

PHOTOMETRIC OBSERVATIONS OF SEVEN MINOR PLANETS

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

(Received: 2020 Oct 11 Revised: 2020 Nov 8)

Phased lightcurves and synodic rotation periods for seven main-belt asteroids are presented, based on CCD observations made from 2020 September through 2020 October. 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, 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 seven asteroids were obtained between 2020 September and 2020 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.

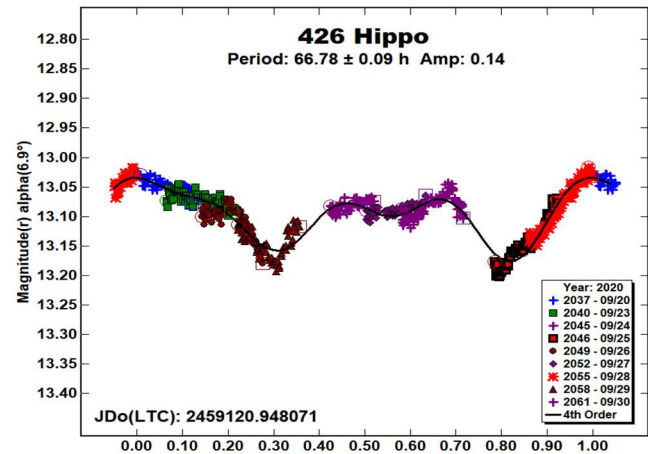
The data reduction and period analysis were done using *MPO Canopus* (Warner, 2020). The 45′×30′ field of the CCD typically enables the use of the same field center for three consecutive nights. In these fields, the asteroid and three to five comparison stars were measured. Comparison stars were selected 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.

Most asteroids were selected from the CALL website (Warner, 2011) using the criteria of magnitude greater than 15.5 and quality of results, U , less than 2+. In this set of observations, 1 of the 7 asteroids had no previous period analysis, 1 had $U = 1$, and 3 had $U = 2$. 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.

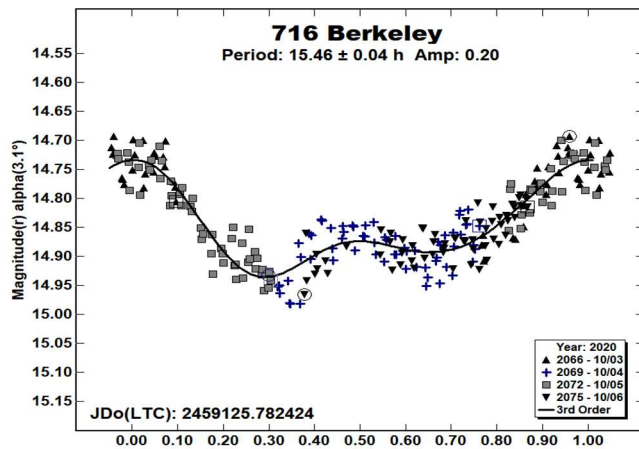
426 Hippo. Auguste Charlois discovered this asteroid in a highly eccentric orbit from Nice in 1897. Pray (2006) published a synodic period of 34.3 ± 0.2 h. More recent period analyses claim double that value: Durech (2018) computed 67.504 ± 0.002 h and Pal (2020) shows 67.5309 ± 0.0005 h. During nine nights, 715 images were gathered, resulting in a period of 66.78 ± 0.09 h, agreeing with the more recent values. The amplitude is 0.14 mag, with an RMS error of 0.014 mag.



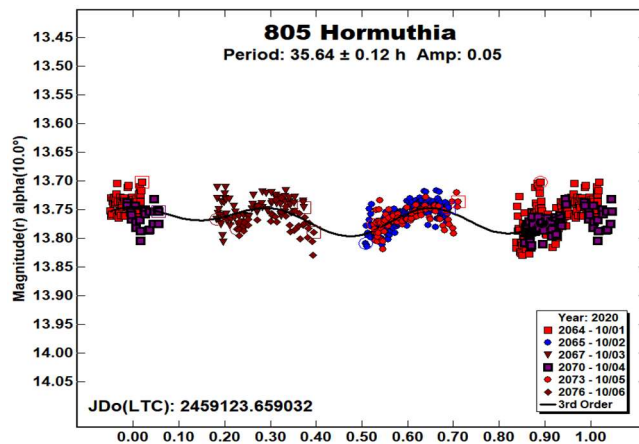
716 Berkeley. This outer main-belt asteroid was discovered at Vienna in 1911 by Johann Palisa. Garlitz (2011) shows a period of 15.55 ± 0.04 h, and Behrend (2018) obtained 34.3 ± 0.06 h. A total of 233 data points gathered over four nights were used to compute a period of 15.46 ± 0.04 h, agreeing with Garlitz’s value. The lightcurve has an amplitude of 0.20 mag, and an RMS error of 0.029 mag.

Number	Name	2020/mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
426	Hippo	09/20–09/30	6.9, 7.1	2	19	66.78	0.09	0.14	0.01	MB-O
716	Berkeley	10/03–10/06	3.1, 3.7	7	-7	15.46	0.04	0.21	0.03	MB-O
805	Hormuthia	10/01–10/06	9.9, 11.6	345	-1	35.64	0.12	0.05	0.02	MB-O
1537	Transylvania	09/23–09/30	3.4, 6.4	357	4	144.2	0.2	0.78	0.03	MB-O
1576	Fabiola	10/06–10/07	3.5, 3.9	5	0	6.891	0.007	0.24	0.02	THM
2299	Hanko	09/23–09/30	4.3, 1.4	6	-2	87.60	0.12	0.43	0.03	MB-I
3970	Herran	10/03–10/05	3.3, 3.8	7	-5	8.053	0.005	0.59	0.04	EUN

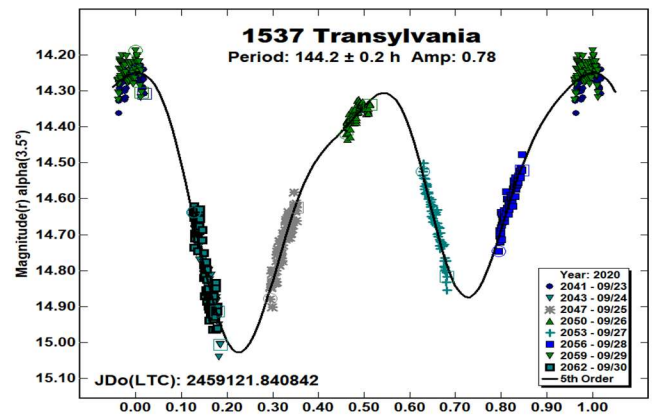
Table I. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009).



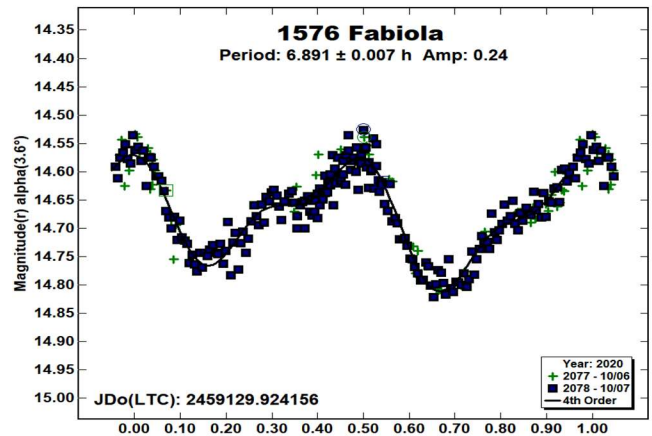
805 Hormuthia is a Max Wolf discovery, made in 1915 at Heidelberg. Two periods appear in the LCDB, both made difficult by the minor planet's small amplitude. Pilcher and Benishek (2009) computed 9.510 ± 0.001 h, and Behrend (2019) produced a period of 23.76 ± 0.05 h. A total of 576 data images obtained during six nights were used to calculate a trimodal solution of 35.64 ± 0.12 h, disagreeing with prior assessments. The data did not respond well to force-fitting either of the two published periods. The RMS error on the fit of 0.020 mag is significant relative to the amplitude of 0.050 mag.



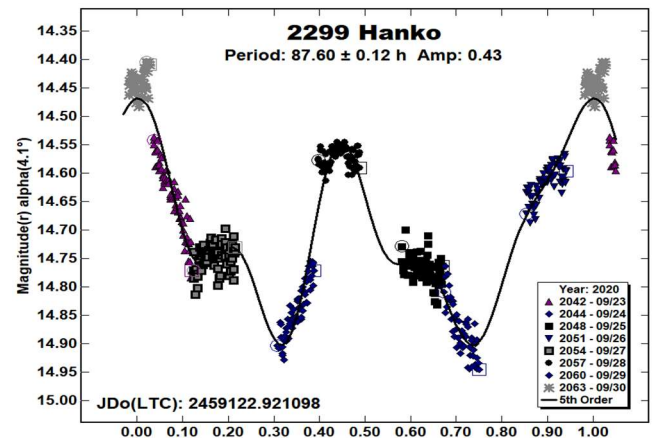
1537 Transylvania. Gyula Strommer discovered this minor planet in 1950 from Budapest. No precise periods appear in the LCDB. The slow rotation rate required eight nights and 543 data points to obtain a good period solution of 144.2 ± 0.2 h. The amplitude is a generous 0.78 mag, with an RMS error on the fit of 0.029 mag. Note that the 2020 opposition was very favorable for this eccentric orbit, and the asteroid will be significantly fainter until the 2025 opposition.



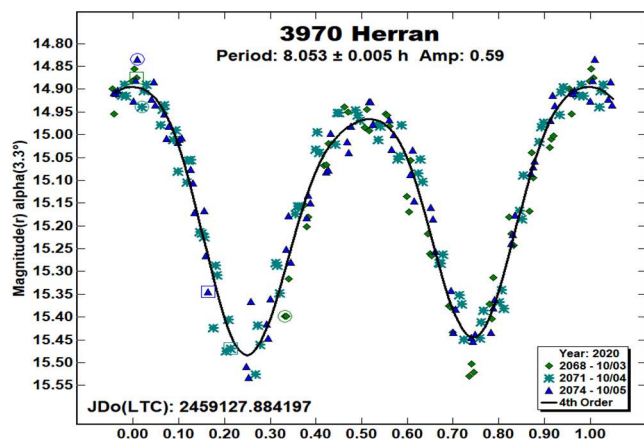
1576 Fabiola is a Themis-family asteroid, discovered by Sylvain Arend at Uccle in 1948. Despite its short period, only two solutions appear in the LCDB. Lagerqvist (1987) used photographs to obtain a period of 6.7 h, and Benishek (2018) used modern methods to refine it to 6.8890 ± 0.0003 h. Only two nights and 268 images were sufficient to compute a period of 6.891 ± 0.007 h, in agreement with published values. The amplitude is 0.24 ± 0.023 mag.



2299 Hanko is an inner main-belt minor planet in a highly eccentric orbit. Yrjö Väisälä discovered it in 1941 at Turku. It has no published periods. During eight nights near the very favorable 2020 opposition, 489 images were gathered, producing a new solution of 87.60 ± 0.12 h. The amplitude is 0.43 ± 0.029 mag.



3970 Herran is a member of the Eunomia family, discovered by Carlos Torres in 1979 at Cerro El Roble. Two agreeing period solutions are published: Kim (2014) shows 8.09 ± 0.05 h, and Pal (2020) calculated 8.04608 ± 0.0619 h. During three nights, 168 images were taken, and the resulting period solution is 8.053 ± 0.005 h, in agreement with prior estimates.



Acknowledgements

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. (2018, 2019). Observatoire de Geneve web site. http://obswww.unige.ch/~behrend/page_cou.html
- Benishek, V. (2018). "Lightcurve and Rotation Period Determinations for 29 Asteroids." *Minor Planet Bull.* **45**, 82-91.
- Durech, J.; Hanus, J.; Ali-Lagoa, V. (2018). "Asteroid models reconstructed from the Lowell Photometric Database and WISE data." *Astron. Astrophys.* **617**, A57.
- Garlitz, J. (2011). Personal web site. <http://eoni.com/~garlitzj/Period.htm>
- 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.
- Harris, A.W.; Young, J.W.; Bowell, E.; Martin, L.J.; Millis, R.L.; Poutanen, M.; Scaltriti, F.; Zappala, V.; Schober, H.J.; Debehogne, H.; Zeigler, K.W. (1989). "Photoelectric Observations of Asteroids 3, 24, 60, 261, and 863." *Icarus* **77**, 171-186.
- Kim, M.-J.; Choi, Y.-J.; Moon, H.-K.; Byun, Y.-I.; et al. (2014). "Rotational Properties of the Maria Asteroid Family." *Astron. J.* **147**, A56.
- Lagerqvist, C. (1987). "Photographic photometry of 110 main-belt asteroids." *Astron. Astrophys. Suppl.* **31**, 361-381.
- Pal, A.; Szakáts, R.; Kiss, C.; Bódi, A.; Bognár, Z.; Kalup, C.; Kiss, L.L.; Marton, G.; Molnár, L.; Plachy, E.; Sárneczky, K.; Szabó, G.M.; Szabó, R. (2020). "Solar System Objects Observed with TESS – First Data Release: Bright Main-belt and Trojan Asteroids from the Southern Survey." *Ap. J. Supl. Ser.* **247**, 26-34.
- Pilcher, F.; Benishek, V. (2009). "Period Determinations for 634 Ute and 805 Hormuthia." *Minor Planet Bull.* **36**, 29-30.
- Pray, D.P. (2006). "Lightcurve analysis of asteroids 326, 329, 426, 619, 1829, 1967, 2453, 10518 and 42267." *Minor Planet Bull.* **33**, 4-5.
- Tonry, J.L.; Denneau, L.; Flewelling, H.; Heinze, A.N.; and five additional co-authors. (2018). "The ATLAS all-sky stellar reference catalog." *Astrophys. J.* **867**, 105.
- Warner, B.D.; Harris, A.W.; Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2020 Aug. <http://www.minorplanet.info/lightcurvedatabase.html>
- Warner, B.D. (2011). Collaborative Asteroid Lightcurve Link website. <http://www.minorplanet.info/call.html>
- Warner, B.D. (2020). MPO Canopus software. <http://bdwpublishing.com>