

PHOTOMETRY AND LIGHTCURVE ANALYSIS OF 26 ASTEROIDS

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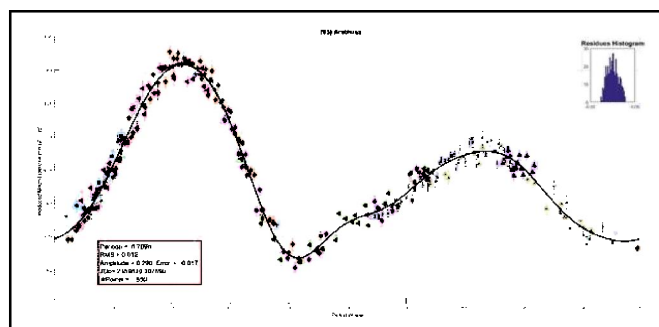
Based on observations from 2022 January to 2023 September, lightcurves and rotation periods were found for 95 Arethusa (8.705 h), 164 Eva (13.687 h), 303 Josephina (12.454 h), 310 Margarita (12.608 h), 624 Hektor (6.920 h), 631 Philippina (5.899 h), 751 Faina (23.667 h), 771 Libera (5.890 h), 841 Arabella (3.138 h), 885 Ulrique (4.893 h), 904 Rockefeller (5.022 h), 911 Agamemnon (6.592 h), 964 Subamara (6.867 h), 1511 Dalera (3.881 h), 1523 Piekasamaki (5.321 h), 1589 Fanatica (2.580 h), 2004 Lexell (5.442 h), 2965 Surikov (9.076 h), 3223 Forsius (2.460 h), 3698 Manning (3.062 h), 3710 Bogoslovskij (8.014 h), 4253 Marker (2.397 h), 6137 Johnfletcher (6.932 h), 6147 Straub (10.304 h), 9628 Sendaiotsuna (2.674 h), and (98943) 2001 CC21 (5.023 h).

In many cases, analysis of the data we obtained for the rotation periods of 26 asteroids are in good agreement with those previously published in the literature. However, the shape and amplitudes of

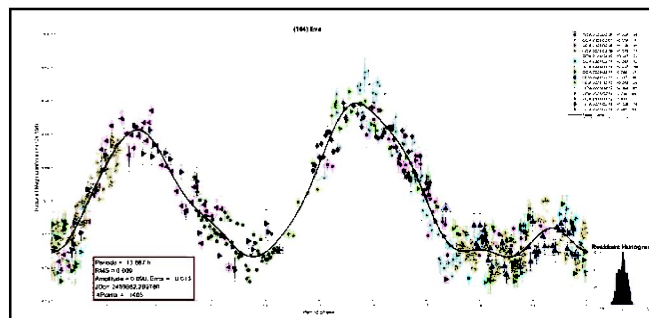
the lightcurve were often different because the observations were at different phase angles. We were not able to find a rotation period for 3710 Bogoslovskij, 4523 Marker, 6137 Johnfletcher, 6147 Straub, or 9628 Sendaiotsuna.

All observations reported here were unfiltered. The images were calibrated in the standard way (bias, darks and flats). Images were measured, and periods analysis were done using *FotoDif* (Castellano, 2021) *Tycho Tracker* (Parrott, 2022) and *Periodos* (Mazzone, 2020) packages. All data were light-time corrected. The results are summarized below. Individual lightcurve plots along with additional comments as required are also presented.

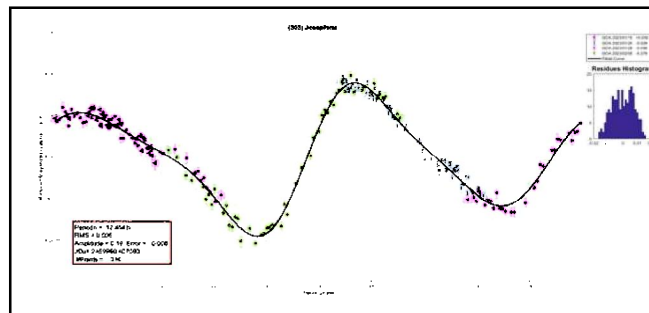
95 *Arethusa* was previously studied by, among others, Alton (2013) in 2012. Our result of 8.705 h, based on observations in 2022 October–November, confirm Alton's period of 8.705 h. Our lightcurve amplitude is 0.32 ± 0.03 mag.



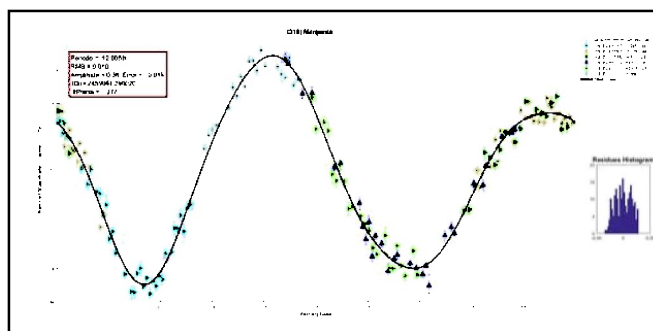
164 *Eva*. There are several previous results. For example, Behrend (2016web) who found a period of 13.660 h. The shape of our lightcurve is different from Behrend's, but our period is in good agreement with his. Our data, were obtained during the first half of 2023 February, gave a rotation period of 13.687 ± 0.009 hours and an amplitude of 0.09 ± 0.02 mag.



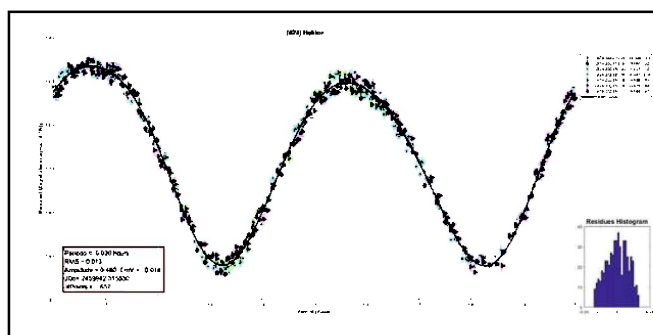
303 *Josephina*. Discovered in 1891 February at the Collegio Romano observatory in Rome, Italy, the rotation period we found is 12.454 ± 0.006 hours with an amplitude of 0.19 ± 0.01 mag.



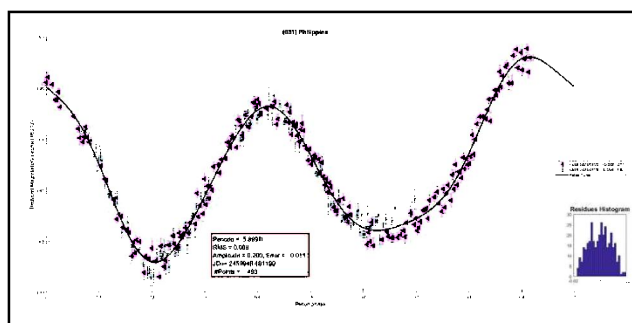
310 Margarita. Pilcher and Oey (2010) found a period of 12.070 h based on observations in 2010. Given that more than a decade had passed, we thought that an update was appropriate. Our data yielded a period of 12.068 ± 0.010 h, as previously published, and an amplitude of 0.36 ± 0.02 mag. The different lightcurve shape and amplitude from Pilcher and Oey (2010) were as expected.



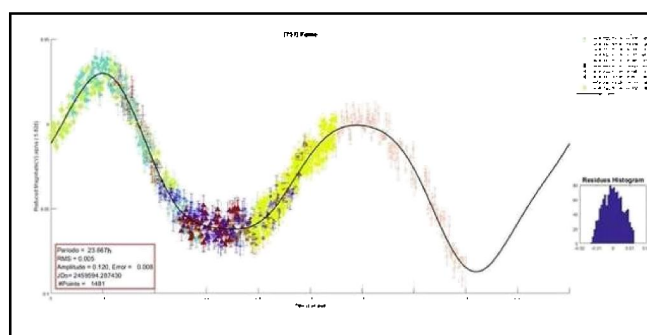
624 Hektor. The latest published reference in the LCDB for this Jupiter Trojan dates back to 2022 (Stephens and Warner, 2022), who proposed a period of 6.923 hours. Our data set of 657 points led to a very similar result of 6.920 ± 0.013 h. The lightcurve amplitude is 0.46 ± 0.02 mag.



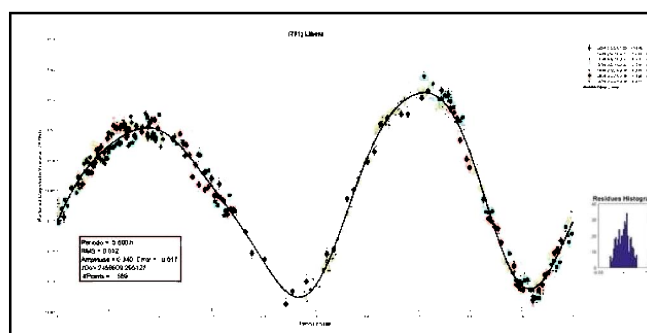
631 Philippina. For this main-belt asteroid, discovered in 1907 from Germany, we obtained results very much in line with those recently published from the Geneva observatory by Behrend (2020web). Our results were a period of 5.899 ± 0.008 hours and an amplitude of 0.20 ± 0.01 mag. There is a 3-D model from Hanuš et al. (2013) found in the DAMIT database (Durech and Jovtech, 2023).



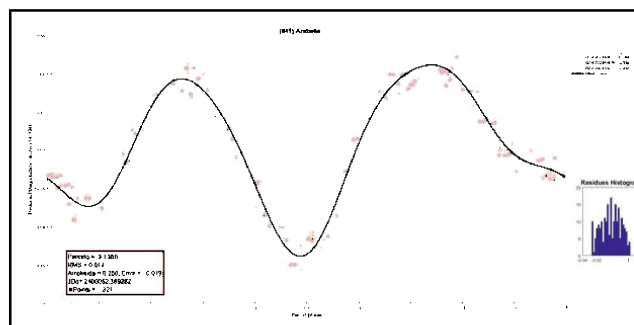
751 Faina. According to the data we obtained for this asteroid, its rotation period is 23.667 ± 0.005 hours with an amplitude of 0.12 ± 0.01 mag. Miles (1989) found almost exactly the same period. Behrend (2019web) reported a period that is one-half of ours.



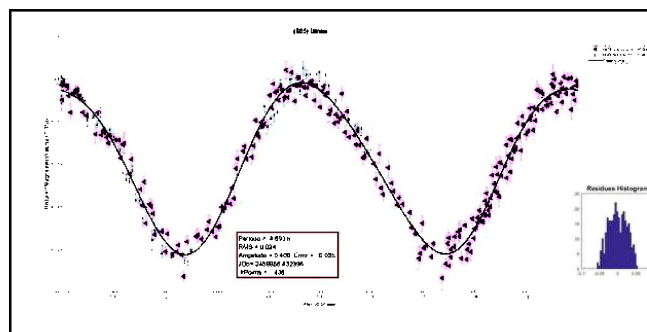
771 Libera. Our lightcurve of 569 points for this asteroid allowed us to conclude a rotation period of 5.890 ± 0.012 hours and an amplitude of 0.34 ± 0.02 mag.



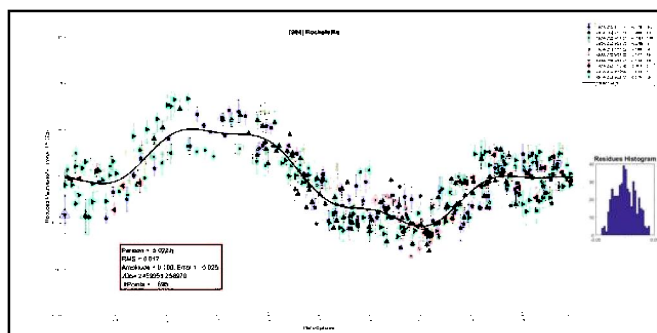
841 Arabella. Our rotation period of 3.138 ± 0.014 h is within 0.002 h of the period reported by Stephens and Warner (2019). Our lightcurve has an amplitude of 0.25 ± 0.02 mag, or about 0.07 smaller than from Stephens and Warner (2019).



885 Ulrike. Our lightcurve for this asteroid had a total of 436 points, which allowed us to deduce a rotation period of 4.893 ± 0.024 hours and an amplitude of 0.40 ± 0.04 mag. Behrend (2020web) found a period of 4.90567 hours, making the two consistent within the error bars.

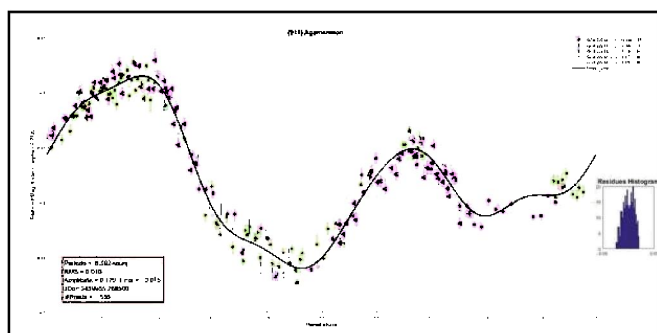


904 Rockefeller is a main-belt asteroid that was discovered on 1918 October 29 by Maximilian Franz Wolf from the observatory of Heidelberg-Königstuhl, Germany. We found a rotation period of 5.022 ± 0.017 hours and an amplitude of 0.10 ± 0.03 mag. Colazo et al. (2013) found a period of 6.823 h. The two periods have a close to 4:3 ratio, which suggests the possibility is an alias of the other.

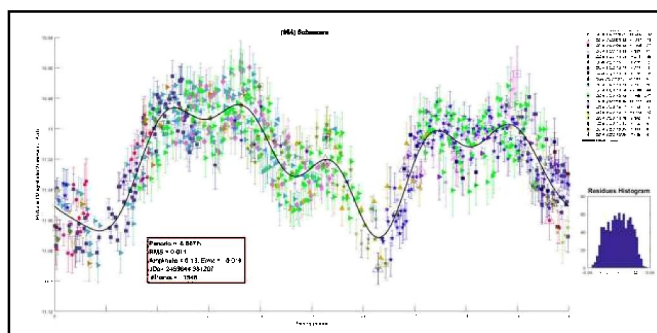


911 Agamemnon is a Trojan asteroid about 170 km in diameter. Its lightcurve and period were studied in 2021 by Stephens and Warner (2021). Our period and theirs of 6.582 hours are in good agreement. Using a data set of 550 points, we found a period of 6.592 ± 0.010 hours and amplitude of 0.17 ± 0.02 mag.

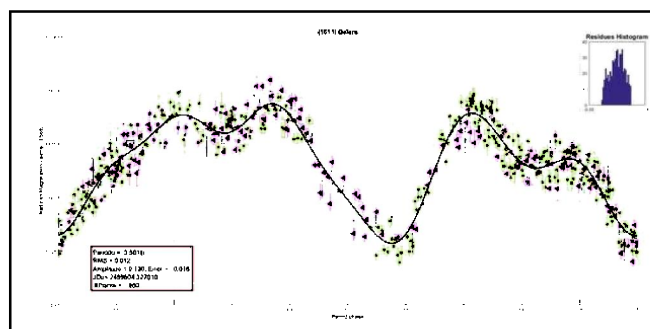
Other studies carried out by Diez Alonso et al. (2023) from the University of Oviedo (ICTEA, Spain) in 2023 suggest that the asteroid may be a binary.



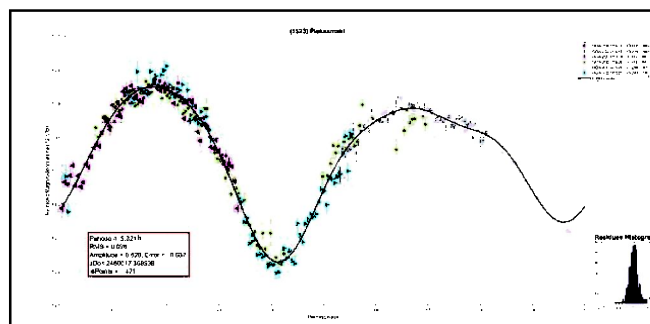
964 Subamara. There are not many references to this asteroid in the specialized literature. The most recent one in the LCDB is from Polakis (2018), who found a period of 6.8695 h. Our results are similar to his. We found a period of 6.867 ± 0.011 hours and an amplitude of 0.13 ± 0.02 mag. There is no 3-D model on DAMIT.



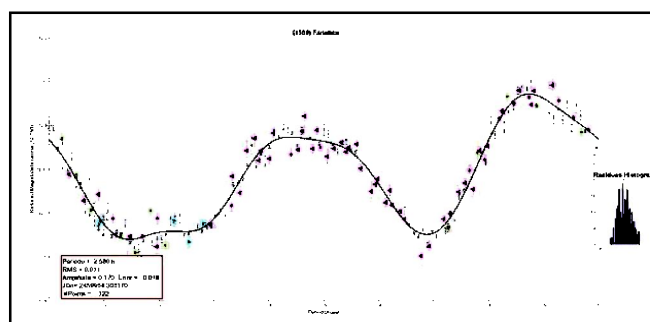
1511 Dalera. The data obtained for this asteroid allowed us to deduce a rotation period of 3.881 ± 0.012 hours, which is in accordance with a sidereal period published by Durech et al. (2020). The lightcurve amplitude is 0.13 ± 0.02 mag.



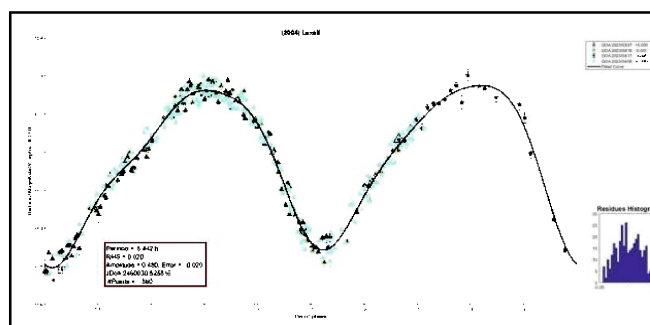
1523 Piekasakki. Our lightcurve is based on 471 points and has a synodic period 5.321 ± 0.026 hours; its amplitude is 0.52 ± 0.04 mag. Other recent results are from Stephens and Warner (2019; 5.326 h) and Franco et al. (2023; 5.3210 h).



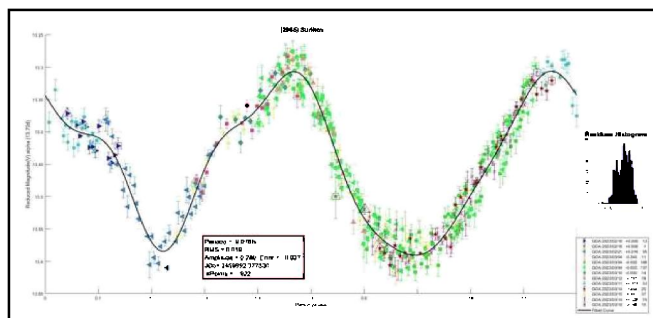
1589 Fanatica. We were able to observe this asteroid in both 2020 and 2023. The results obtained for its rotation period are in agreement with those previously published by Stephens and Warner (2020). We obtained a period of 2.580 ± 0.011 hours and amplitude of 0.17 ± 0.02 mag.



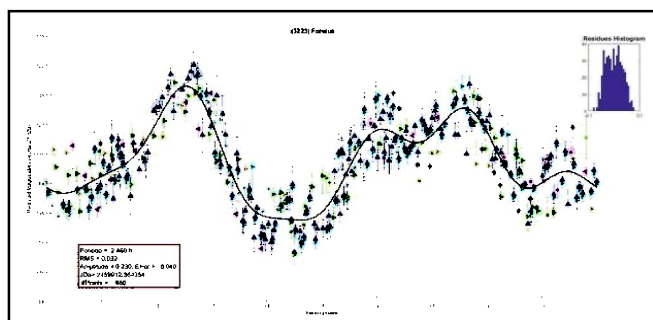
2004 Lexell. The data we obtained for this asteroid in 2023 March and April allowed us to deduce a rotation period of 5.442 ± 0.020 hours with a lightcurve amplitude of 0.48 ± 0.03 mag.



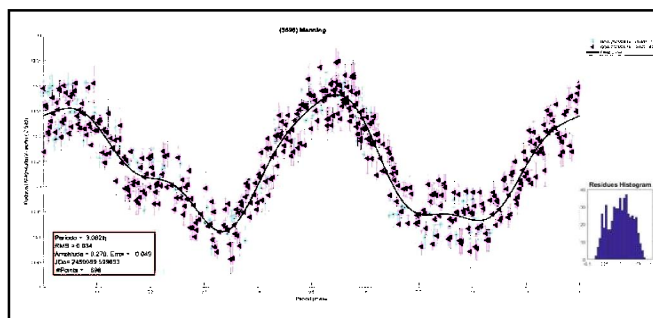
2965 Surikov. Provisionally designated as 1975 BX, this asteroid was discovered in 1975 January by Liudmila Chernyj at the Crimean Astrophysical Observatory. Our rotation period is 9.076 ± 0.019 hours and the amplitude is 0.28 ± 0.03 mag.



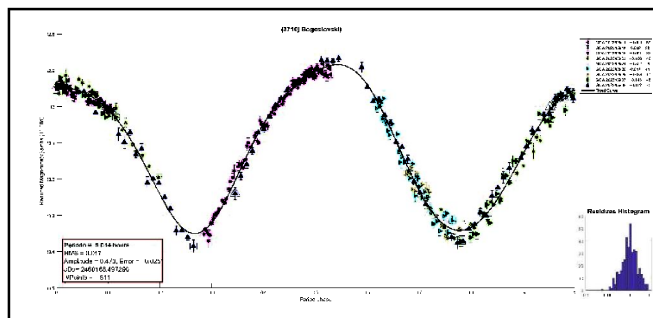
3223 Forsius. The most recent data on this asteroid found in the literature are from (Liu, 2006). Those results are in good agreement our period period of 2.460 ± 0.032 hours. The lightcurve amplitude is 0.23 ± 0.05 mag.



3698 Manning. According to our data, Manning is a fast rotator with $P = 3.062 \pm 0.034$ h with a lightcurve amplitude of 0.27 ± 0.05 mag.

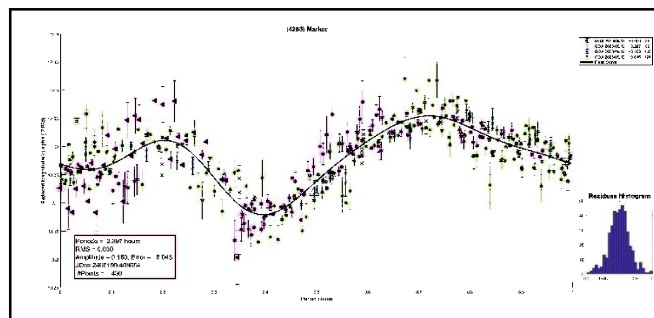


3710 Bogoslovskij. We found no previously reported period for this asteroid, which was discovered on 1978 September 13 by N.S. Chernykh from the Crimean Astrophysical Observatory.



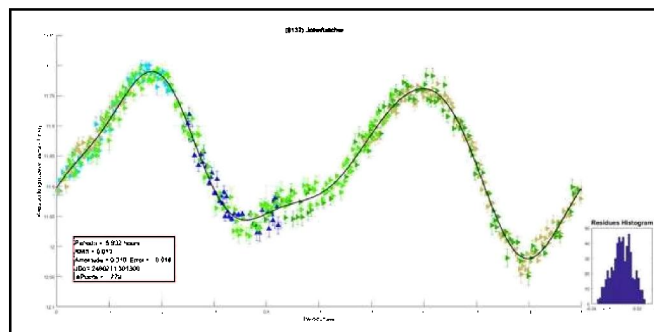
Our studies went from 2023 August to September. The lightcurve with 511 points has a period of 8.014 ± 0.017 hours and amplitude of 0.47 ± 0.03 mag.

4253 Marker. This main-belt asteroid, discovered on 1985 October 11 Carolyn Shoemaker from the Mount Palomar Observatory. Our study of this asteroid was carried out in 2023 September. The result was a short rotation period of 2.397 ± 0.030 hours and amplitude of 0.18 ± 0.04 mag.

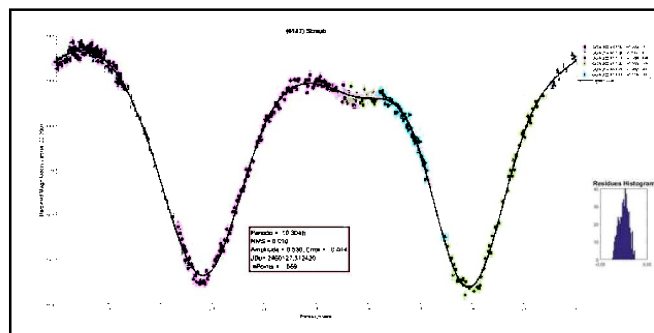


6137 Johnfletcher. We did not find a published period or lightcurve for this 31-km main-belt asteroid. Initially designated 1991 BY, it was discovered on 1991 January 25 by Akira Natori and Takeshi Urata, from Yakiimo Station, Shimizu-ku, in Japan.

Our team of asteroid observers (GOAS) carried out the study of this object in 2023 September, obtaining a result of 6.932 ± 0.013 hours for its rotation period and an amplitude of 0.31 ± 0.02 mag.



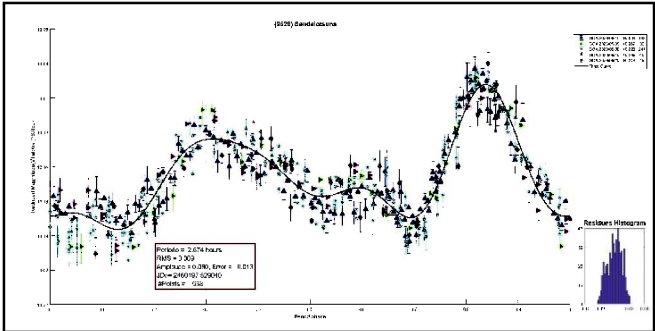
6147 Straub. Our observations of this asteroid were made in 2023 July and August. The data led to a rotation period of 10.304 ± 0.010 hours and amplitude of 0.53 ± 0.02 mag. Behrend (2023web) reported a period of 10.9 ± 0.1 h.



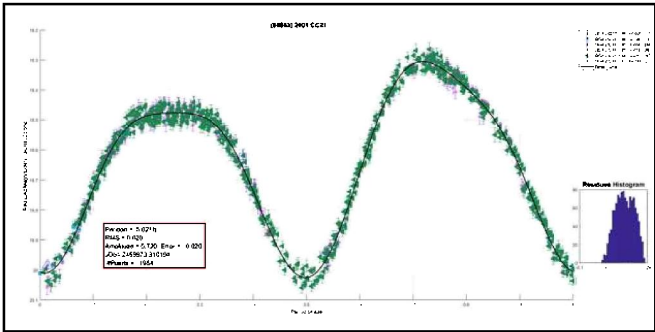
Number	Asteroid	20yy mm/dd	Phase	Period(h)	P.E.	Amp	A.E.
95	Arethusa	22/10/17-11/25	20.0-20.2	8.705	0.012	0.320	0.017
164	Eva	23/02/06-02/14	24.5-24.9	13.687	0.009	0.090	0.013
303	Josephina	23/01/15-02/05	02.9-09.4	12.454	0.006	0.190	0.008
310	Margarita	23/01/02-02/05	01.5-13.7	12.068	0.010	0.360	0.015
624	Hektor	22/12/28-01/11	04.2-06.5	6.920	0.013	0.460	0.018
631	Philippina	23/01/03-01/05	18.3-17.9	5.899	0.008	0.200	0.011
751	Faina	22/01/18-02/06	05.8-18.3	23.667	0.005	0.120	0.008
771	Libera	22/08/12-08/27	06.8-04.8	5.890	0.012	0.340	0.017
841	Arabella	23/04/17-04/18	15.3-15.7	3.138	0.014	0.250	0.019
885	Ulrike	23/02/12-02/12	17.7-17.7	4.893	0.024	0.400	0.035
904	Rockefelia	23/01/10-01/22	13.1-16.0	5.022	0.017	0.100	0.025
911	Agamemnon	23/01/10-01/14	07.8-08.3	6.592	0.010	0.170	0.015
964	Subamara	22/09/21-10/06	08.7-06.9	6.867	0.011	0.130	0.016
1511	Dalera	22/01/04-01/31	05.3-02.3	3.881	0.012	0.130	0.018
1523	Pieksamaki	23/03/14-03/27	13.0-18.0	5.321	0.026	0.520	0.037
1589	Fanatica	23/01/09-01/14	12.1-14.2	2.580	0.011	0.170	0.016
2004	Lexell	23/03/27-04/17	04.0-07.4	5.442	0.031	0.500	0.045
2965	Surikov	23/02/16-03/19	13.6-26.2	9.076	0.019	0.280	0.027
3223	Forsius	22/11/26-23/01/05	21.5-23.0	2.460	0.032	0.230	0.046
3698	Manning	23/02/13-02/14	02.8-02.4	3.062	0.034	0.270	0.049
3710	Bogoslovskij	23/08/11-09/08	11.4-08.8	8.014	0.017	0.470	0.025
4253	Marker	23/09/11-09/13	03.0-02.1	2.397	0.030	0.180	0.043
6137	Johnfletcher	23/09/23-09/30	07.8-06.0	6.932	0.013	0.310	0.018
6147	Straub	23/07/01-07/30	22.4-13.9	10.304	0.010	0.530	0.014
9628	Sendaitsuna	23/09/09-09/10	18.1-17.8	2.674	0.009	0.080	0.013
98943	2001 CC21	23/01/29-02/01	24.5-27.5	5.020	0.026	0.710	0.037

Table I. Observing circumstances and results. Phase is the solar phase angle given at the start and end of the date range. If preceded by an asterisk, the phase angle reached an extrema during the period.

9628 Sendaitsuna. The estimated diameter is 8.45 km based on $H=12.42$. There were no rotation periods found in the LCDB. Our study was carried out during 2023 September. Data analysis of 668 points found a rotation period 2.674 ± 0.009 hours and an amplitude of 0.08 ± 0.02 mag.



(98943) 2001 CC21. We studied this asteroid in 2023 January and February. Pravec et al. (2022web) reported 5.0247 h while Warner (2023) found 5.0159 h. Our rotation period 5.021 ± 0.020 hours is in good agreement with theirs. The lightcurve amplitude is 0.72 ± 0.02 mag, which is the smallest of the three results.



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PHOTOMETRIC OBSERVATIONS AND ROTATION PERIOD DETERMINATION FOR 14 MINOR PLANETS

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Photometric measurements of fourteen main-belt asteroids were conducted from 2023 September through 2023 November. Phased lightcurves and rotation periods for each one are presented here. Six of the asteroids have no prior published period solutions. All lightcurve data has been submitted to the ALCDEF database.

CCD observations of fourteen main-belt asteroids were performed at NAC Observatory (MPC U98) in Benson, AZ. Images were taken using a 0.35m f/4.7 Corrected Dall-Kirkham telescope. Images were captured using an SBIG CCD47-10 CCD camera. It utilizes a back-illuminated Teledyne E2V CCD47-10 AIMO sensor and is operated at 1×1 binning with a scale of 1.60 arc seconds per pixel. Table I shows observing circumstances and results. All images for these observations were obtained between 2023 September and 2023 November.

Data reduction and period analysis were done using *Tycho* (Parrott, 2023). The CCD camera provides a 27'×27' field of view. The asteroid and five or more 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.

Comparison star magnitudes were obtained from the ATLAS catalog (Tonry et al., 2018), which is incorporated directly into *Tycho*. 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. The measuring aperture diameter for asteroids and comp stars was set to a value equal to the average FWHM of the session data set multiplied by four. Interference from field stars necessitated the exclusion of affected observations. Period determination was done using *Tycho*.

Asteroids were selected from the CALL website (Warner, 2011), either for having uncertain periods ($U \leq 2$) or no reported period at all. In this set of observations, six of the fourteen asteroids had no previous period analysis listed. The Asteroid Lightcurve Database (LCDB; Warner et al., 2009) was consulted to locate previously published results. All new data for these asteroids has been submitted to the ALCDEF database.

1109 Tata is a Hygiea family asteroid with two reported periods in the LCDB. Behrend (2005web) reported a period of 8.277 ± 0.002 h and Polakis (2020) reported a differing period of 55.50 ± 0.12 h. During this apparition 402 observations were made over six nights in 2023 September. The best period fit 33.03 ± 0.01 h with an amplitude of 0.102 ± 0.011 mag. This result disagrees with those of both Behrend and Polakis.