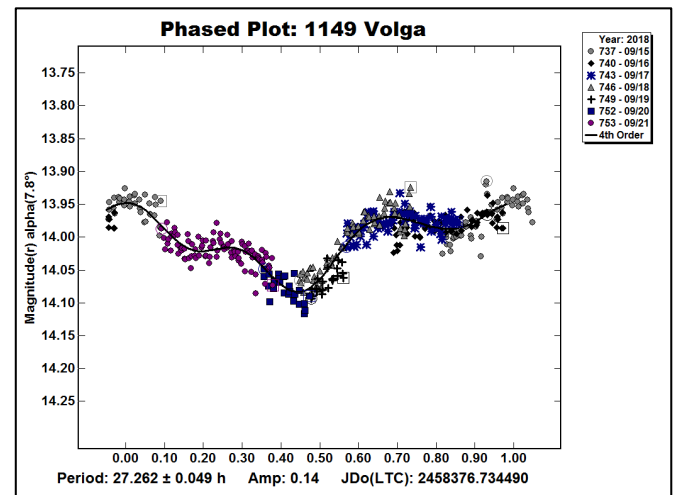
1006 Lagrangea. Sergey Belyavsky discovered this asteroid at Simeis in 1923. Its highly eccentric orbit results in opposition distances ranging from 1.1 to 4.5 a.u.; the 2018 opposition was favorably placed near the minor planet's perihelion.

The rotation period published by Behrend (2001) is 32.79 ± 0.06 h. A total of 400 data points were acquired on five nights. A rotation period of 19.497 ± 0.024 h was computed, disagreeing with Behrend's. The full amplitude is 0.11 ± 0.01 mag, and the RMS scatter of the fit is 0.014 mag.



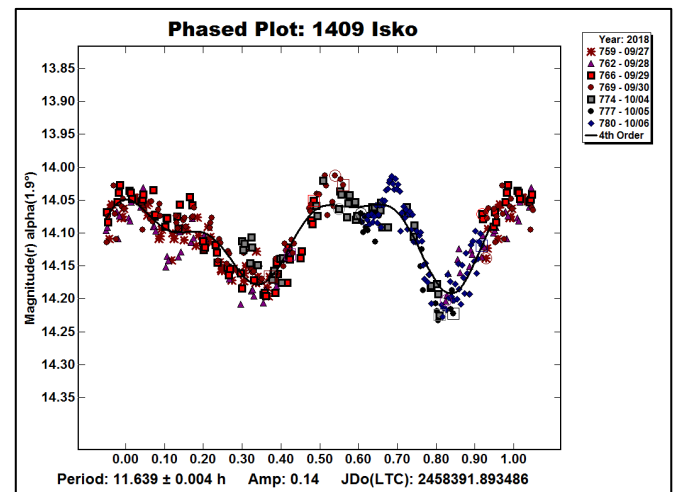
1149 Volga. This outer-belt asteroid was discovered in 1929 by Evgenii Skvortsov at Semeis. The LCDB shows one period solution: Binzel (1987), who published 27.5 h.

After seven nights, 427 images were gathered, producing a period solution of 27.262 ± 0.049 h, in accordance with Binzel's result. The lightcurve has an amplitude of 0.14 ± 0.02 mag, and the RMS error on the fit of 0.017 mag.



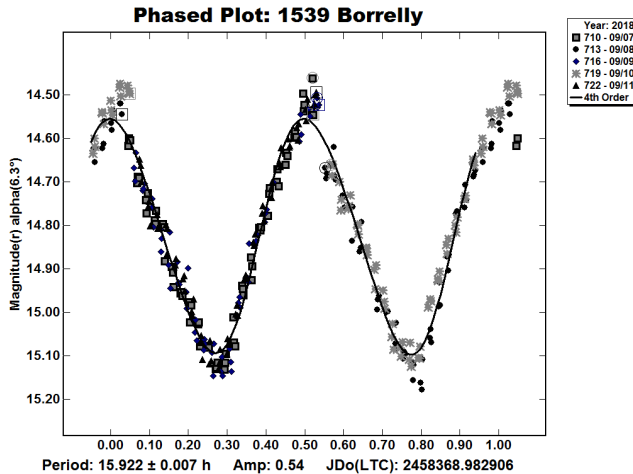
1409 Isko was discovered at Heidelberg by Karl Reinmuth in 1937. Behrend (2001) obtained a period of 11.6426 ± 0.0007 h.

A total of 371 images were acquired during seven nights. The period solution of 11.639 ± 0.004 h agrees with Behrend's value. The RMS scatter on the fit is 0.025 mag. The amplitude is 0.14 ± 0.03 mag.



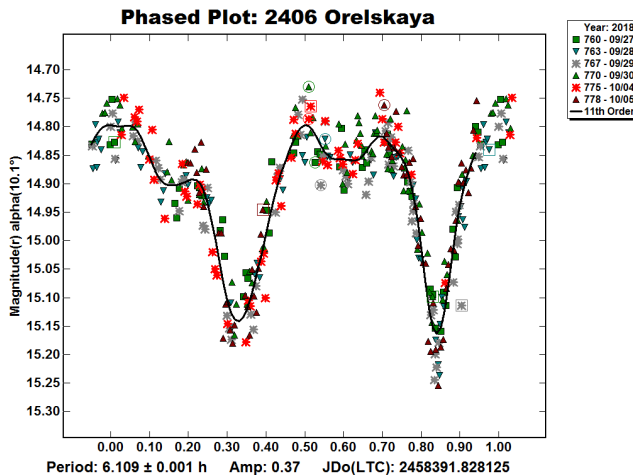
1539 Borrelly. In 1940, André Patry discovered this asteroid at Nice. No period solutions for it appear in the LCDB.

Due to its large amplitude, sufficient data were acquired to derive its rotation period in only five nights, using 314 images. A synodic period of 15.922 ± 0.007 h was computed. The amplitude of the lightcurve is 0.54 ± 0.04 mag, and the RMS error on the fit is 0.038 mag.



2406 Orelskaya was discovered at the Crimean Astrophysical Observatory in 1966. The only period published in the LCDB is that of Waszczak et al. (2015), who used sparse data from the Palomar Transient Factory to calculate 6.11 ± 0.009 h.

During six nights, 363 images were obtained. The period solution of 6.109 ± 0.001 h is in close agreement with Waszczak's result. Two very steep minima required an 11th order fit, whose RMS error is 0.040 mag. The amplitude is 0.37 ± 0.04 mag.



Acknowledgments

The author would like to express his gratitude to Brian Skiff for his indispensable mentoring in data acquisition and reduction. Thanks also go out to Brian Warner for support of his *MPO Canopus* software package.

References

- Behrend, R. (2001, 2008). Observatoire de Geneve web site. http://obswww.unige.ch/~behrend/page_cou.html
- Binzel, R.P. (1987). "A photoelectric survey of 130 asteroids." *Icarus* **72**, 135-208.
- 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.
- Hayes-Gehrke, M.; Berenhaus, J.; Mascone, A.; Lopez-Lahocki, M.; Levantis, G.; Haigh, E.; Yang, Z.; Guerci, J.; Wasli, Z.; Koester, K. (2014). "Rotation Period of 983 Gunila." *Minor Planet Bull.*, **41**, 77.
- VizieR (2017). <http://vizier.u-strasbg.fr/viz-bin/VizieR>
- Warner, B.D. (2002). "Asteroid Photometry at the Palmer Divide Observatory: Results for 573 Recha, 1329 Eliane, and 8041 Masumoto." *Minor Planet Bull.* **29**, 14-15.
- Warner, B.D., Harris, A.W., Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2016 Feb. <http://www.minorplanet.info/lightcurvedatabase.html>
- Warner, B.D., (2011). Collaborative Asteroid Lightcurve Link website. <http://www.minorplanet.info/call.html>
- Warner, B.D. (2017). *MPO Canopus* software. <http://bdwpublishing.com>
- Waszczak, A., Chang, C.-K., Ofeck, E.O., Laher, F., et al. (2015). "Asteroid Light Curves from the Palomar Transient Factory Survey: Rotation Periods and Phase Functions from Sparse Photometry." *Astron. J.* **150**, A75.