

LIGHTCURVES OF TWELVE MAIN-BELT MINOR PLANETS

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Synodic rotation periods were determined for twelve main-belt asteroids: 394 Burdigala, 399.8 ± 0.7 h; 464 Megaira, 12.860 ± 0.012 h; 858 El Djezir, 14.830 ± 0.015 h; 1269 Rollandia, 28.277 ± 0.017 h; 1585 Union, 12.798 ± 0.005 h; 1603 Neva, 6.423 ± 0.002 h; 1614 Goldschmidt, 16.540 ± 0.013 h; 1720 Niels, 250.9 ± 0.9 h; 2162 Anhui, 8.090 ± 0.005 h; 3040 Kozai, 4.512 ± 0.008 h; 5321 Jagras, 2.6370 ± 0.0004 h; and (18736) 1998 NU, 2.4755 ± 0.0002 h. All the data have been submitted to the ALCDEF database.

CCD photometric observations of twelve 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 images was 2 minutes. The image scale after 2x2 binning was 1.76 arcsec/pixel. Table I shows the observing circumstances and results. With one exception, all of the images for these twelve asteroids were obtained between 2019 January and March.

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, 2019). The $45^\circ \times 30'$ field 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.

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. 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.

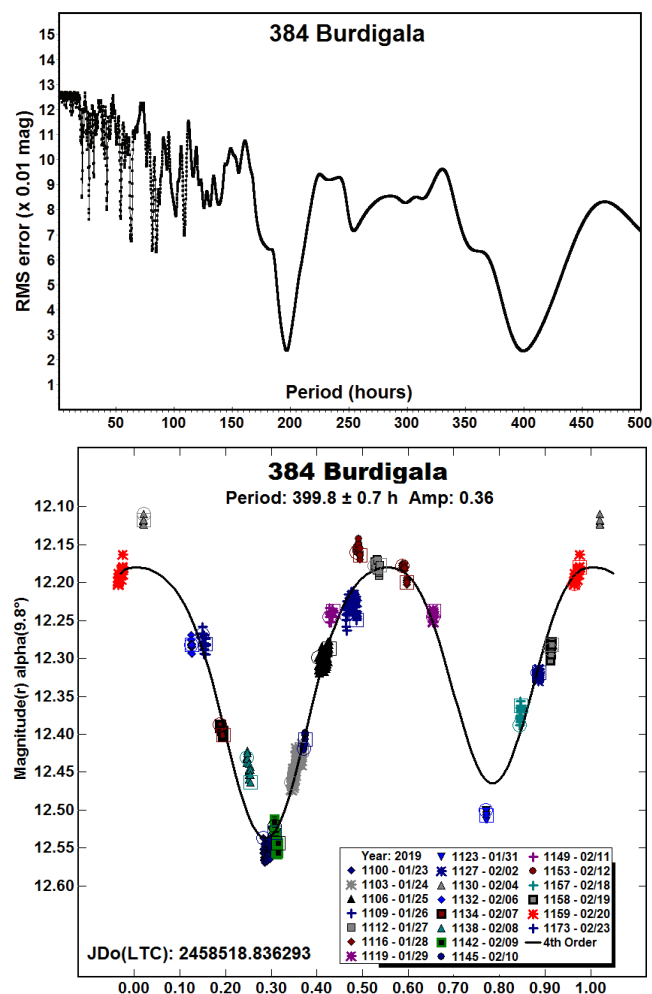
A 9-pixel (16 arcsec) diameter measuring aperture was used for asteroids and comp stars. It was typically necessary to employ star subtraction to remove contamination by field stars. For the asteroids described here, I note the RMS scatter on the phased

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 (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.

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 2+. In this set of observations, seven of the 11 asteroids had no previous period analysis. The Asteroid Lightcurve Database (LCDB; Warner et al., 2009) was consulted to locate previously published results. All the new data for these twelve asteroids can be found in the ALCDEF database.

384 Burdigala was discovered by Fernand Courty at Bordeaux in 1894. The LCDB gives two rotation periods, both based on rather sparse data; Robinson (2011) obtained a period of >17 h, and Behrend (2011) shows 21.1 ± 0.1 h. It would come to a perihelic opposition in early 2019.

The first three nights of observations at V02 showed a steady rise in brightness, indicating that the period would be much longer than published values. In all, 594 images were gathered over the course of 21 nights. The minimum in the period spectrum at 399.8 ± 0.7 h produced a satisfactory, bi-modal lightcurve. The amplitude is 0.36 ± 0.02 mag, and the RMS scatter on the fit shown in the phased plot is 0.023 mag.

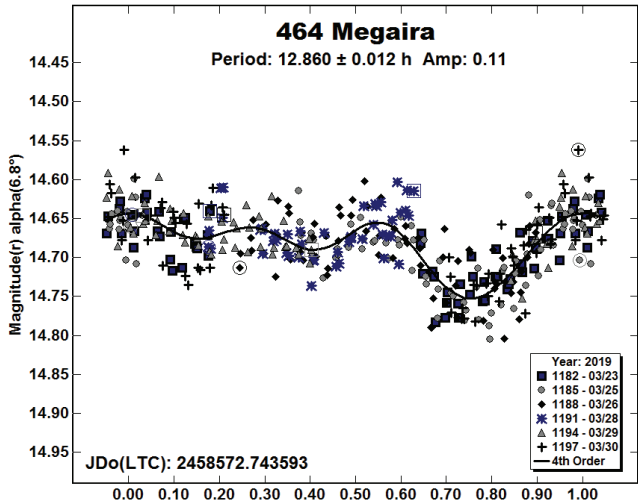


Number	Name	yyyy mm/dd	Pts	Phase	L _{PAB}	B _{PAB}	Period (h)	P.E.	Amp	A.E.	Grp
384	Burdigala	2019 01/23-02/23	594	9.7, 20.6	107	7	399.8	0.7	0.36	0.02	MB-M
464	Megaira	2019 03/23-03/30	387	6.8, 8.6	165	11	12.860	0.012	0.11	0.03	MB-O
858	El Djezair	2019 03/23-03/31	539	4.9, 6.5	180	11	14.830	0.015	0.07	0.02	MB-O
1269	Rollandia	2019 02/10-02/28	422	2.7, 8.2	132	0	28.277	0.017	0.13	0.02	HIL
1585	Union	2019 02/23-02/28	414	9.1, 10.9	135	-6	12.798	0.005	0.24	0.02	MB-O
1603	Neva	2019 01/29-02/09	302	10.9, 14.5	103	-4	6.423	0.002	0.25	0.04	MB-O
1614	Goldschmidt	2019 03/23-03/30	315	8.6, 11.1	161	1	16.540	0.013	0.15	0.04	MB-O
1720	Niels	2019 01/23-02/12	482	3.7, 15.0	117	0	250.9	0.9	0.61	0.05	MB-I
2162	Anhui	2019 01/23-01/28	482	7.0, 9.8	111	-1	8.090	0.005	0.14	0.03	FLOR
3040	Kozai	2019 02/24-02/25	207	16.2, 16.4	158	22	4.512	0.008	0.25	0.06	MC
5321	Jagras	2018 10/10-10/18	274	3.5, 5.8	16	5	2.6370	0.0004	0.06	0.03	EUN
18736	1998 NU1	2019 01/27-02/08	290	9.9, 19.5	121	-1	2.4755	0.0002	0.12	0.02	NEA

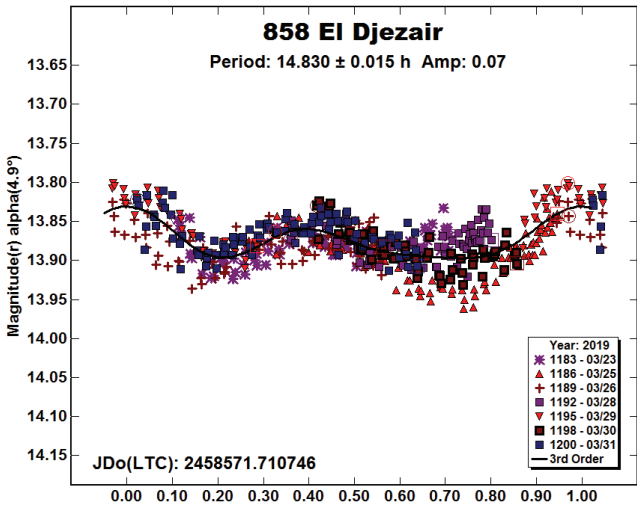
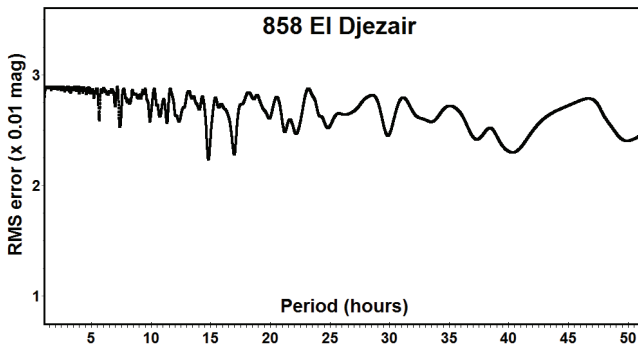
Table I. Observing circumstances and results. The phase angle (α) is given at the start and end of each date range, unless it reached a minimum or maximum, which is then the second of three values. LPAB and BPAB are each the average phase angle bisector longitude and latitude (see Harris et al., 1984).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

464 Megaira. This outer-belt asteroid was discovered by Max Wolf while at Heidelberg in 1901. Harris and Young (1989) derived a period of 12.726 ± 0.003 h while Waszczak et al. (2015) found 12.871 ± 0.0073 h.

A total of 387 images were gathered during six nights. The low amplitude of the lightcurve presented difficulty in obtaining a satisfactory period solution; the RMS scatter of 0.030 mag. is nearly one fourth of the amplitude of 0.11 ± 0.03 mag. The fourth-order solution produced a period of 12.860 ± 0.012 h, which agrees with previous assessments.

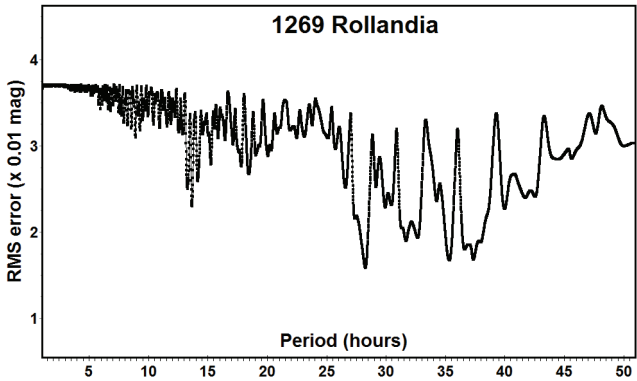


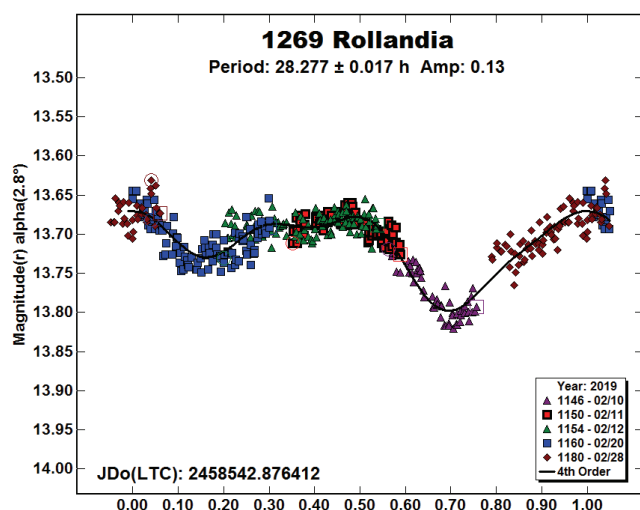
858 El Djezair is one of Frédéric Sy's discoveries while working at Agiers in 1916. Warner (2005) published a period of 22.31 ± 0.2 h. Behrend (2007) obtained 19.0 ± 1.0 h.



Over the course of nine nights, seven were useable, resulting in 539 data points. The lowest trough in the period spectrum occurs at 14.830 ± 0.015 h, which does not agree with published values. The full amplitude is 0.07 ± 0.02 mag, and the RMS scatter of the fit is 0.023 mag.

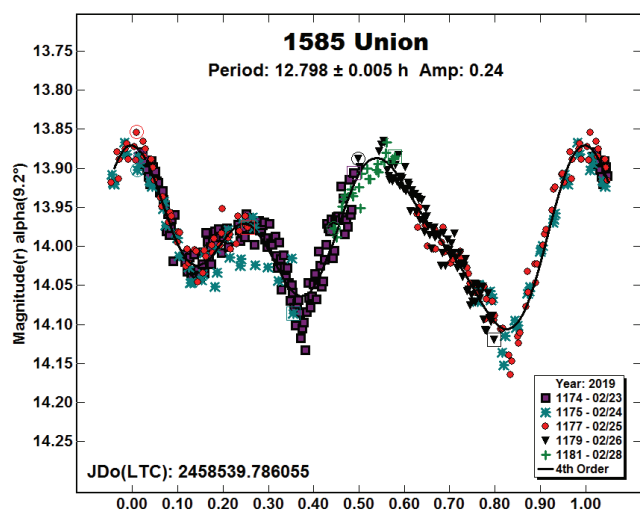
1269 Rollandia. Grigory Neujmin discovered this Hilda asteroid from Simeis in 1930. Several period solutions have been published: Franco (2012, 15.4 ± 0.1 h), Slyusarev (2012, 30.98 ± 0.93 h), and Fauvud (2013, 15.32 ± 0.03 h).





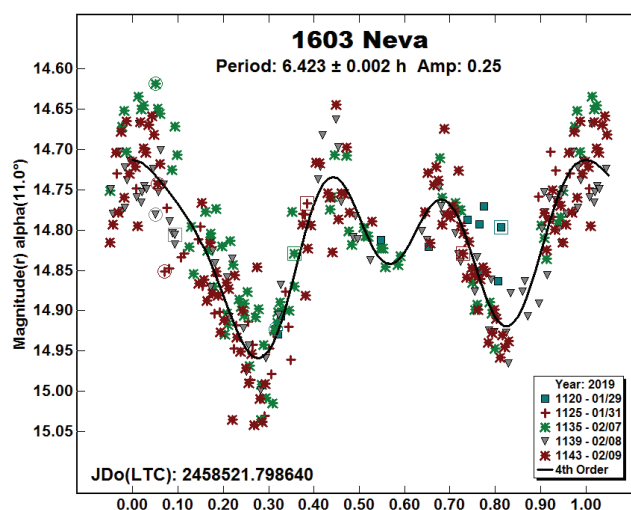
During five nights in February, 422 images were taken. The most prominent solution in the period spectrum occurs at 28.277 ± 0.017 h, differing from values in the LCDB. The lightcurve has an amplitude of 0.13 ± 0.02 mag and an RMS error on the fit of 0.016 mag.

1585 Union. Ernest Johnson discovered this minor planet at Union Observatory in 1947. *Binzel (1987) published a period of 9.38 h* and Behrend (2004) computed 24 h. The generous amplitude of the lightcurve results in a robust period solution at 12.798 ± 0.005 h, disagreeing with the two previous assessments. The RMS scatter on the fit is 0.018 mag. The amplitude is 0.24 ± 0.02 mag.



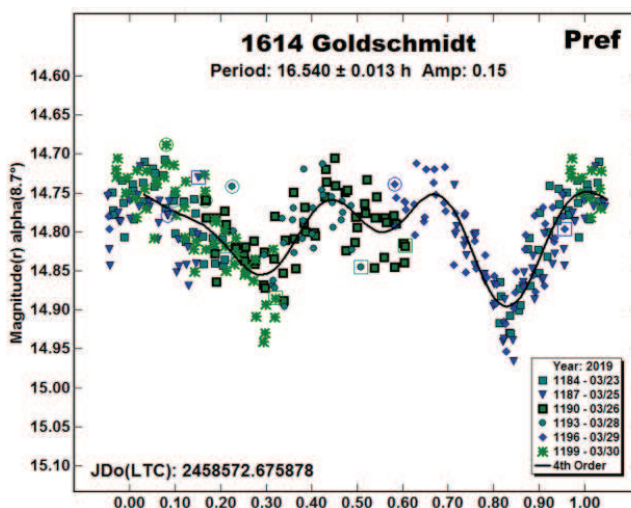
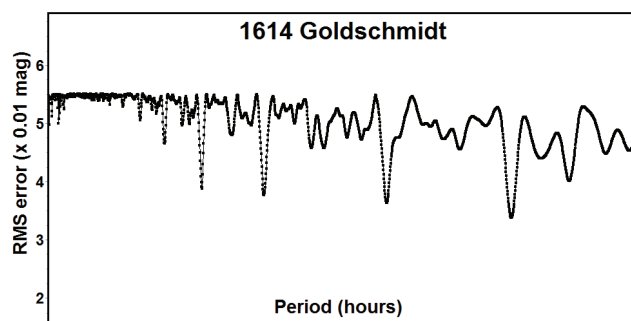
1603 Neva is another of Grigory Neujmin's finds, made while working at Simeis in 1926. Several authors have published periods, all roughly in agreement with each other: Behrend (2004, 6.4249 ± 0.0001 h), Aznar (2016, 6.430 ± 0.015 h), and Fuller (2019, 6.426 ± 0.001 h).

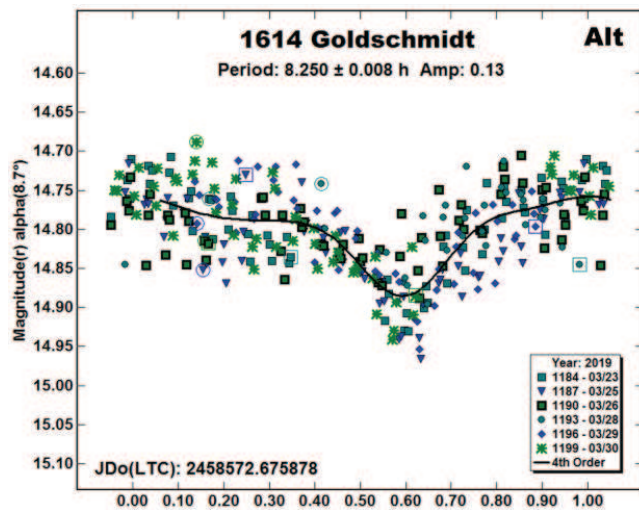
Five observing nights were sufficient to obtain a synodic period of 6.423 ± 0.002 h, which is in agreement with the previous values. The amplitude of the lightcurve is 0.25 ± 0.04 mag and the RMS error on the fit is 0.044 mag.



1614 Goldschmidt. Alfred Schmitt discovered this minor planet at Uccle in 1952. He named it after Hermann Goldschmidt, who by 1861 had discovered 14 asteroids. The LCDB lists two period solutions: Warell (2015) with 7.74 ± 0.02 h and Kozdon (2016) with 8.873 ± 0.002 h.

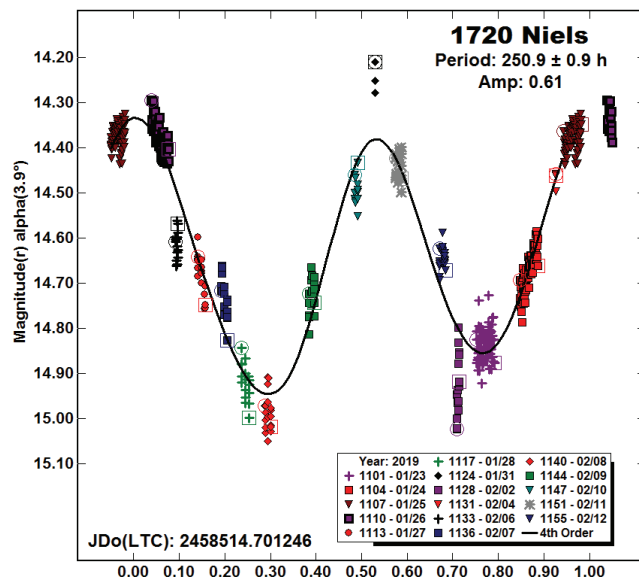
After six nights, 315 data points were collected. The period spectrum shows prominent troughs at roughly 16 h and the half-period of 8 h, but the fit reveals quite a bit of uncertainty, as previous authors noted. The best fit occurs at 16.540 ± 0.013 h. The monomodal solution of 8.250 ± 0.008 cannot be ruled out.





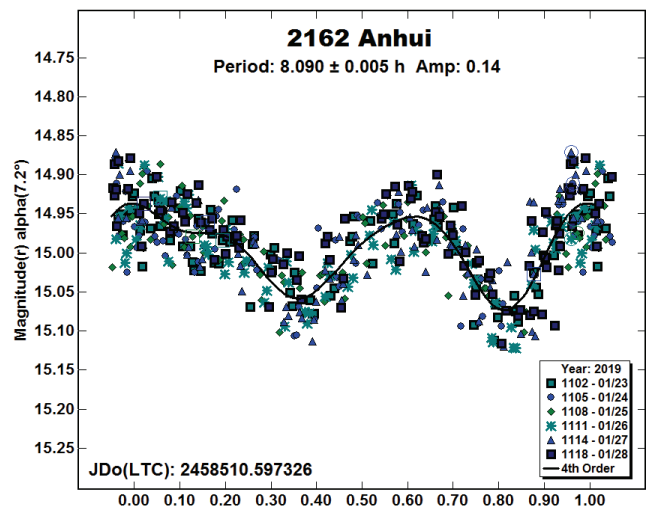
1720 *Niels* is an inner-belt asteroid, discovered at Heidelberg in 1935 by Karl Reinmuth. Using an incomplete dataset, Clark (2007) obtained a synodic period of 9.976 h. Behrend (2008) shows 19.2 h.

During a three-week period, 482 images were gathered on 16 nights in 2019 January to February. The photometry revealed a much longer period than the previous assessments: 250.9 ± 0.9 h. RMS scatter on the fit is 0.054 mag. The amplitude of the lightcurve is 0.61 ± 0.05 mag.



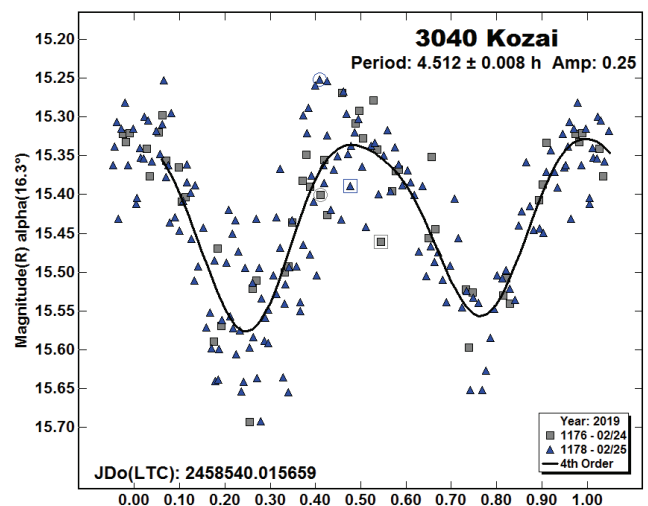
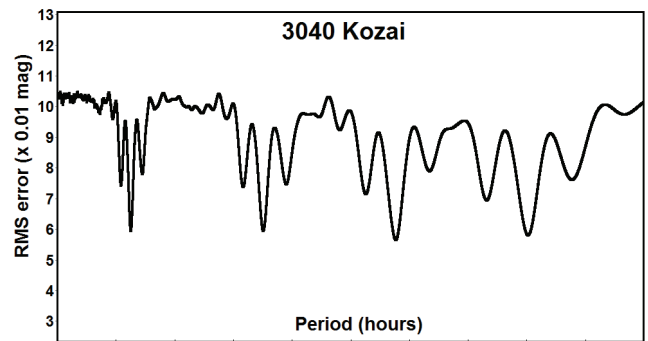
2162 *Anhui* is a Flora-family asteroid, discovered in 1966 at Purple Mountain Observatory. Behrend (2018) obtained a period of 8.106 ± 0.001 h and Pravec (2018) computed a similar period of 8.1048 ± 0.0005 h.

During six January nights, 471 images of the asteroid were taken. A synodic period of 8.090 ± 0.005 h was obtained, which is in line with the two previous values. The lightcurve amplitude is 0.14 ± 0.03 mag and the RMS error of the curve fit is 0.034 mag.



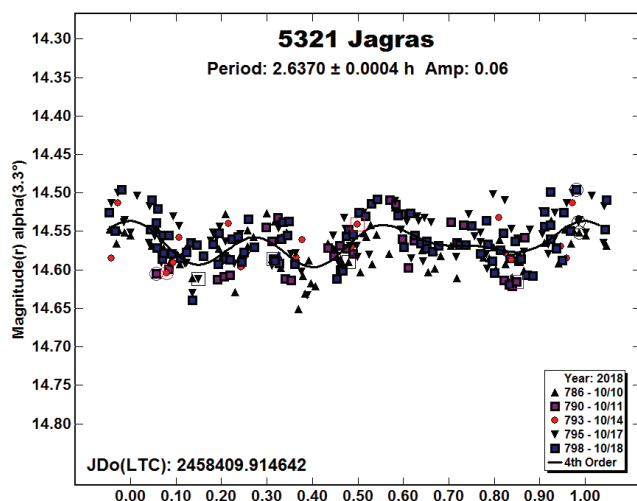
3040 *Kozai* is a Mars crosser with an orbital inclination of 47 deg. Its discovery was made by William Liller at Cerro Tololo in 1979. Recent period evaluations made by Pravec (2019) and Stephens and Warner (2019) show periods of 4.515 ± 0.002 h and 4.518 ± 0.001 h, respectively.

After two nights, the 207 images were sufficient to obtain a rough period estimate of 4.512 ± 0.008 h, albeit with large scatter due to the brightness being below the comfortable limit for this telescope and site. This period is in line with those from Pravec and Stephens and Warner. The amplitude of the lightcurve is 0.25 ± 0.06 mag and the RMS error of the fit is 0.059 mag.



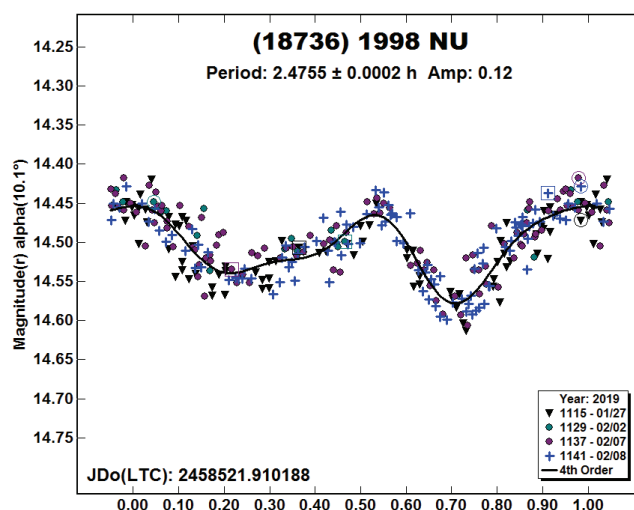
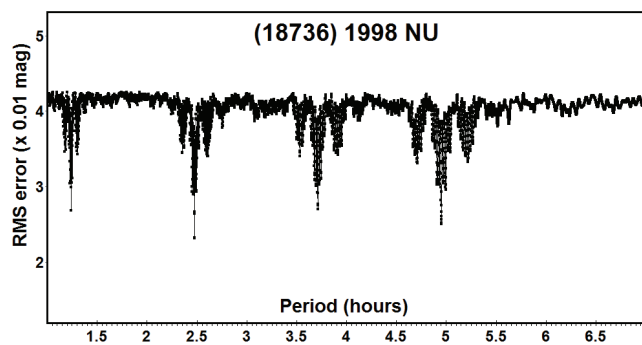
5321 Jagras This Eunomia-family asteroid was discovered in 1985 by Kaare Jensen and Karl Augustesen at Brorfelde. Again, only two, very recent period assessments have been published, both consistent with each other. Mollica (2019) published a period of 2.6375 ± 0.0001 h and Papini (2019) computed 2.638 ± 0.001 h. The author gave up on this asteroid after five nights and 274 images in 2018 October that showed mostly flat raw lightcurve morphology. Only after learning about the recent work were the data resurrected for period analysis.

Consistent with the recent calculations, a rotational period of 2.6370 ± 0.0004 h appears as a small trough in the period spectrum. Since the RMS scatter of 0.025 mag is nearly half of the amplitude, the lightcurve is very crude; observations would benefit from a larger telescope and a darker site.



(18736) 1998 NU is a near-earth asteroid that was discovered by the Spacewatch telescope. Its high eccentricity orbit brought it to a very favorable 2019 opposition distance of 0.27 AU. The LCDB shows four consistent period solutions: Carreno (2019, 2.473 ± 0.003 h); Pravec (2019, 2.47542 ± 0.00003 h); and Warner and Stephens (2019b, 2.471 ± 0.002 h and 2.4753 ± 0.0003 h). The first result of Warner and Stephens (2019b) is a revision of a previously reported period of 3.796 h (Warner and Stephens, 2019a).

Four nights and 290 images were sufficient to assess its short period, which came out to 2.4755 ± 0.0002 h. The amplitude of the fit is 0.12 ± 0.02 mag, and the RMS scatter of the curve fit is 0.023 mag.



Acknowledgments

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References

- Aznar Macias, A. (2016). "Parameters of Rotation and Shapes of Main-belt Asteroids from APT Observatory Group: Second Quarter 2016." *Minor Planet Bull.* **43**, 350-353.
- Behrend, R. (2004, 2007, 2008, 2009, 2011, 2018). Observatoire de Geneve web site.
http://obswww.unige.ch/~behrend/page_cou.html
- Binzel, R. (1987). "A photoelectric survey of 130 asteroids." *Icarus* **72**, 135-208.
- Carreño, A., Arce, E., Fornas, G., Mas, V. (2019). "Eleven Main-belt Asteroids and One Near-Earth Asteroid Lightcurves at Asteroids Observers (OBAS) - MPPD: 2017 May - 2019 Jan." *Minor Planet Bull.* **46**, 200-203.
- Clark, M. (2007). "Lightcurve Results for 1318 Nerina, 222 Lermontov 3015 Candy, 3089 Oujianquan, 3155 Lee, 6410 Fujiwara, 6500 Kodaira, (8290) 1992 NP, 9566 Rykhlava, (42923) 1999 SR18, and 2001 FY." *Minor Planet Bull.* **34**, 19-22.
- Fauvaud, S., Fauvaud, M. (2013). "Photometry of Minor Planets. I. Rotation Periods from Lightcurve Analysis for Seven Main-belt Asteroids." *Minor Planet Bull.* **40**, 224-229.
- Franco (2012). Balzoretto Observatory web site.
http://digilander.libero.it/A81_Observatory
- Fuller, K., Sanchez, C., Montgomery, K. (2019). "Rotational Periods and Lightcurves of Four Asteroids." *Minor Planet Bull.* **43**, 1-2.
- 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. (1989). "Asteroid lightcurve observations from 1979-1981." *Icarus*, **81**, 314.

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.

Kozdon, J., Cantue, S., Montgomery, K. (2016). "Lightcurves of Asteroids 891 Gunhild and 1614 Goldschmidt." *Minor Planet Bull.* **43**, 171-172.

Mollica, M., Noschese, A., Vecchione, A. (2019), "Lightcurve Analysis and Rotation Period for 5321 Jagras." *Minor Planet Bull.* **46**, 206-207.

Muñoz, J.L., Evans, D.W. (2014). "The CMC15, the last issue of the series Carlsberg Meridian Catalogue, La Palma." *Astron. Nach.* **335**, 367.

Munari, U., Henden, A., Frigo, A., Zwitter, T., Bienayme, O., Bland-Hawthorn, J., Boeche, C., Freeman, K.C., Gibson, B.K., Gilmore, G., Grebel, E.K., Helmi, A., Kordopatis, G., Levina, S.E., and 13 coauthors. (2015). "APASS Landolt-Sloan BVgri photometry of RAVE stars. I. Data, effective temperatures, and reddening." *Astron. J.*, **148**, 81.

Papini, R., Banfi, M., Salvaggio, F., Marchini, M., Franco, L. (2019). "Rotation Period Determination of the Asteroid 5321 Jagras (1985 VN)." *Minor Planet Bull.* **46**, 218-219.

Pravec, P., Wolf, M., Sarounova, L. (2018, 2019). <http://www.asu.cas.cz/~ppravec/neo.htm>

Robinson, L. (2011). <http://btboar.tripod.com/lightcurves>

Slyusarev, I.G., Shevchenko, V.G., Belskaya, I.N., Krugly, Yu.N., Chiorny, V.G. (2012). *ACM 2012*, #6398.

Stephens, R.D., Warner, B.D. (2019). "Main-belt Asteroids Observed from CS3: 2019 January - March." *Minor Planet Bull.* **46**, 298-301 (this issue).

Warell, J. (2015). "Lightcurve Observations of 1614 Goldschmidt." *Minor Planet Bull.* **42**, 21-22.

Warner, B. (2005). "Asteroid lightcurve analysis at the Palmer Divide Observatory - spring 2005." *Minor Planet Bull.* **32**, 90-92.

Warner, B.D. (2011). Collaborative Asteroid Lightcurve Link website. <http://www.minorplanet.info/call.html>

Warner, B.D. (2019). *MPO Canopus* software. <http://bdwpublishing.com>

Warner, B.D., Harris, A.W., Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2019 Mar. <http://www.minorplanet.info/lightcurvedatabase.html>

Warner, B.D., Stephens, R.D. (2019a). "Near-Earth Asteroid Lightcurve Analysis at the Center for Solar System Studies: 2018 September-December." *Minor Planet Bull.* **46**, 144-152.

Warner, B.D., Stephens, R.D. (2019b). "Near-Earth Asteroid Lightcurve Analysis at the Center for Solar System Studies: 2019 January-April." *Minor Planet Bull.* **46**, 304-314 (this issue).

Waszczak, A., Chang, C.-K., Ofek, E.O., Laher, R., Masci, F., Levitan, D., Surace, J., Cheng, Y.-C., Ip, W.-H., Kinoshita, D., Helou, G., Prince, T.A., Kulkarni, S. (2015). "Asteroid Light Curves from the Palomar Transient Factory Survey: Rotation Periods and Phase Functions from Sparse Photometry." *Astron. J.* **150**, A75.

A RE-EVALUATION OF ASTEROID 4181 KIVI

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Asteroid 4181 Kivi was reported by the author (Rowe, 2019) as having a rotational period of 89.1 h and a monomodal lightcurve; this was incorrect. The reported period should be 178.2 h.

The 89.1 h period reported for 4181 Kivi was based on a similar split halves plot for the 178 h period. However, Tom Polakis (private communication) called attention to the fact that it is almost impossible to have a monomodal lightcurve with an amplitude greater than 0.3 mag at low to moderate phase angles (Harris et al., 2014). The reported amplitude for the 89.1 h period was 0.77 mag.

Using a 4th order solution with the same data points gives the revised plot shown here. The author was aware of the magnitude limit for monomodal lightcurves but forgot it in the analysis. Many thanks to Tom Polakis for pointing this out.

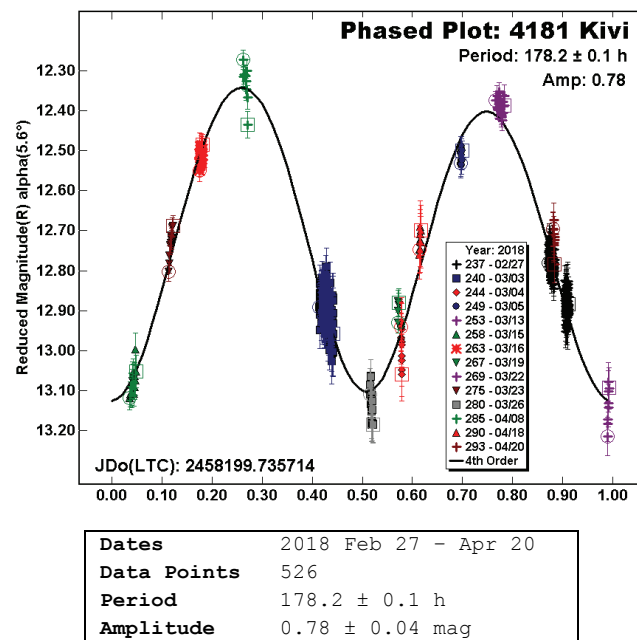


Table I. Revised results for 4181 Kivi. See Table I in Rowe (2019) for the full set of observing circumstances.

References

Harris, A.W., Pravec, P., Galad, A., Skiff, B.A., Warner, B.D., Vilagi, J., Gajdos, S., Carbognani, A., Hornoch, K., Kusnirak, P., Cooney, W.R., Gross, J., Terrell, D., Higgins, D., Bowell, E., Koehn, B.W. (2014). "On the maximum amplitude of harmonics on an asteroid lightcurve." *Icarus* **235**, 55-59.

Rowe, B. (2019). "Lightcurve Analysis of 6 Asteroids from RMS Observatory." *Minor Planet Bull.* **46**, 92-94.