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LIGHTCURVE ANALYSIS FOR FOURTEEN MAIN-BELT MINOR PLANETS

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Synodic rotation periods were determined for fourteen main-belt asteroids: 424 Gratia, 20.075 ± 0.008 h; 504 Cora, 7.58 ± 0.01 h; 791 Ani, 11.174 ± 0.004 h; 821 Fanny, 238.9 ± 0.8 h; 866 Fatme, 5.800 ± 0.002 h; 874 Rotraut, 14.297 ± 0.009 h; 896 Sphinx, 21.038 ± 0.008 h; 1097 Vicia, 100.5 ± 0.3 h; 1237 Genevieve, 16.48 ± 0.03 h; 1315 Bronislaw, 9.578 ± 0.002 h; 1329 Eliane, 137.8 ± 0.3 h; 1334 Lundmarka, 6.2497 ± 0.0008 h; 1793 Zoya, 5.750 ± 0.002 h; and 4142 Dersu-Uzala, 276.0 ± 1.0 h. All the data have been submitted to the ALCDEF database.

CCD photometric observations of fourteen 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 fourteen asteroids were obtained during 2018 May and June, when southern Arizona enjoyed 35 photometric nights.

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 $45^\circ \times 30'$ 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

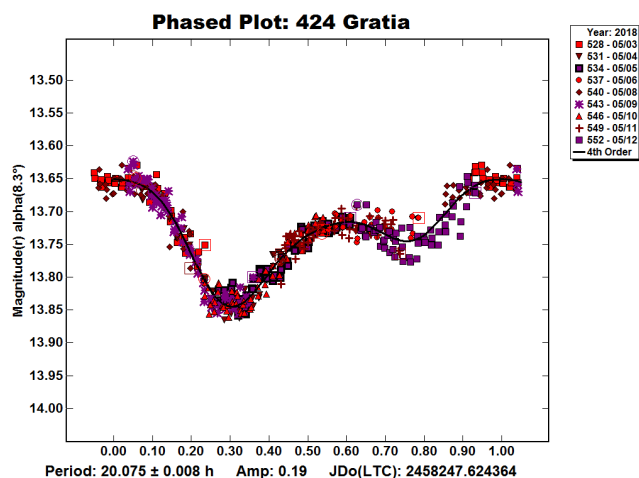
asteroids described here, I note the RMS scatter on the phased lightcurves, which gives an indication of the overall data quality including errors from the calibration of the frames, measurement of the comp stars, the asteroid itself, and the period-fit. Period determination was done using the *MPO Canopus* 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 14.5 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 fourteen asteroids may be found in the ALCDEF database.

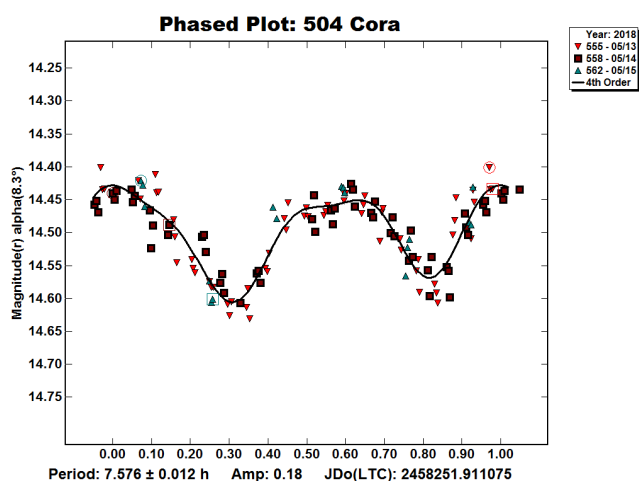
424 Gratia. This outer-belt asteroid was discovered by Auguste Charlois at Nice in 1896. Only one rotation period appears in the LCDB (Florczyk et al., 1997), whose result is 19.47 ± 0.01 h.

A total of 516 data points were obtained over the course of nine nights. The period spectrum showed a good solution of 20.075 ± 0.008 h, roughly agreeing with Florczyk's result. The amplitude is 0.19 ± 0.02 mag, and the RMS scatter on the fit shown in the phased plot is 0.015 mag.



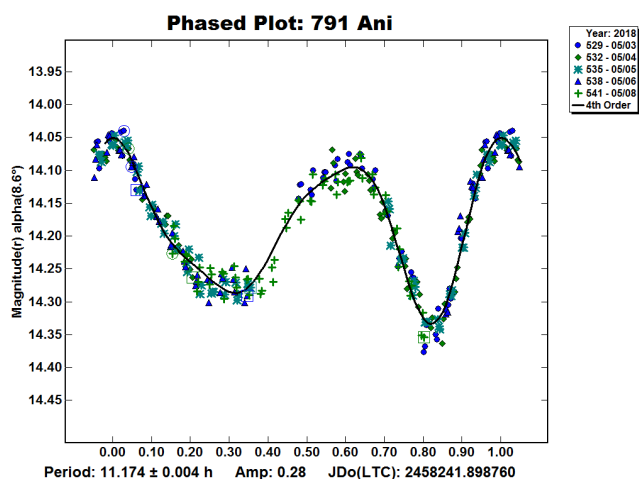
504 Cora is an outer-belt asteroid in a moderately eccentric orbit. It was discovered at Arequipa in 1902 by Solon Irving Bailey. Among the three published periods are those of Waszczak et al. (2015) and Higgins (2011), who both calculated 7.588 h.

Only three nights and 127 images were sufficient to compute a period solution of 7.58 ± 0.01 , agreeing with previously determined periods. The amplitude is 0.18 ± 0.03 mag. The RMS scatter on the fit is 0.025 mag.



791 Ani. Gregory Neujmin discovered this asteroid in a high-inclination orbit from Simeis in 1914. Sauppe et al. (2007) computed a synodic period of 16.72 ± 0.03 h, while Behrend (2004 and 2009) calculated 22.85 h in both cases.

Due to its short period, this asteroid required only five nights and 294 data points to ascertain an unambiguous solution of 11.174 ± 0.004 h. This result is very close to half of Behrend's, suggesting that theirs may be an alias. The full amplitude is 0.28 ± 0.02 mag; the RMS scatter of the fit is 0.019 mag.

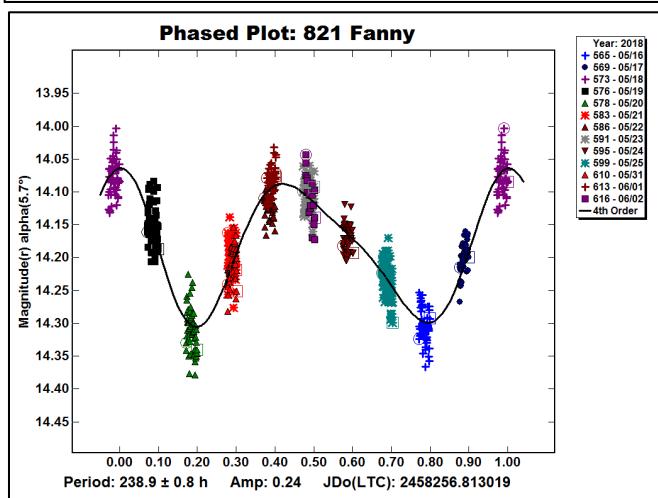


821 Fanny was discovered by Max Wolf at Heidelberg in 1916. The LCDB shows only one period solution: Behrend (2013) with 5.44 ± 0.05 h and a quality rating, $U = 1$.

It became apparent after several nights that the period would in fact be much longer than one day. During 13 nights, 669 images were secured, producing a period solution of 238.9 ± 0.8 h. Data points separated by 10 nights overlaid closely on the phased curve, showing no evidence of tumbling. The amplitude of the lightcurve is 0.24 ± 0.03 mag, with an RMS error on the fit of 0.027 mag.

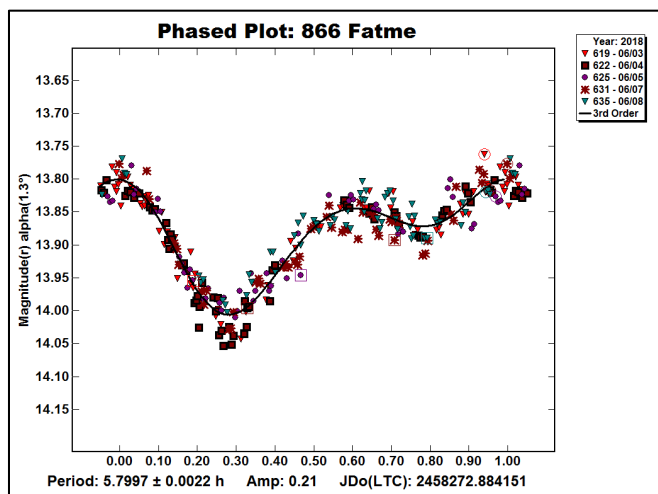
Number	Name	2018/mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period (h)	P.E.	Amp	A.E.	Grp
424	Gratia	05/03-05/12	516	8.3, 11.0	204	10	20.075	0.008	0.19	0.02	MB-O
504	Cora	05/13-05/15	127	8.2, 8.7	216	14	7.58	0.01	0.18	0.03	MB-O
791	Ani	05/03-05/08	294	8.6, 9.6	205	19	11.174	0.004	0.28	0.02	MB-O
821	Fanny	05/16-06/02	669	5.6, 13.8	226	3	238.9	0.8	0.24	0.03	MB-O
866	Fatme	06/03-06/08	293	1.3, 1.9	253	3	5.800	0.002	0.21	0.02	MB-O
874	Rotraut	05/09-05/12	288	9.4, 8.5	249	11	14.297	0.009	0.29	0.03	MB-O
896	Sphinx	06/06-06/23	651	8.8, 3.1	268	3	21.038	0.008	0.16	0.03	MB-I
1097	Vicia	06/09-06/25	758	11.6, 2.9	276	2	100.5	0.3	0.14	0.03	MB-M
1237	Genevieve	05/19-05/24	310	6.3, 8.3	224	2	16.48	0.03	0.11	0.03	MB-M
1315	Bronislawa	06/03-06/12	451	1.6, 2.8	255	3	9.578	0.002	0.17	0.02	MB-O
1329	Eliane	05/03-05/18	859	11.3, 15.7	208	19	137.8	0.3	0.43	0.04	MB-M
1334	Lundmarka	05/13-05/15	323	6.8, 6.7	235	15	6.2497	0.0008	0.72	0.02	MB-O
1793	Zoya	05/31-06/02	201	9.8, 10.8	234	1	5.750	0.002	0.44	0.03	FLOR
4142	Dersu-Uzala	05/20-06/10	731	12.7, 21.5	223	7	276.0	1.0	0.52	0.08	H

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. LPAB and BPAB 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).



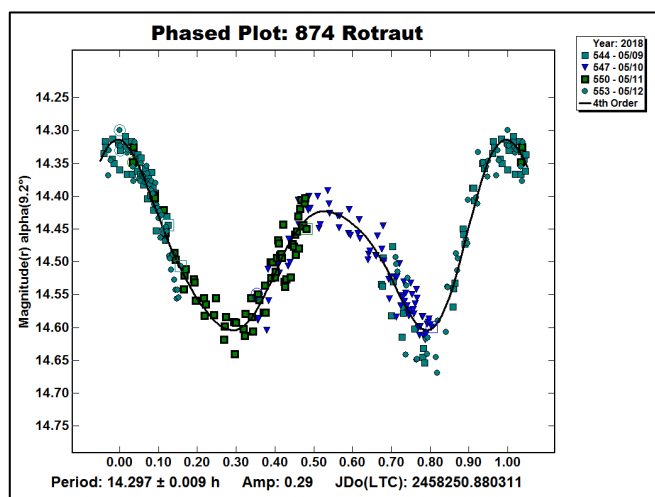
866 Fatme is an outer-belt asteroid discovered at Heidelberg by Max Wolf in 1917. Several entries appear in the LCDB. Behrend (2004 and 2012) obtained a period of roughly 9.4 h in both instances. Stephens (2002) computed 20.03 ± 0.01 h, and Aznar et al. (2016) shows 20.7 ± 0.1 h.

The asteroid was observed on five nights, during which 293 images were obtained. The period solution of 5.800 ± 0.002 h differs from previously published values. The RMS scatter on the fit is 0.021 mag. The amplitude is 0.24 ± 0.02 mag.



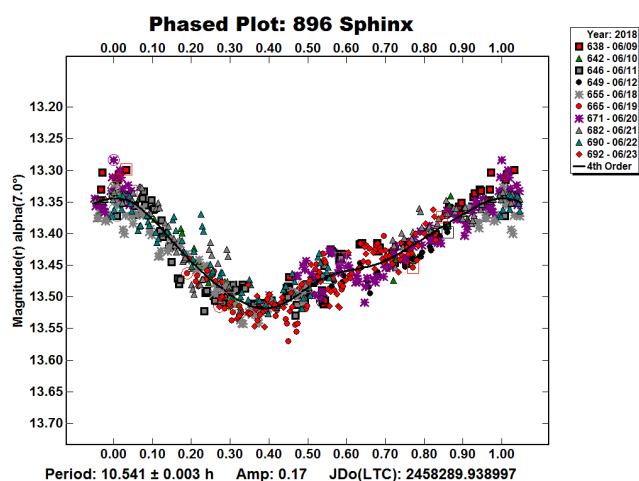
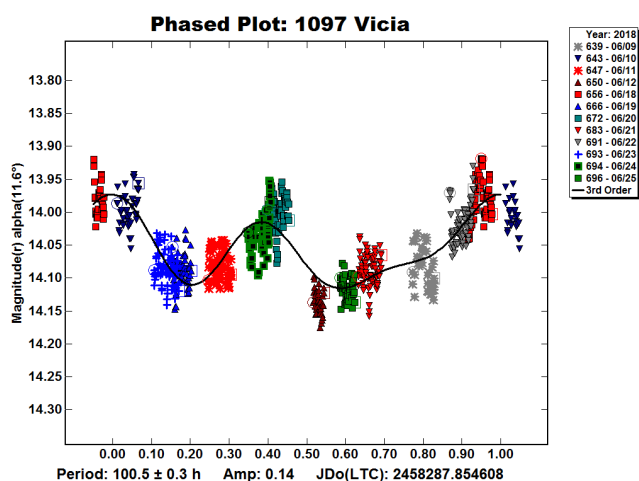
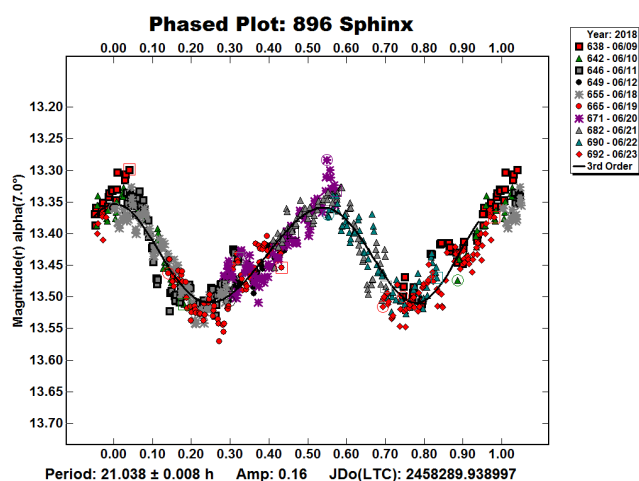
874 Rotraut. Another of Max Wolf's 1917 discoveries, this asteroid has only one published period. Behrend (2004) computed a result of 14.586 ± 0.003 h.

A total of 288 images were taken during four nights. The derived period of 14.297 ± 0.009 h is in good agreement with Behrend's determination. The amplitude is 0.29 ± 0.03 mag, and the RMS error on the fit is 0.026 mag.



896 Sphinx is again a Max Wolf discovery from 1917. Behrend (2001) provided the only published period: 26.27 ± 0.02 h.

Due to its opposition location near the galactic center, this asteroid presented difficulties with unreliable comparison star magnitudes, and required extensive star subtraction. After ten nights, 651 images had been obtained. The bi-modal curve fit produces a period of 21.038 ± 0.008 h, which disagrees with published results. While this is the preferred solution, the "Split Halves" feature in Canopus showed that the mono-modal solution of 10.541 ± 0.003 h is possible. For the bi-modal solution, the amplitude is 0.16 ± 0.03 mag, with an RMS scatter of the fit of 0.026 mag. For the mono-modal solution, these values are 0.17 ± 0.02 mag, and 0.022 mag. Both lightcurves are presented.

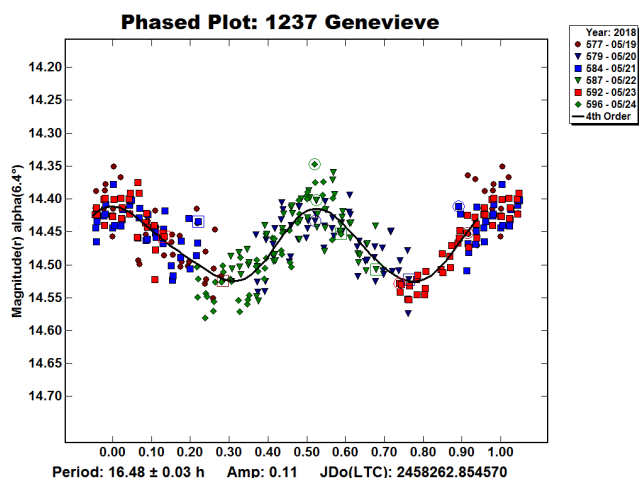


1097 Vicia is a Main Belt asteroid with a high eccentricity of 0.29. It was identified by Karl Reinmuth at Heidelberg in 1928. The only period determination was made by Gartrelle (2012), who published 26.5 ± 0.1 h.

Observations and reductions for 1097 Vicia were again complicated by its location near the Galactic center. After accumulating 758 data points in 12 nights, the synodic period remained ambiguous. The best result is 100.5 ± 0.3 h which disagrees with Gartrelle's solution. The amplitude of the lightcurve is 0.14 ± 0.03 mag. with the curve fit having an RMS scatter of 0.030 mag.

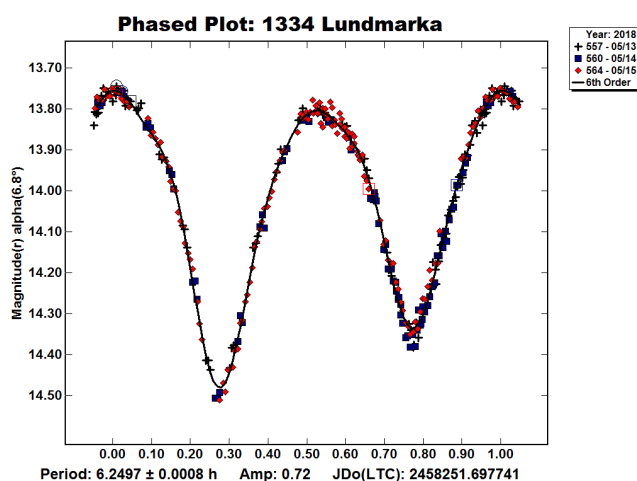
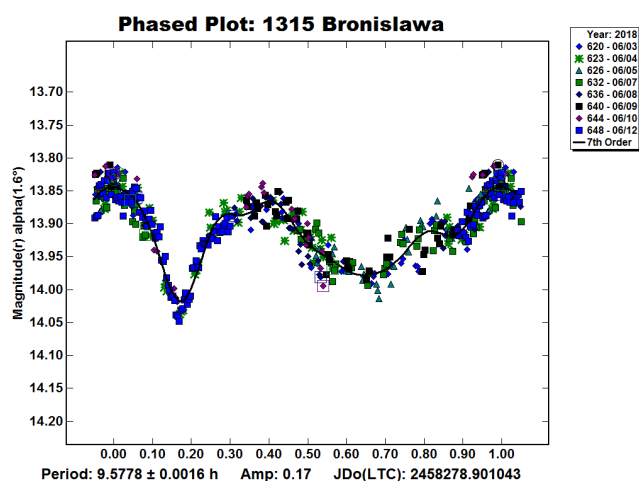
1237 Genevieve was discovered by Guy Reiss in 1931 at Algiers. Behrend (2005) found a period of 24.82 ± 0.07 h, while Binzel (1987) computed 16.37 ± 0.10 h.

During six nights, 310 data points were acquired. The period is 16.48 ± 0.03 h, agreeing with Binzel's determination. The amplitude is 0.11 ± 0.03 mag, with an RMS scatter on the fit of 0.030 mag.



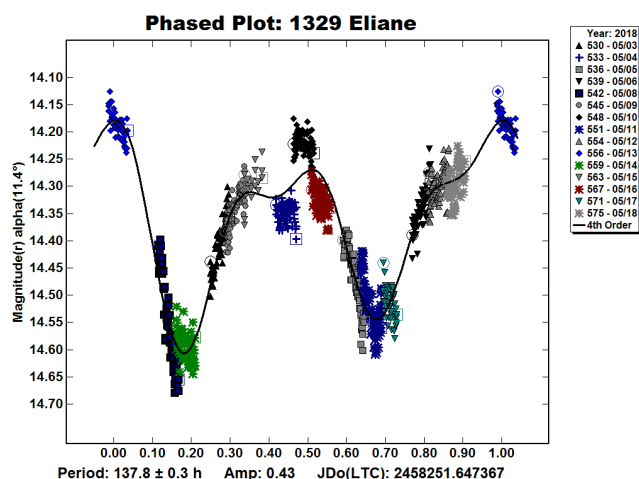
1315 Bronislawa, Sylvain Arrend discovered this outer-belt asteroid at Uccle in 1933. The two periods in the LCDB are those of Ditteon and West (2011), who found 9.565 ± 0.006 h, and Moravec et al. (2013), which is 10.01 ± 0.03 .

A total of 451 images were gathered during eight nights, resulting in a synodic period of 9.578 ± 0.002 h., which agrees closely with Ditteon. The lightcurve's amplitude is 0.17 ± 0.02 , and RMS scatter of the fit is 0.019 mag.



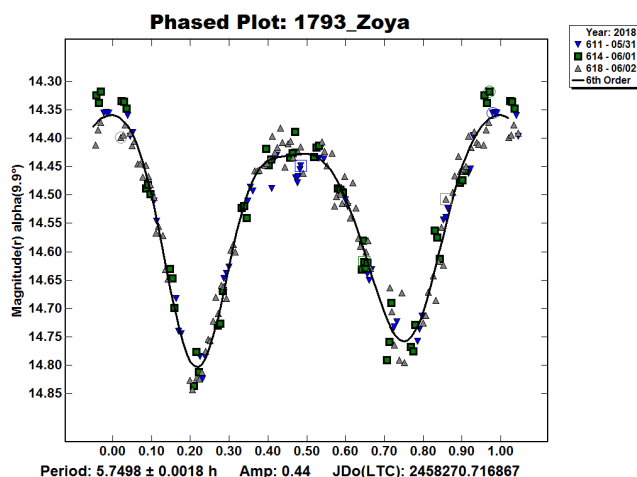
1329 Eliane. This asteroid was discovered in 1933 by Eugene Delporte at Uccle. Behrend (2005) shows a period of 72 ± 2 h. More recently, Warner (2010) published a period of 106 ± 25 h.

After 15 nights during which 859 data points were taken, the period of 1329 Eliane remained ambiguous. The best match for a bi-modal lightcurve in the period spectrum appears at 137.8 ± 0.3 h, differing from published values. The nature of the lightcurve suggests that the minor planet is tumbling, although inadequate data exists to determine the tumbling period. The amplitude of the lightcurve is 0.57 ± 0.04 mag. RMS scatter of the fit is 0.038 mag.



1793 Zoya is a Flora-family asteroid, discovered in 1968 by Tamara Smirnova at Nauchnyj. Three recent period solutions in the literature are as follows: Brinsfield (2008) 5.753 ± 0.001 h, Durech et al. (2016) 5.75187 ± 0.00001 , Hanus et al. (2016) 5.751872 ± 0.000005 h.

On three nights, 201 images were obtained, resulting in a period of 5.750 ± 0.002 h, agreeing with previous solutions. The asteroid's amplitude is 0.44 ± 0.03 mag, with an RMS scatter of 0.027 mag.

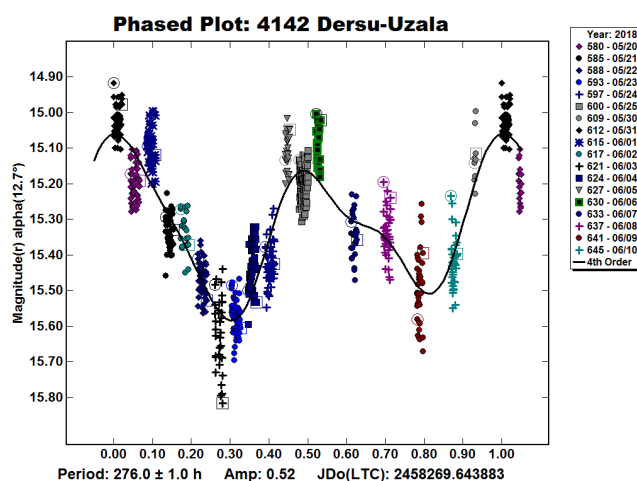


1334 Lundmarka. Karl Reinmuth identified this outer-belt asteroid at Heidelberg in 1934. The two published periods are consistent with each other. Bohn et al. (2015) shows 6.250 ± 0.003 h, and Durech et al. (2016) computed 6.25033 ± 0.00001 h.

On three consecutive nights, 323 images were sufficient to define the lightcurve, and compute a synodic period of 6.2497 ± 0.0008 , in line with published solutions. The amplitude is 0.72 ± 0.02 mag, with an RMS error on the fit of 0.018 mag.

4142 Dersu-Uzala. This Hungaria asteroid has an inclination of 26° . Its discovery was made by Zdenka Vavrova at Klet in 1981. Warner (2009) showed a period of 140 ± 3 h, which he revised (Warner 2015) to 71 ± 3 h.

Beginning at magnitude 15 and fading during the observing interval, signal-to-noise for this minor planet was low from my urban site. After obtaining 731 images in 18 nights, a rough solution of 276 ± 1.0 h was calculated, in disagreement with published periods. The large scatter and variations at similar phases in the lightcurve suggest that the asteroid is tumbling. Amplitude is high, at 0.52 ± 0.08 mag, with an RMS scatter on the fit of 0.082 mag.



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