

PHOTOMETRIC OBSERVATIONS OF TWENTY-SEVEN MINOR PLANETS

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Phased lightcurves and synodic rotation periods for 26 main-belt asteroids are presented, based on CCD observations made from 2020 March through 2020 June. A raw lightcurve is included for one asteroid for which no period solution was found. All the data have been submitted to the ALCDEF database.

CCD photometric observations of 27 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 27 asteroids were obtained between 2020 March and 2020 June.

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'×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.

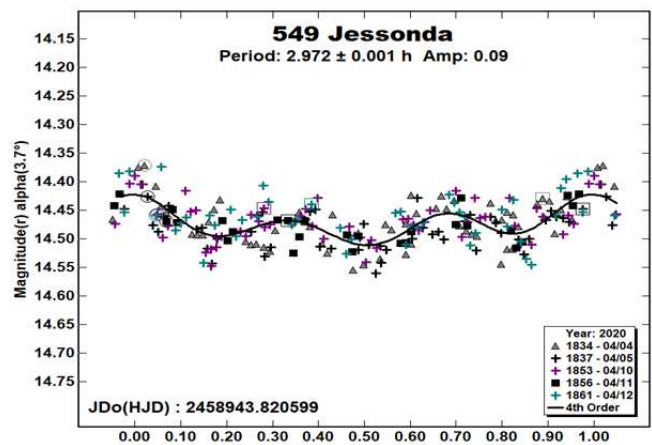
Since the sensitivity of the KAF-6303 chip peaks in the red, the clear-filtered images were reduced to Sloan r' to minimize error with respect to a color term. Comparison star magnitudes were obtained from the ATLAS catalog (Tonry et al., 2018), which is incorporated directly into *MPO Canopus*. The 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

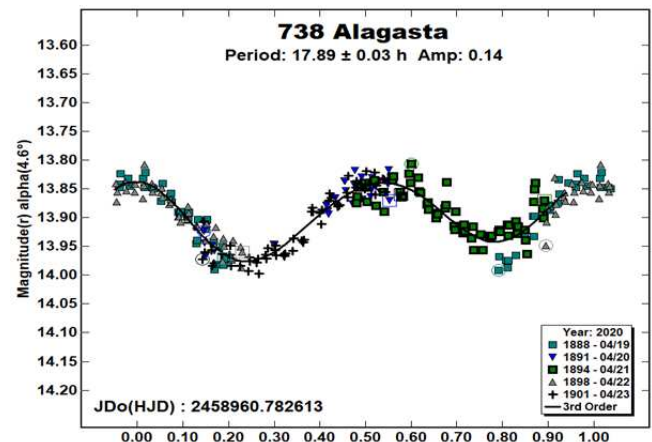
of the comp stars, the asteroid itself, and the period-fit. Period determination was done using the *MPO Canopus* Fourier-type FALC fitting method (cf. Harris et al., 1989). Phased lightcurves show the maximum at phase zero. Magnitudes in these plots are apparent and scaled by *MPO Canopus* to the first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

Most asteroids were selected from the CALL website (Warner, 2011a) 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 27 asteroids had no previous period analysis, 1 had $U = 1$, and 24 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.

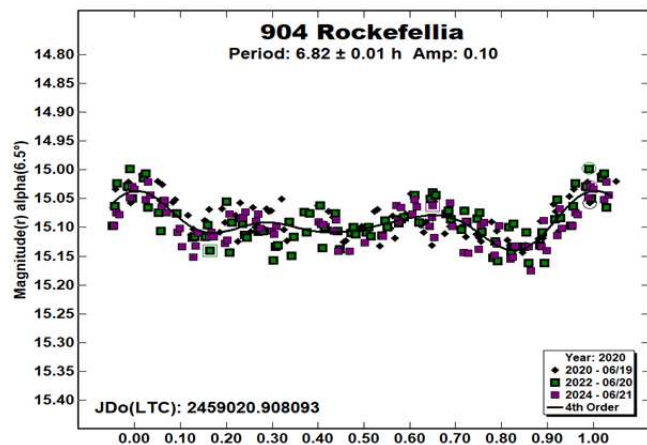
549 Jessonda. Max Wolf discovered this asteroid in a highly eccentric orbit from Heidelberg in 1904. Three previous analyses produced similar periods: Behrend (2005), 2.9709 ± 0.0002 h; Warner (2011b), 2.971 ± 0.001 h; and Stephens (2015), 2.962 ± 0.002 h. A total of 233 images were taken in five nights, resulting in a trimodal lightcurve with a synodic period of 2.972 ± 0.002 h, agreeing with previous assessments. The amplitude is 0.09 mag, with an RMS error of 0.029 mag.



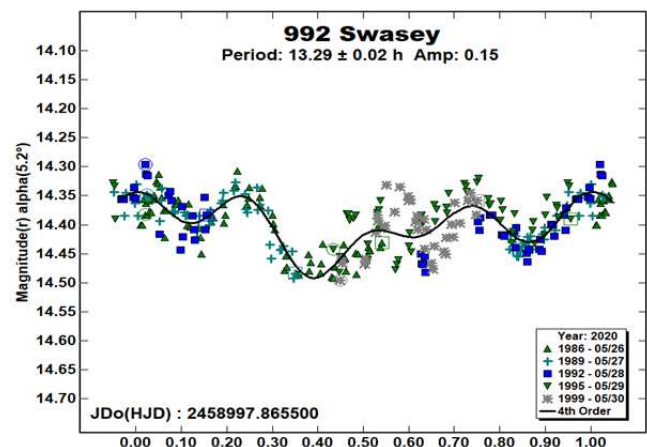
738 Alagasta was discovered at Heidelberg in 1913 by Franz Kaiser. Sada et al. (2005) published a period of 17.83 ± 0.04 h, and Garcera et al. (2016) obtained 18.86 ± 0.01 h. During five nights, 264 images were used to compute a period of 17.89 ± 0.03 h, agreeing with Sada et al.'s value. The lightcurve has an amplitude of 0.14 mag, and an RMS error of 0.019 mag.



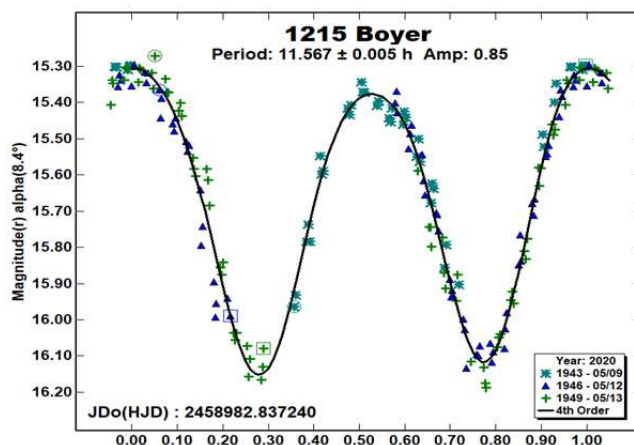
904 Rockefeller. This outer main-belt asteroid is another of Max Wolf's discoveries at Heidelberg. Many disagreeing periods are found in the LCDB. They include Fauvaud and Fauvaud (2013), with 5.82 ± 0.01 h, Behrend (2004), who computed 12.72 ± 0.05 h, and Polakis (2018) who calculated 5.826 ± 0.004 h. Additionally, Polakis (2019) observed the asteroid on 13 nights around the 2019 opposition, and was unable to resolve a period. The 2020 opposition proved to be more favorable, and three nights and 239 data points were sufficient to produce a period solution of 6.820 ± 0.010 h. The amplitude of the lightcurve is 0.10 mag, with an RMS error on the fit of 0.024 mag.



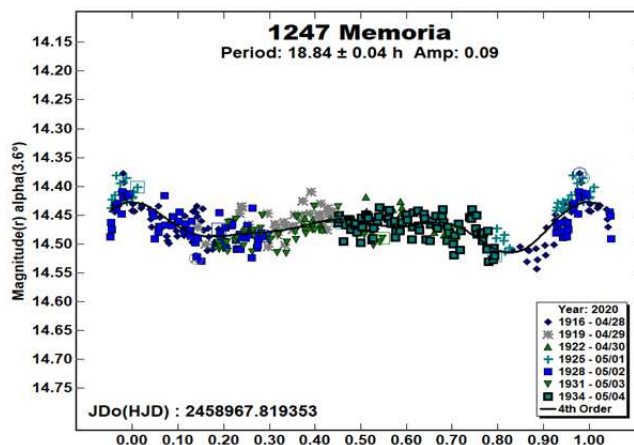
992 Swasey. Otto Struve discovered this Eos-family minor planet in 1922 from Williams Bay. Behrend (2004) computed a synodic period of 13.308 ± 0.003 h, while Pál et al. (2020) published nearly double this value: 26.3193 ± 0.0005 h. A total of 289 data points from five nights yielded a period of 11.564 ± 0.006 h. The period spectrum did not show signals at either of the previous solutions. The amplitude is 0.15 mag, with an RMS error on the fit of 0.029 mag.



1215 Boyer is a Eunomia-family object with an inclination of 16° . Its discovery was made by Alfred Schmitt at Algiers in 1932. Kim et al. (2014) published a period of 10.36 ± 0.05 h. During three nights, 169 images were sufficient to compute an unambiguous period of 11.567 ± 0.005 h, which disagrees with Kim's value. The amplitude is 0.85 ± 0.046 mag.



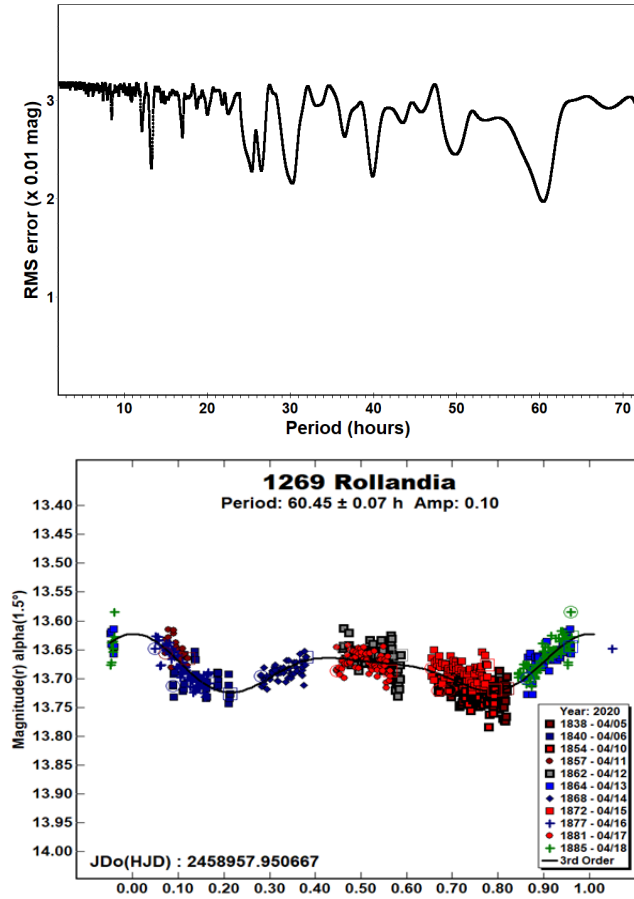
1247 Memoria is a Themis-family asteroid that came to a favorable opposition in 2020. It was discovered at Uccle in 1932 by Paul-Auguste-Ernest Laugier. The only period in the LCDB is that of Behrend (2019), who computed 18.79 ± 0.02 h. In a seven-night interval, 351 images were gathered, producing a solution of 18.840 ± 0.040 h, in agreement with Behrend. The amplitude of the lightcurve is 0.09 ± 0.021 mag.



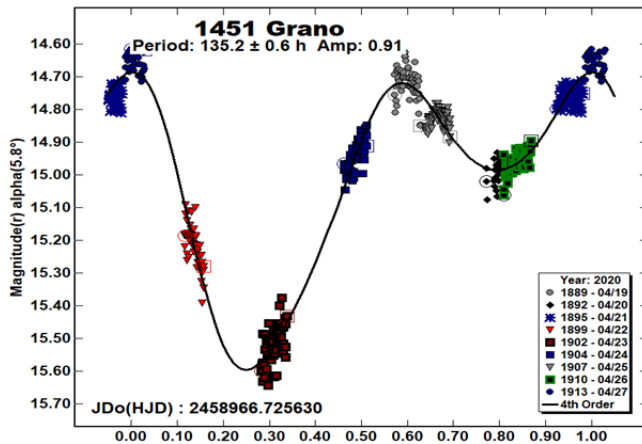
1269 Rollandia is a Hilda-family minor planet, discovered by Grigory Neujmin in 1930 at Simeis. Determining a rotation period has been problematic, with multiple authors yielding no clear solution. This is a partial list of unique periods that have been published in the past decade: Fauvaud and Fauvaud (2013), 15.32 ± 0.03 h; Warner and Stephens (2017), 19.98 ± 0.02 h; Polakis (2019), 28.277 ± 0.017 h; and Warner and Stephens (2019), 17.12 ± 0.02 h.

In an attempt to resolve the problem, the asteroid was observed at V02 on 11 nights, during which 698 images were obtained. The period spectrum shows multiple troughs, with the best bimodal solution landing at 60.45 ± 0.07 h, which is yet another unique solution. The amplitude is 0.10 mag, with an RMS fit error of 0.025 mag.

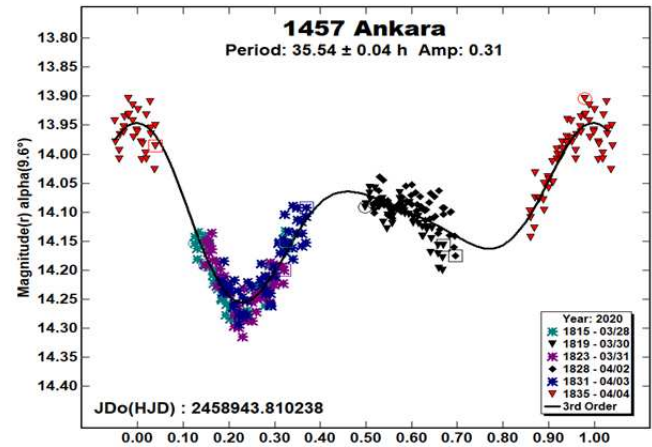
Period Spectrum: 1269 Rollandia



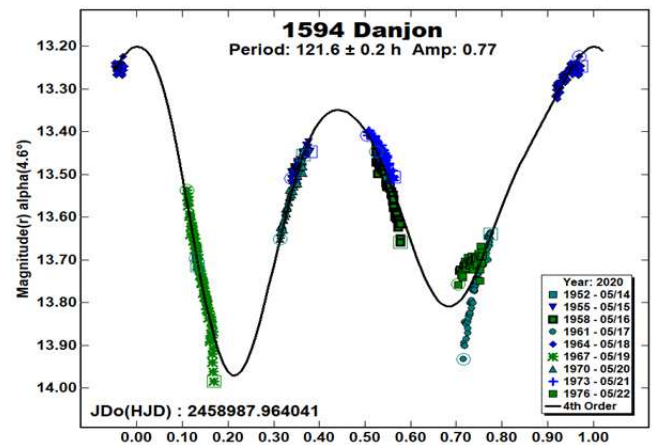
1451 Grano belongs to the Flora family. It was discovered at Turku in 1938 by Yrjö Väisälä. Behrend (2007) ascertained a period of 5.109 ± 0.004 h, while Stephens (2010), observing for a longer interval, found a period of 138 ± 0.05 h. The longer period appears to be better supported, as 485 data points over nine nights produced a synodic period of 135.2 ± 0.6 h, with a large amplitude of 0.91 ± 0.043 mag.



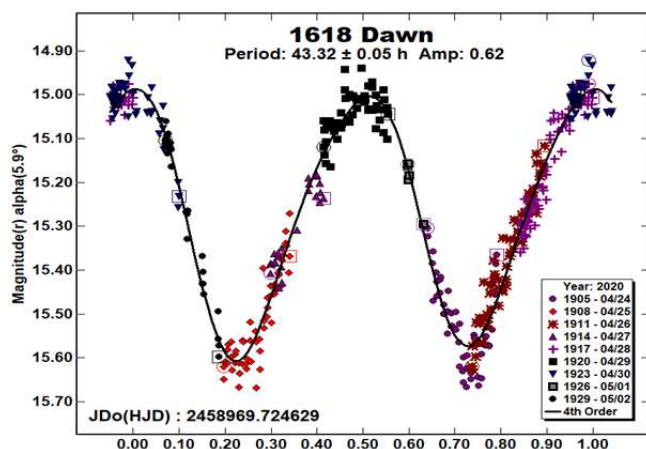
1457 Ankara was discovered at Heidelberg by Karl Reinmuth in 1937. The only period in the LCDB is that of Behrend (2004), who computed 31.8 ± 0.6 h. During six nights, 317 images were used to ascertain a synodic period of 35.54 ± 0.05 h. The amplitude is 0.31 mag, with an RMS error on the fit of 0.026 mag.



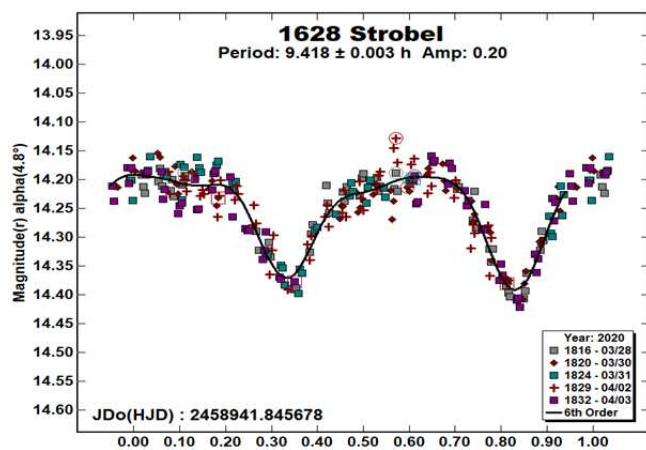
1594 Danjon is an inner-belt object with a high eccentricity of 0.20. Its discovery was made by Louis Boyer at Algiers in 1949. It is named after André-Louis Danjon, who created the familiar Danjon scale to gage the brightness of Earthshine. Behrend (2006) shows a period of >12 h. During nine nights, 462 images were taken. The resulting period is 121.6 ± 0.2 h, with an amplitude of 0.77 ± 0.032 mag. The asteroid was followed for only $1\frac{1}{2}$ rotations, and the trailing points away from the Fourier fit may indicate tumbling.



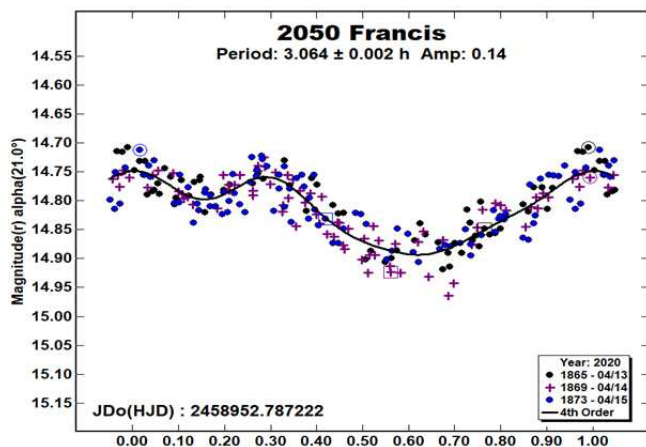
1618 Dawn is a member of the Karin family, which all share a similar orbit as 832 Karin. Five agreeing solutions appear in the LCDB. Slivan (2008) published a period of 43.19 ± 0.05 h, Hanuš et al. (2013) calculated 43.219 ± 0.005 h, and Waszczak et al. (2015) computed 43.242 ± 0.2574 h. A total of 413 data points was gathered over nine nights to produce a period solution of 43.64 ± 0.04 h, agreeing with previous assessments. The amplitude is 0.61 mag, with an RMS error of 0.043 mag.



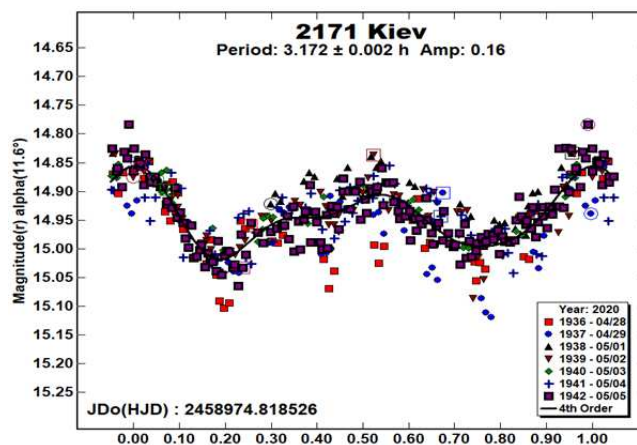
1628 Strobel, is another of Karl Reinmuth's discoveries, working from Heidelberg in 1923. Binzel (1987) produced a period solution of 11.80 h, and Behrend (2005) obtained 9.52 ± 0.01 h. More recently, Pál et al. (2020) published a period of 9.4244 ± 0.0005 h. During five nights, 279 images were gathered to compute a similar rotation period of 9.418 ± 0.003 h. The amplitude is 0.20 mag, with an RMS error of 0.024 mag.



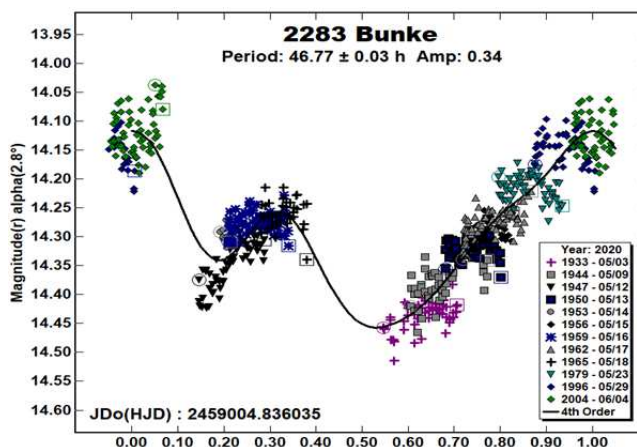
2050 Francis. Elanor Helin found this Phocaea-family asteroid in 1974 at Palomar. Franco et al. (2013) calculated a rotation period of 3.069 ± 0.001 h, and Behrend (2020) obtained nearly double this period, with 6.136 ± 0.001 h. After three nights, 234 images were obtained. The resulting bimodal solution is a period of 3.064 ± 0.002 h. The amplitude of the lightcurve is 0.14 ± 0.027 mag.



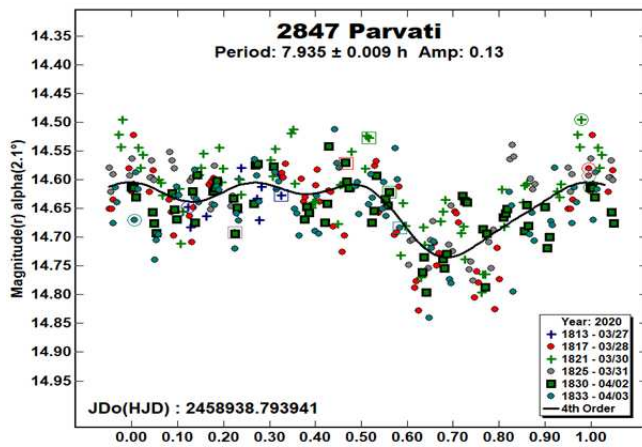
2171 Kiev is a Flora-family object in an eccentric orbit. It was discovered by Tamara Smirnova at Nauchnyj in 1973. No period solutions appear in the LCDB. Despite its short period, seven nights and 461 images were required to derive an acceptable solution of 3.172 ± 0.002 h. The RMS error of the fit of 0.036 mag is significant relative to the amplitude of 0.16 mag.



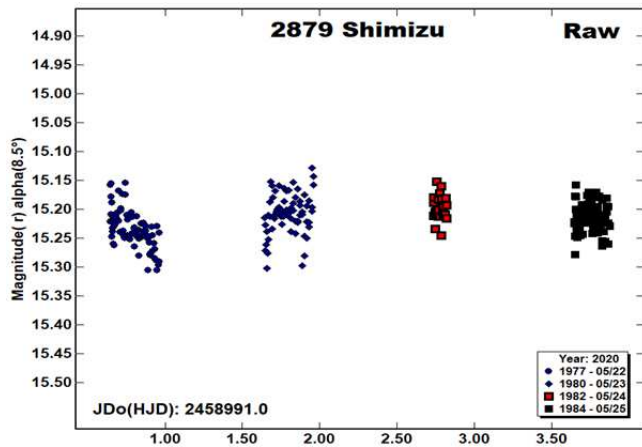
2283 Bunke. Irina Zhuravleva discovered this minor planet in 1974, working at Nauchnyj. Menke (2005) found a period of 3.96 ± 0.01 h, and Kryszczyńska et al. (2012) published a period of 4.3 ± 0.1 h. After 12 nights, data points were used to compute a rotation period of 46.77 ± 0.03 h, disagreeing with past assessments. The amplitude of the lightcurve is 0.34 ± 0.04 mag. The lightcurve is incomplete owing to commensurability with two earth rotations.



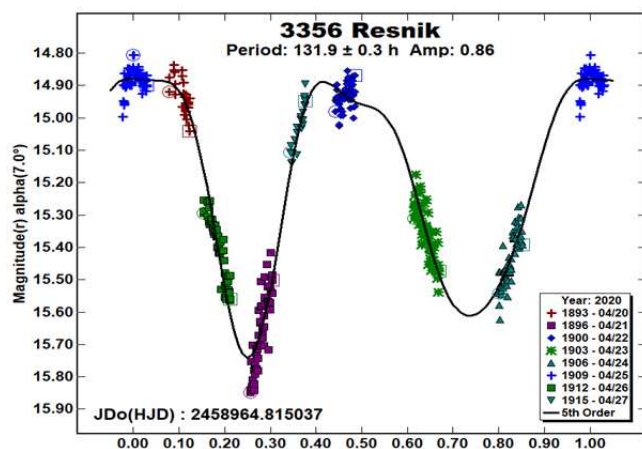
2847 Parvati was discovered at Lowell Observatory in Flagstaff in 1959. Two solutions in the LCDB are by Behrend (2018), 22.757 ± 0.002 h; and Mas et al. (2018), 2.640 ± 0.003 h. A total of 289 data points collected in six nights were taken. The resulting period solution is 7.935 ± 0.009 h, disagreeing with both previous values. The amplitude is 0.13 mag, with a significant RMS error of 0.051 mag.



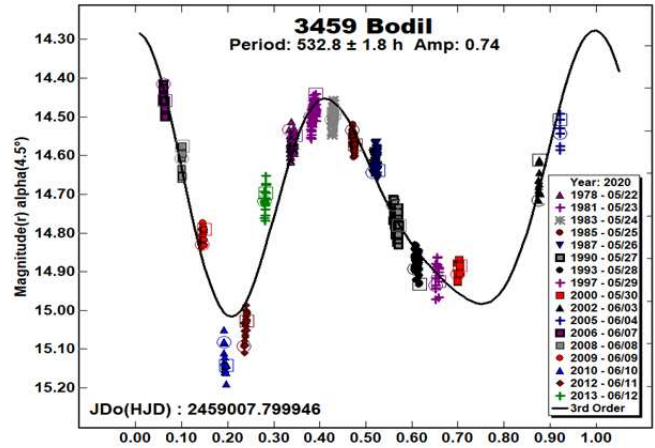
2879 Shimizu was discovered at Heidelberg in 1932 by Karl Reinmuth. Behrend (2006) gives a period of 18.72 ± 0.05 h, while Pál et al. (2020) shows a result of 55.3718 ± 0.0005 h. After reducing data from four nights with 249 data points, it became apparent that a period solution would not be achievable during this apparition. The raw lightcurve is presented.



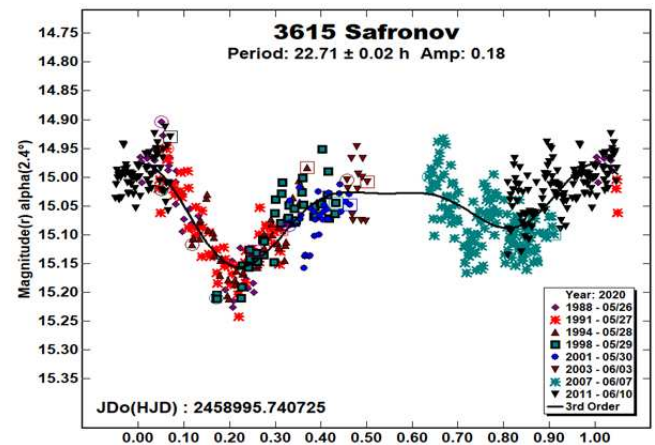
3356 Resnik was discovered in 1984 at Flagstaff by Edward Bowell, who named it after STS-51-L crew member Judith Resnik. The only period solution in the LCDB is that of Higgins (2008), who shows >32 h. A total of 387 images were taken during nine nights, revealing it to be a slow rotator, with a synodic period of 131.9 ± 0.3 h, and an amplitude of 0.86 ± 0.049 mag.



3459 Bodil is a Flora-family minor planet in an eccentric orbit. It was discovered by Poul Jensen in 1986 from Brorfelde. The only period solution in the LCDB is that of Erasmus et al. (2020), who published 52.572 ± 0.231 h. It was observed around its favorable opposition on 17 nights, during which 536 images were taken. The slow rotator has a synodic period of 532.9 ± 1.8 h, with an amplitude of 0.74 ± 0.053 mag.



3615 Safronov. Observing at Flagstaff in 1983, Edward Bowell found this Themis-family asteroid. The only period in the LCDB belongs to Chang et al. (2014), who shows >16 h. A total of 499 images taken during eight nights were used to secure a rotation period of 22.71 ± 0.02 h. The amplitude is 0.18 mag, with an RMS error on the fit of 0.042 mag.

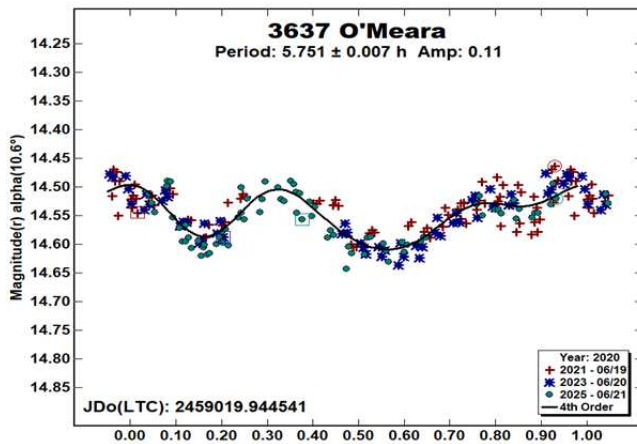


3637 O'Meara is a minor planet in the Eunomia family. The discovery was made at Flagstaff in 1984 by Brian Skiff, who named it after the prolific amateur astronomer and author Steven O'Meara. Aznar Macias (2017) published a rotation period of 4.118 ± 0.25 h, and Pál et al. (2020) computed 5.77146 ± 0.00005 h. Aznar Macias' analysis, based on his dense dataset taken over a range of 24 days, suggested that the object may be a binary asteroid.

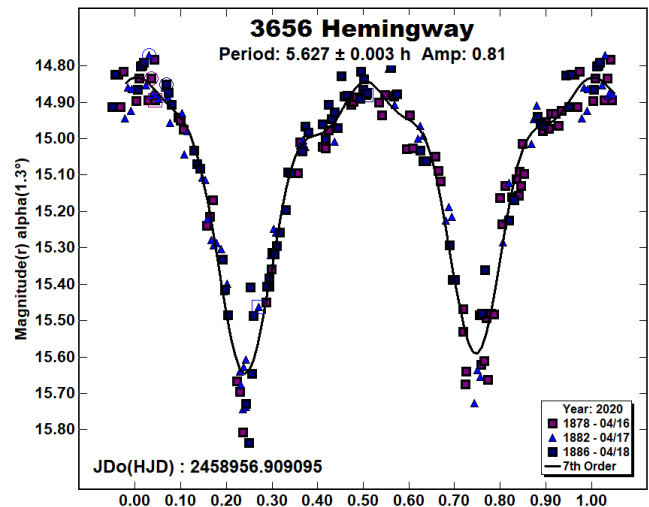
During three nights, 213 images were taken, yielding a period of 5.751 ± 0.007 h, agreeing with Pál's value. The amplitude of the lightcurve is 0.11 ± 0.023 mag. While this dataset used less images and covered only three nights, the period spectrum and resulting lightcurve do not support the binary nature suggested by Aznar Macias.

Number	Name	2020/mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
549	Jessonda	04/04–04/12	3.7, 6.8	189	–5	2.972	0.001	0.09	0.03	MB–M
738	Alagasta	04/19–04/23	4.6, 3.2	220	4	17.89	0.03	0.14	0.02	MB–O
904	Rockefellia	06/19–06/21	6.5, 6.4	271	18	6.820	0.010	0.10	0.02	MB–O
992	Swasey	05/26–05/30	5.2, 6.6	235	6	13.29	0.02	0.15	0.03	EOS
1215	Boyer	05/03–05/13	8.0, 8.9	223	20	11.567	0.005	0.85	0.05	EUN
1247	Memoria	04/28–05/04	3.6, 1.4	227	2	18.840	0.040	0.09	0.02	THM
1269	Rollandia	04/05–04/18	*1.5, 3.2	199	3	60.45	0.07	0.10	0.03	HIL
1451	Grano	04/19–04/27	5.8, 3.6	217	5	135.2	0.60	0.91	0.04	FLOR
1457	Ankara	03/28–04/04	9.6, 12.5	170	–7	35.54	0.05	0.31	0.03	MB–M
1594	Danjon	05/14–05/22	*4.6, 1.7	240	2	121.6	0.2	0.77	0.03	MB–I
1618	Dawn	04/24–05/02	5.9, 8.9	201	4	43.64	0.04	0.61	0.04	KAR
1628	Strobel	03/28–04/03	4.8, 7.2	176	–1	9.418	0.003	0.20	0.02	MB–O
2050	Francis	04/13–04/15	21.0, 21.0	202	31	3.064	0.002	0.14	0.03	PHO
2171	Kiev	04/28–05/05	11.6, 8.5	234	9	3.172	0.002	0.16	0.04	FLOR
2283	Bunke	05/03–06/04	2.8, 16.9	224	5	46.77	0.03	0.34	0.04	FLOR
2847	Parvati	03/27–04/03	2.1, 5.2	186	–3	7.935	0.009	0.13	0.05	FLOR
2879	Shimizu	05/22–05/25	8.5, 9.3	231	14	--	--	--	--	MB–O
3356	Resnik	04/19–04/27	7.5, 4.2	219	6	131.9	0.3	0.86	0.05	FLOR
3459	Bodil	05/22–06/12	*4.7, 9.6	247	4	532.9	1.8	0.74	0.05	FLOR
3615	Safronov	05/26–06/10	2.4, 8.2	241	3	22.71	0.02	0.18	0.04	THM
3637	O'Meara	06/19–06/21	10.6, 10.5	273	18	5.751	0.007	0.11	0.02	EUN
3656	Hemingway	04/16–04/18	1.3, 0.8	208	–1	5.627	0.003	0.81	0.06	MB–I
4041	Miyamotoyohko	05/19–05/21	7.4, 7.9	225	11	5.142	0.004	0.23	0.03	EOS
4353	Onizaki	05/09–05/13	4.7, 5.9	226	7	4.429	0.001	0.36	0.03	MB–I
4570	Runcorn	04/04–04/18	11.4, 18.6	178	–2	233.4	0.5	1.35	0.08	FLOR
7910	Aleksola	05/14–05/18	6.2, 5.4	239	7	6.440	0.008	0.17	0.03	MB–I
15710	Bocklin	05/19–05/21	6.6, 6.4	240	9	7.516	0.004	0.77	0.04	FLOR

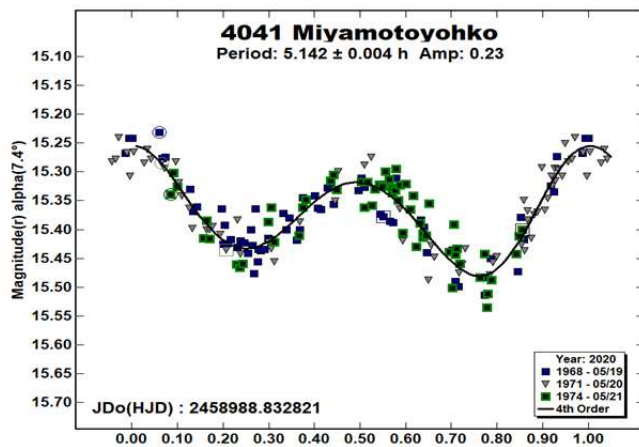
Table I. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984).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



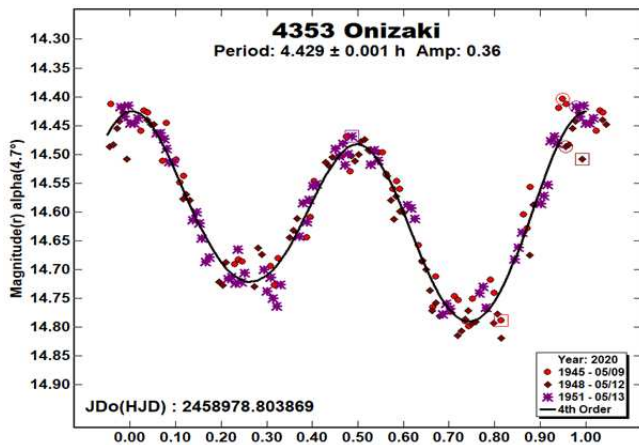
3656 Hemingway was discovered by Lyudmila Chernykh at Nauchnyj in 1978. Two similar periods appear in the LCDB: Waszczak et al. (2015), 5.626 ± 0.052 h and Durech et al. (2018), 5.63027 ± 0.00002 h. During three consecutive nights, 190 data points were sufficient to ascertain a rotation period of 5.627 ± 0.003 h, in agreement with previously published values. The lightcurve has an amplitude of 0.81 ± 0.062 mag.



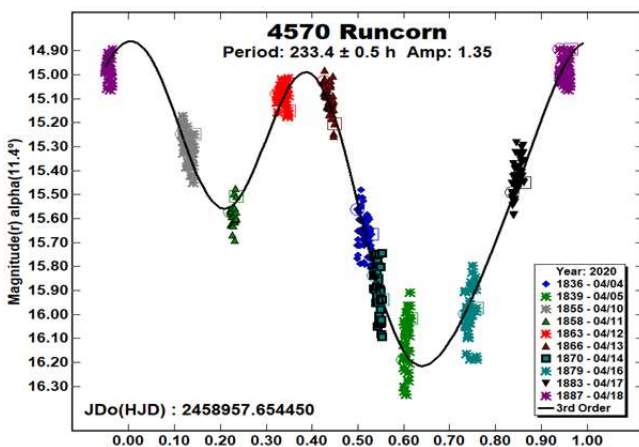
4041 Miyamotoyohko was discovered by Takuo Kojima at Chiyoda in 1988. Behrend (2015) shows a period of 7.694 ± 0.001 h. During three nights in 2020 May, 187 images were collected, and a synodic period of 5.142 ± 0.004 h was computed, disagreeing with Behrend's result. The lightcurve's amplitude is 0.23 mag, with an RMS error on the fit of 0.027 mag.



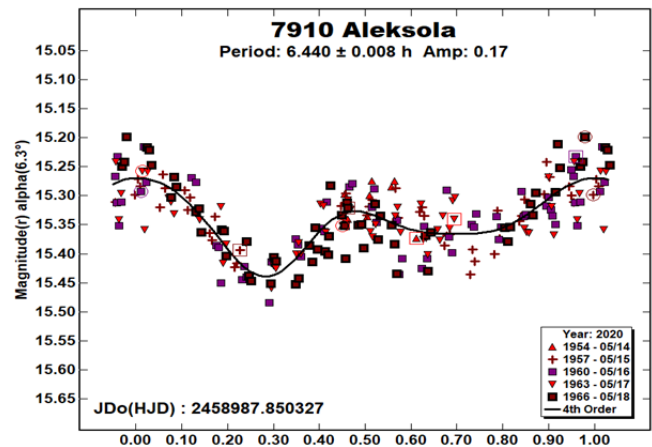
4353 Onizaki was discovered by Mizuno and Furuta at Kani in 1989. Waszczak et al. (2015) computed a period of 4.429 ± 0.0273 h, and Pravec et al. (2020) calculated 4.4296 ± 0.0002 h. A total of 165 images were used to acquire a rotation period of 4.429 ± 0.001 h, agreeing with previous values. The amplitude is 0.36 ± 0.028 mag.



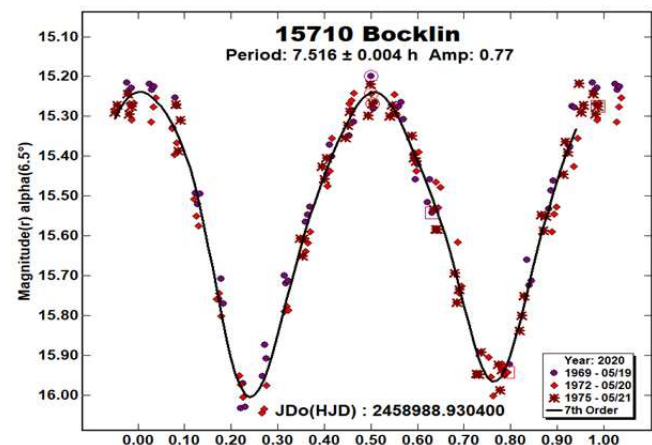
4570 Runcorn is a Flora-family asteroid discovered by Edward Bowell in 1985 from Flagstaff. Hanuš et al. (2016) published a period of 20.1514 ± 0.0005 h. This slow rotator required ten nights and 451 images to obtain a period solution of 233.4 ± 0.5 h, disagreeing with that of Hanuš. The amplitude is 1.35 ± 0.077 mag. Signal-to-noise ratio became a concern around its minimum magnitude of $r' \sim 16$, which is typically beyond the practical range of this telescope and sky conditions.



7910 Aleksola was discovered by Nikolai Chernykh from Crimea in 1976. Pál et al. (2020) published a period of 6.41852 ± 0.00005 h. During five nights, 219 images were obtained. They produced a period solution of 6.440 ± 0.008 h, agreeing with Pál's value. The lightcurve has an amplitude of 0.17 ± 0.034 mag.



15710 Bocklin. This Flora-family minor planet was found by Freimut Borngen at Tautenburg in 1989. Durech et al. (2018) shows a period of 7.52272 ± 0.00002 h, and Erasmus et al. (2020) published 7.521 ± 0.005 h. During three nights, 160 images were gathered, and used to compute a synodic period of 7.516 ± 0.004 h, agreeing with previous assessments. The lightcurve has an amplitude of 0.77 mag, with an RMS error on the fit of 0.042 mag.



Acknowledgements

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