

LIGHTCURVES AND SYNODIC ROTATION PERIODS FOR 30 ASTEROIDS FROM SOPOT ASTRONOMICAL OBSERVATORY: 2023 APRIL – DECEMBER

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The results of lightcurve and synodic rotation period determinations for 30 asteroids obtained from CCD photometric observations carried out at the Sopot Astronomical Observatory in the time span 2023 April - December are summarized in this paper.

Photometric observations of 30 asteroids were conducted at Sopot Astronomical Observatory (SAO) from 2023 April through 2023 December in order to determine the asteroids' synodic rotation periods. For this purpose, two 0.35-m $f/6.3$ Meade LX200GPS Schmidt-Cassegrain telescopes were employed. The telescopes are equipped with a SBIG ST-8 XME and a SBIG ST-10 XME CCD cameras. The exposures were unfiltered and unguided for all targets. Both cameras were operated in 2×2 binning mode, which produces image scales of 1.66 arcsec/pixel and 1.25 arcsec/pixel for ST-8 XME and ST-10 XME cameras, respectively. Prior to measurements, all images were corrected using dark and flat field frames.

Photometric reduction was conducted using *MPO Canopus* (Warner, 2018). Differential photometry with up to five comparison stars of near solar color ($0.5 \leq B-V \leq 0.9$) was performed using the Comparison Star Selector (CSS) utility. This helped ensure a satisfactory quality level of night-to-night zero-point calibrations and correlation of the measurements within the standard magnitude framework. Field comparison stars were calibrated using standard Cousins R magnitudes derived from the Carlsberg Meridian Catalog 15 (VizieR, 2022) Sloan r' magnitudes using the formula: $R = r' - 0.22$ in all cases presented in this paper. In some instances, small zero-point adjustments were necessary in order to achieve the best match between individual data sets in terms of achieving the most favorable statistical indicators of Fourier fit goodness.

Lightcurve construction and period analysis was performed using *Perfindia* custom-made software developed in the R statistical programming language (R Core Team, 2020) by the author of this paper. The essence of its algorithm is reflected in finding the most favorable solution for rotational period by minimizing the *residual standard error* of the lightcurve Fourier fit.

The lightcurve plots presented in this paper show so-called 2% error for rotational periods, i.e. an error that would cause the last data point in a combined data set by date order to be shifted by 2% (Warner, 2012) and represented by the following formula:

$$\Delta P = (0.02 \cdot P^2) / T$$

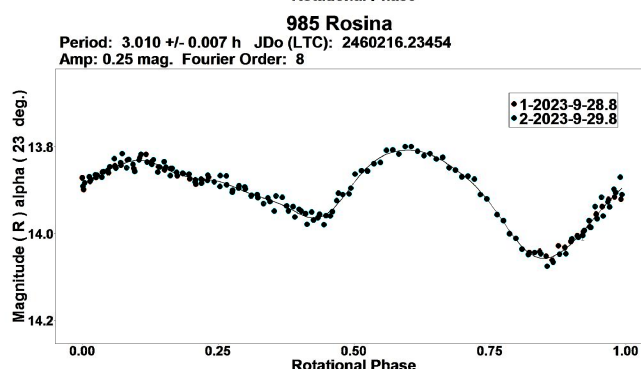
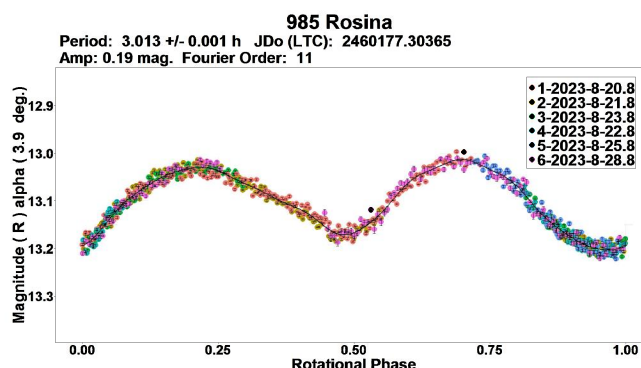
where P and T are the rotational period and the total time span of observations, respectively. Both of these quantities must be expressed in the same units.

Some of the targets presented in this paper were observed within the Photometric Survey for Asynchronous Binary Asteroids (*BinAstPhot Survey*) under the leadership of Dr Petr Pravec from Ondřejov Observatory, Czech Republic.

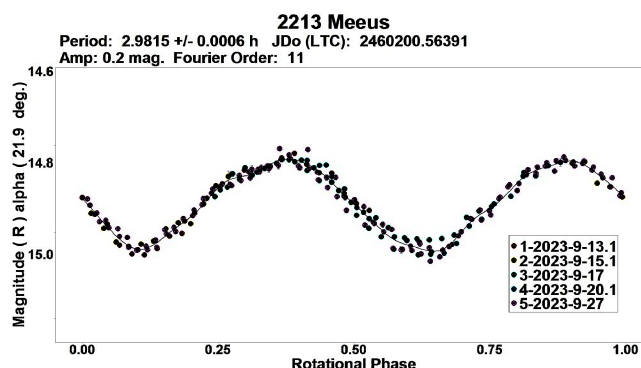
Table I gives the observing circumstances and results summary.

Observations and Results

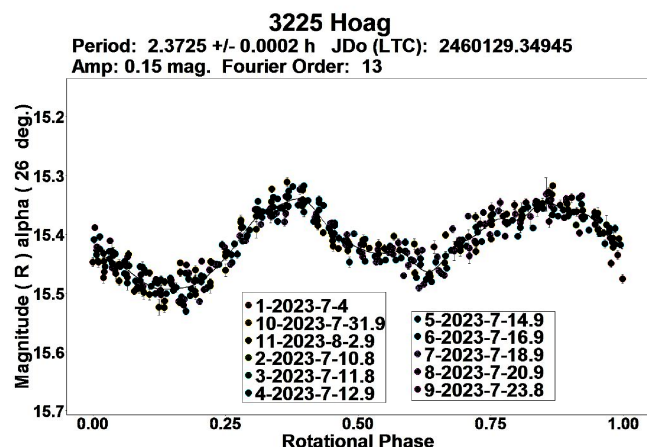
985 Rosina. According to the Asteroid Lightcurve Database (LCDB; Warner et al., 2009) several results for this Mars-crossing asteroid were obtained from the year 2002 onwards. Some of these are as follows: 3.0126 h (Behrend, 2002web), 3.012 h (Martinez et al., 2010), 3.015 h (Skiff et al., 2019), 3.01263 h (Pál et al., 2020). These previous results are in very good agreement with the newly found rotation period values from the SAO observations performed in two different viewing geometries, and therefore established from two separate lightcurves. A period value of $P = 3.013 \pm 0.001$ h was found from the first dataset obtained over 6 nights in late 2023 August, while the second dataset acquired in late 2023 September gave a fairly similar value of $P = 3.010 \pm 0.007$ h.



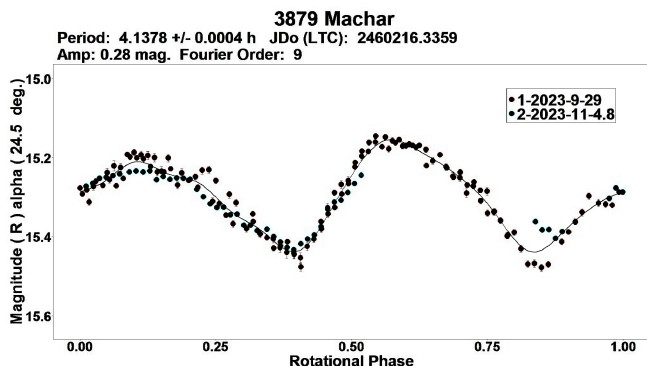
2213 Meeus. A period of $P = 2.9815 \pm 0.0006$ h determined from the dense photometric data obtained at SAO on 5 nights in 2023 September differs somewhat from the only previously reported result by Tomassini et al. (2014, 2.651 h), which is established from a highly scattered combined dataset relating to a rotational cycle containing a gap in data coverage.



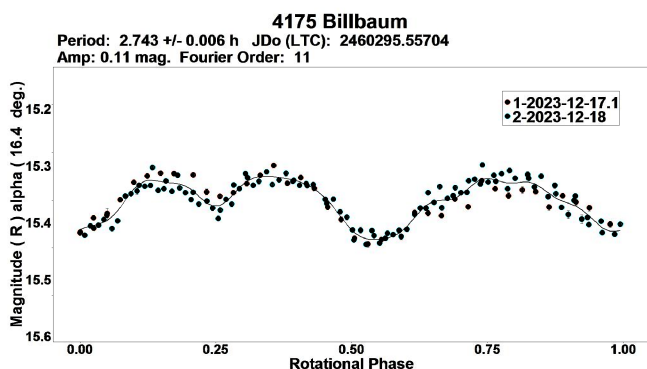
3225 Hoag. A period result of $P = 2.3725 \pm 0.0002$ h, found from the data obtained on 11 nights in 2023 July - August for this Hungaria family asteroid fits very good with the multitude of a previously found period results (in the time span 2007 - 2023) listed in the LCDB (Warner et al., 2009), which are almost all statistically equal to the value of 2.37 hours.



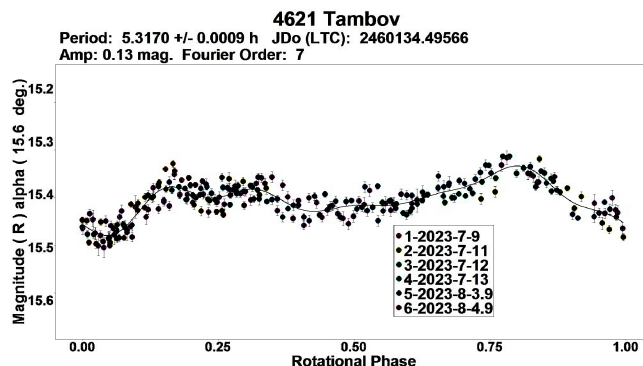
3879 Machar. Dense photometric datasets obtained in 2 temporally quite distant nights at the end of 2023 September and beginning of 2023 November show no noticeable change in the lightcurve shape and yield a bimodal rotation period result of $P = 4.1378 \pm 0.0004$ h. Some of the earlier results shown in the LCDB are: 4.131 h (Behrend, 2012web), 4.14 h (Chang et al., 2015), 4.137 h (Waszczak et al., 2015), and 4.13843 h (Pál et al., 2020).



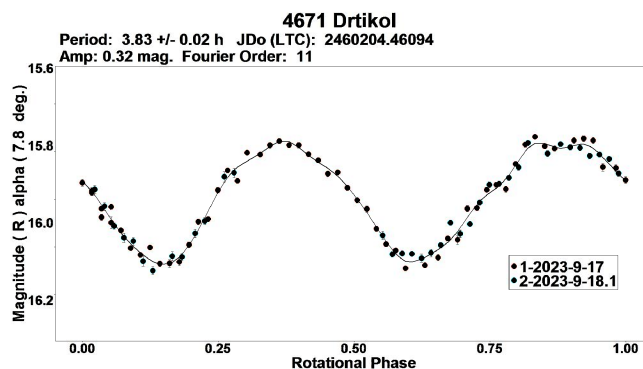
4175 Billbaum. Two consecutive nights data from 2023 December indicate a rotation period solution of $P = 2.743 \pm 0.006$ h. Two previously known periods of 2.7425 h (Ditteon and West, 2011) and 2.730 h (Megna, 2011web) agree well with the new result, but it is slightly different from the value by Aymami (2011, 2.908 h) found from the highly scattered combined dataset.



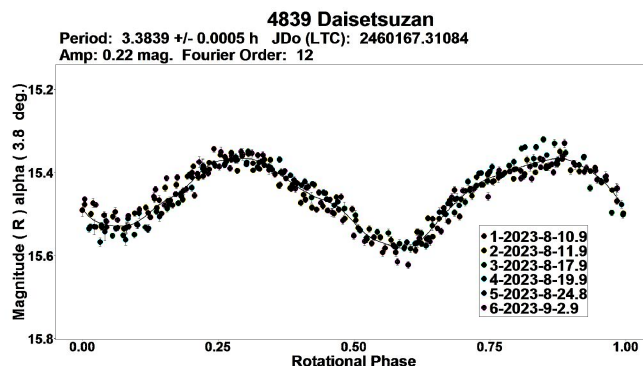
4621 Tambov. No results for previous rotation period determinations were found for this asteroid. Photometric observations carried out in 2023 July - August indicate a period of $P = 5.3170 \pm 0.0009$ h, as statistically the most favorable one.



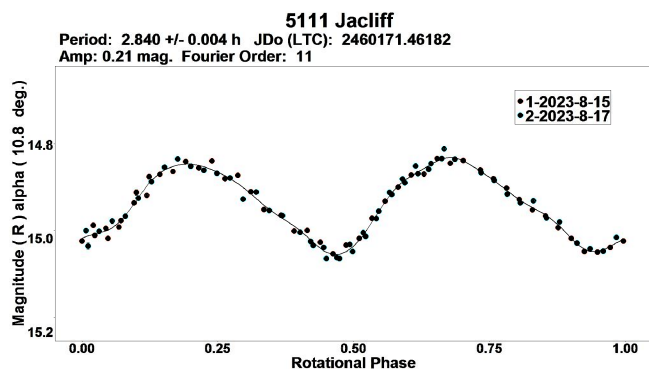
4671 Drtikol. Another asteroid without a previously known rotation period determination results. A bimodal period solution of $P = 3.83 \pm 0.02$ h results from the data obtained on two consecutive nights in 2023 September.



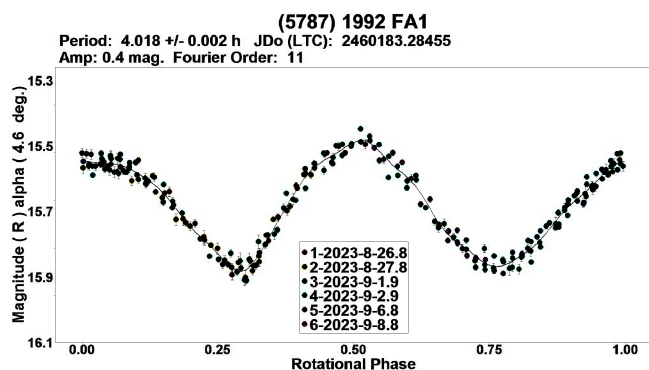
4839 Daisetsuzan. A bimodal period solution ($P = 3.3839 \pm 0.0005$ h) found from the 2023 August - September data strongly corroborates the only prior period determination by Yeh et al. (2020, 3.38 h).



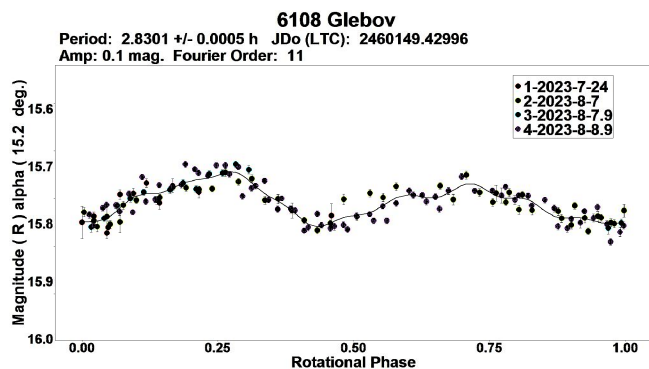
5111 Jacliff. Photometric observations performed at SAO in 2023 August show a bimodal rotation period solution of $P = 2.840 \pm 0.004$ h, which is in accordance with the previously established values listed in the LCDB (Warner et al., 2009), and all of them are in a narrow interval of 2.839 - 2.840 h.



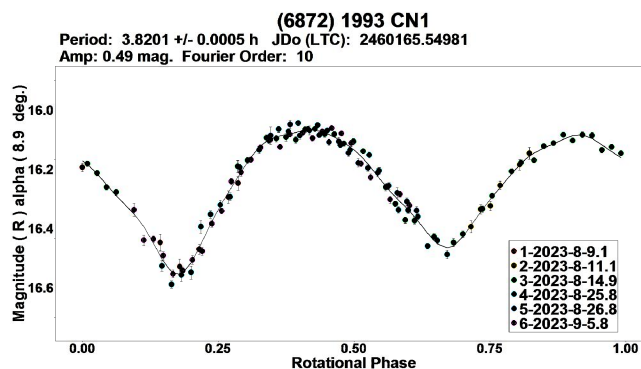
(5787) 1992 FA1. Prior results for period by Ditteon et al. (2010, 4.0176 h), Waszczak et al. (2015, 4.018 h), and Erasmus et al. (2020, 4.017 h) are well supported with the new bimodal period of $P = 4.018 \pm 0.002$ h, obtained from the SAO data collected on 6 nights in late 2023 August and early 2023 September.



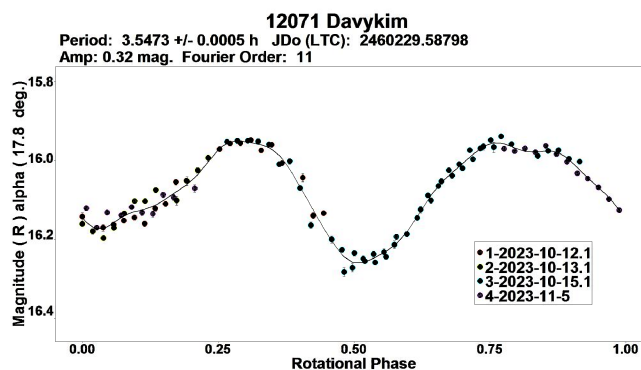
6108 Glebov. Period analysis made upon a combined dataset obtained in 2023 July - August led to an unequivocal solution for period of $P = 2.8301 \pm 0.0005$ h, which is consistent with previously known period determinations by Higgins (2011web, 2.8310 h), and Behrend (2020web, 2.85 h).



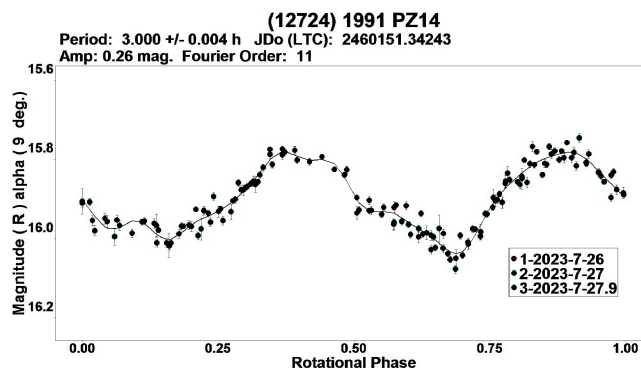
(6872) 1993 CN1. An inspection of the LCDB has not revealed any results for previous rotation period determinations. A bimodal rotational lightcurve of rather large amplitude (0.49 mag.) phased to a period of $P = 3.8201 \pm 0.0005$ h emerges as an unambiguous solution from the period analysis conducted on the dataset obtained in 2023 August - September.



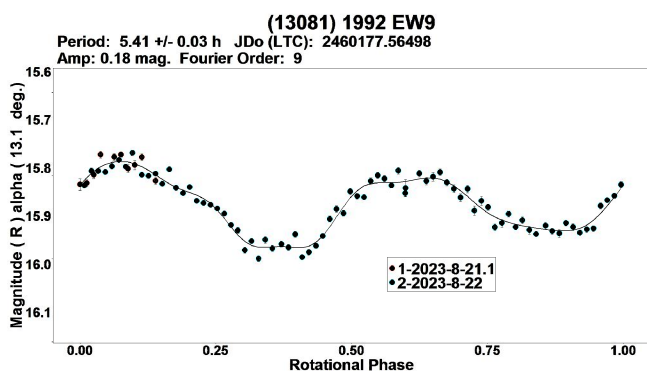
12071 Davykim. Observations conducted over 4 nights in 2023 October - November yielded a bimodal lightcurve phased to a period value of $P = 3.5473 \pm 0.0005$ h, which confirms the previous result found by Higgins (2011web, 3.5483 h).



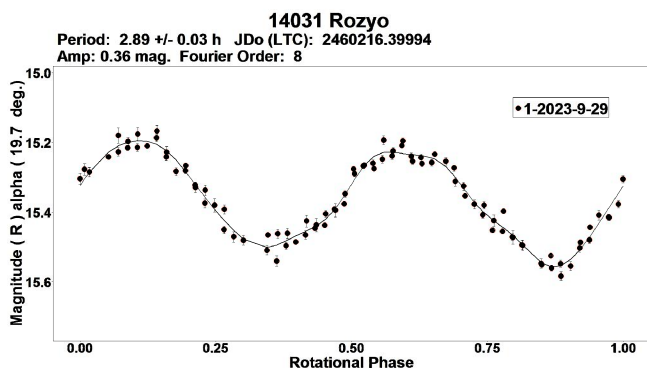
(12724) 1991 PZ14. With no prior references in the LCDB (Warner et al., 2009) this appears to be the first lightcurve and rotation period determination result for this asteroid. A bimodal period solution of $P = 3.000 \pm 0.004$ h was found from the SAO photometric data obtained on 3 consecutive nights in late 2023 July.



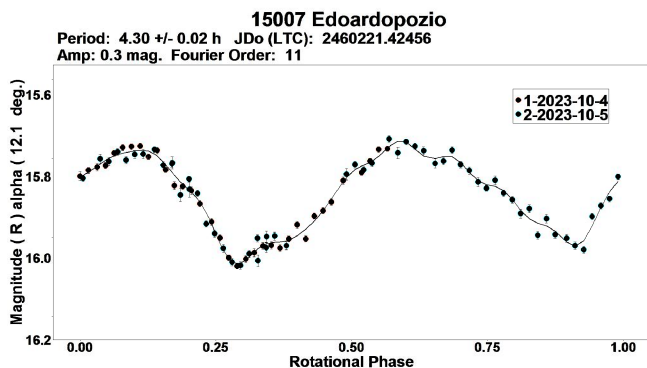
(13081) 1992 EW9. There are no LCDB records of previous lightcurve and rotation period determinations in this case as well. 2023 August data obtained over two consecutive nights reveal a bimodal period of $P = 5.41 \pm 0.03$ h as the most likely solution.



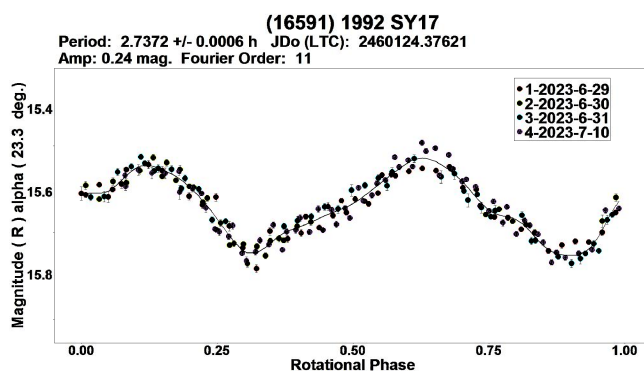
14031 Rozyo. A dense single night photometric dataset from late 2023 September indicates a bimodal rotational period of $P = 2.89 \pm 0.03$ h. Regardless of the fact that the collected amount of data may call into question reliability of the newly derived result, it matches well with the only previously derived (sidereal) rotation period by Ďurech et al. (2016, 2.900652 h).



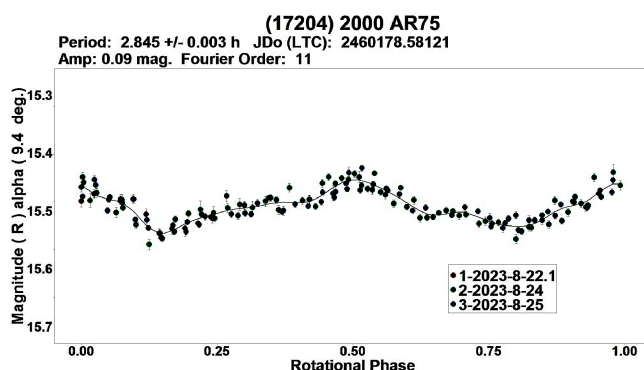
15007 Edoardopozio. Previous lightcurve and rotation period determinations are not known for this asteroid. Observations at SAO over two consecutive nights in 2023 October indicate a bimodal lightcurve phased to a period of $P = 4.30 \pm 0.02$ h as the statistically most favorable solution.



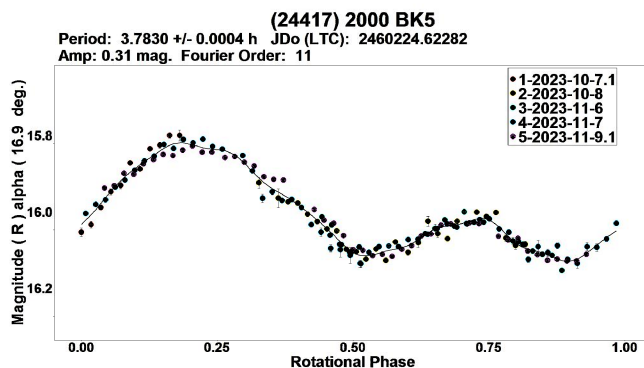
(16591) 1992 SY17. The result for rotation period of $P = 2.7372 \pm 0.0006$ h derived from the data obtained in 2023 June - July is highly consistent with the two previously found values: 2.73728 h (Pravec, 2013web) and 2.73624 h (Pál et al., 2020).



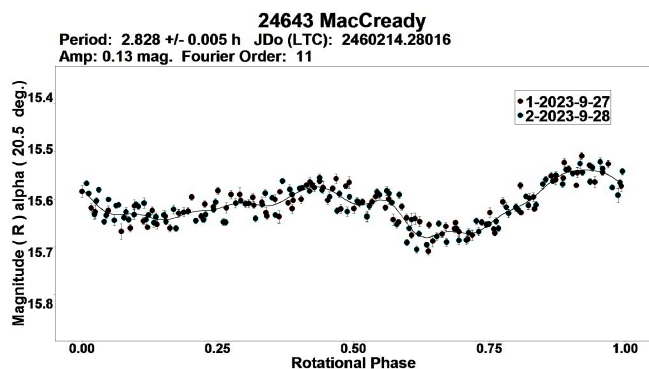
(17204) 2000 AR75. No records on previous rotation period determinations were found in the LCDB. The statistically best solution for the rotation period established from data taken on 3 nights in late 2023 August is: $P = 2.845 \pm 0.003$ h.



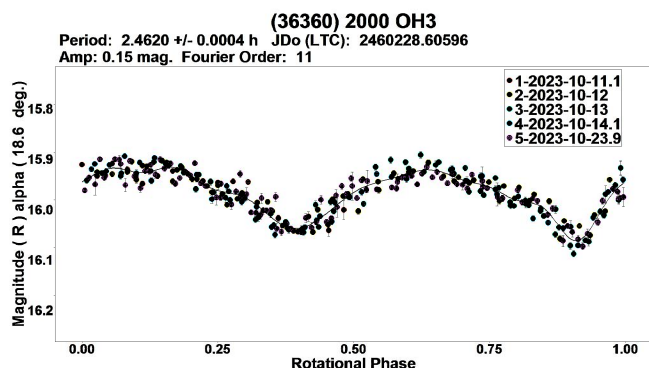
(24417) 2000 BK5. According to the LCDB records this is the first rotation period determination for this asteroid. A bimodal solution for period found from the 2023 October - November photometric data is: $P = 3.7830 \pm 0.0004$ h.



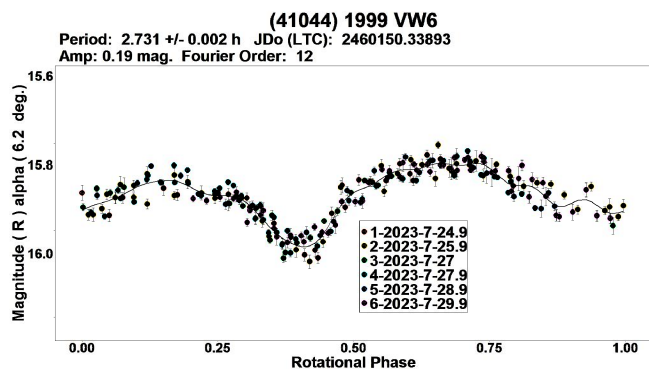
24643 MacCready. Period result ($P = 2.828 \pm 0.005$ h) obtained from observations conducted over 2 consecutive nights in late 2023 September is in very good accordance with the previous result found by Skiff et al. (2019, 2.8291 h).



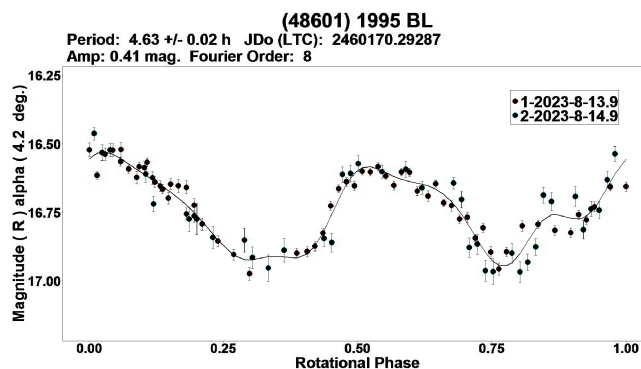
(36360) 2000 OH3. Rotation period found analyzing photometric data obtained at SAO on 5 nights in 2023 October is $P = 2.4620 \pm 0.0004$ h. The LCDB records suggest that this represents the first lightcurve and rotation period determination to date.



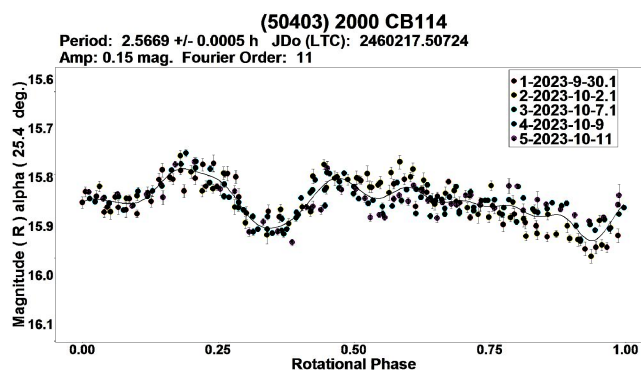
(41044) 1999 VW6. Warner (2013) found a rotation period of 2.734 h. Analysis of the SAO observations obtained in late 2023 July resulted in a very similar rotation period of $P = 2.731 \pm 0.002$ h.



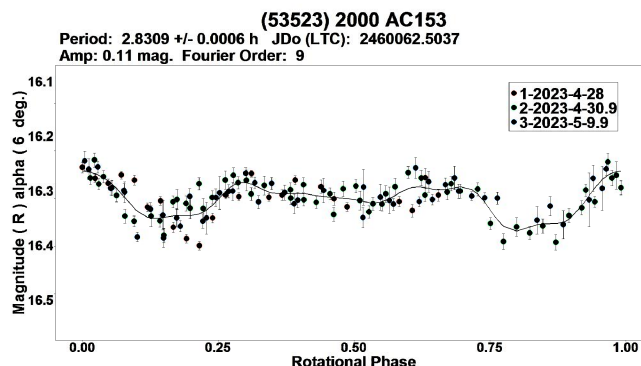
(48601) 1995 BL. In the three apparitions, during 2010, 2014, and in 2015 Warner (2011, 2014, 2016) finds the following values for the rotation period of this Hungaria family member: 4.590 h, 4.60 h, and 4.598 h, respectively. The SAO observations on two consecutive nights carried out in 2023 August at low solar phase angles led to a bimodal lightcurve of rather large amplitude (0.41 mag.) and a corresponding period value of $P = 4.63 \pm 0.02$ h.



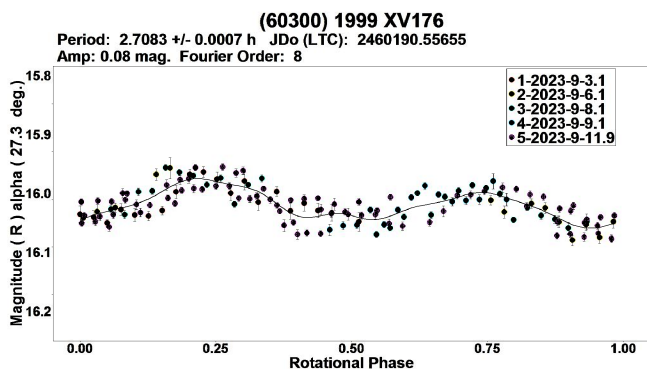
(50403) 2000 CB114. A *BinAstPhot Survey* target observed at SAO on 5 nights in 2023 September - October. A period of $P = 2.5669 \pm 0.0005$ h found from these observations is highly consistent with the period result of 2.5671 h found within the same *Survey* during the 2016 apparition.



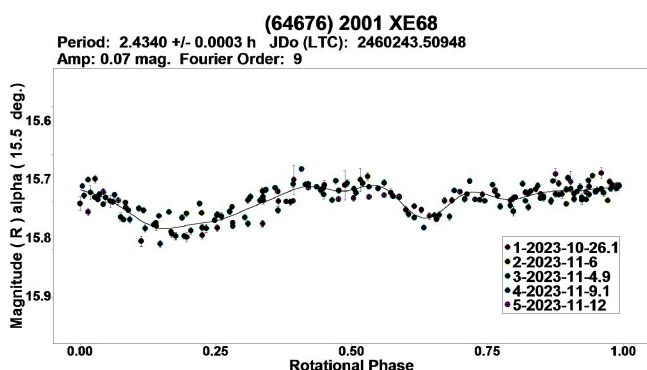
(53523) 2000 AC153. Waszczak et al. (2015) found a rotation period of 2.172 h. The 2023 April - May observations resulted in a rotation period of $P = 2.8309 \pm 0.0006$ h.



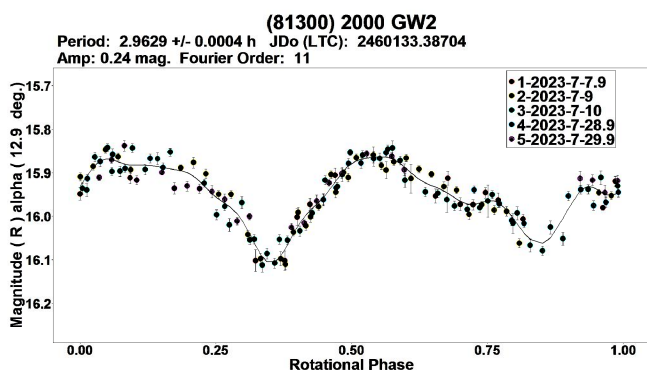
(60300) 1999 XV176. No previous rotation period determination results were found in the LCDB. The 2023 September SAO data revealed a period of $P = 2.7083 \pm 0.0007$ h as the statistically most favorable solution resulting from the period analysis.



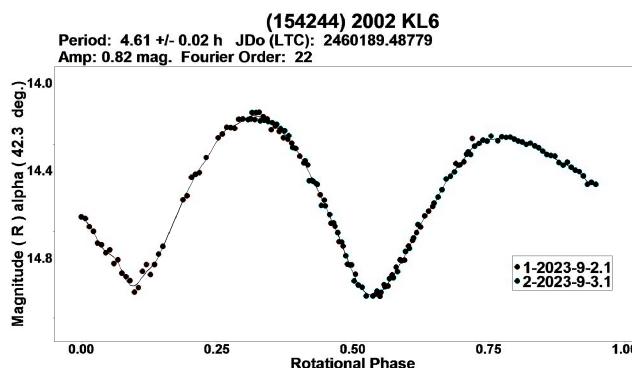
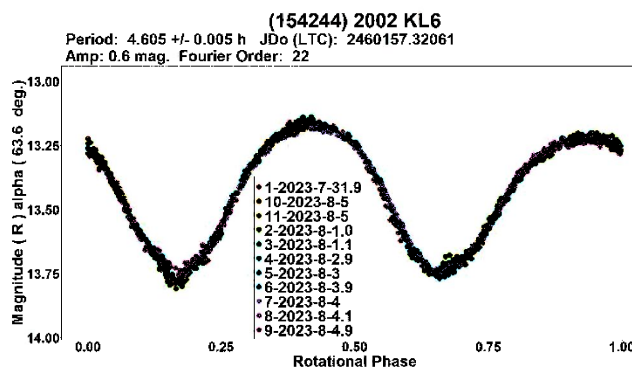
(64676) 2001 XE68. A rotation period of $P = 2.4340 \pm 0.0003$ h was found from the SAO data acquired in 2023 October - November over 5 nights. This is the first ever rotation period determination for this asteroid.



(81300) 2000 GW2. Previous rotation period determinations are not known in this case either. Period analysis performed on dense photometric dataset obtained in 2023 July at SAO indicate a favorable bimodal solution for a synodic rotation period of $P = 2.9629 \pm 0.0004$ h.



(154244) 2002 KL6. The two new rotation period results of $P_1 = 4.605 \pm 0.005$ h and $P_2 = 4.61 \pm 0.02$ h are derived from two independent groups of data obtained at SAO in the time span 2023 July 31 - 2023 August 05 (first group) and on two consecutive nights in early 2023 September (second group), corresponding to two different viewing geometries. These results fit very well in the entire series of previously determined rotation periods (from 2009 through 2023) ranging in a narrow interval of values from 4.605 h to 4.6101 h, as specified in the LCDB (Warner et al., 2009).



Acknowledgements

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Number	Name	20yy/mm/dd	Phase	L _{PAB}	B _{PAB}	Period (h)	P.E.	Amp	A.E.	Grp
985	Rosina	23/08/20–23/08/28	*3.9, 6.0	329	5	3.013	0.001	0.19	0.01	MC
985	Rosina	23/09/28–23/09/29	23.0, 23.5	337	6	3.010	0.007	0.25	0.02	MC
2213	Meeus	23/09/13–23/09/27	21.9, 14.6	19	–8	2.9815	0.0006	0.20	0.02	MB-I
3225	Hoag	23/07/03–23/08/03	26.0, 29.4	276	37	2.3725	0.0002	0.15	0.03	HUN
3879	Machar	23/09/28–23/11/04	24.5, 9.6	43	13	4.1378	0.0004	0.28	0.05	MB-I
4175	Billbaum	23/12/17–23/12/18	16.4, 16.0	112	–16	2.743	0.006	0.11	0.02	MB-M
4621	Tamov	23/07/08–23/08/05	*15.6, 3.1	310	4	5.3170	0.0009	0.13	0.02	MB-I
4671	Drtikol	23/09/16–23/09/18	7.8, 7.2	7	2	3.83	0.02	0.32	0.02	MB-I
4839	Daisetsuzan	23/08/10–23/09/02	*3.8, 11.5	319	6	3.3839	0.0005	0.22	0.03	MB-I
5111	Jacliff	23/08/14–23/08/17	10.8, 9.9	337	8	2.840	0.004	0.21	0.02	V
5787	1992 FA1	23/08/26–23/09/08	4.6, 10.3	329	6	4.018	0.002	0.40	0.03	FLOR
6108	Glebov	23/07/23–23/08/09	15.2, 5.9	321	4	2.8301	0.0005	0.10	0.02	MB-I
6872	1993 CN1	23/08/09–23/09/05	*8.9, 7.4	331	5	3.8201	0.0005	0.49	0.02	MB-I
12071	Davykim	23/10/12–23/11/05	17.8, 3.7	46	–1	3.5473	0.0005	0.32	0.02	FLOR
12724	1991 PZ14	23/07/25–23/07/28	9.0, 8.1	315	8	3.000	0.004	0.26	0.03	MB-I
13081	1992 EW9	23/08/21–23/08/22	13.1, 12.6	351	–4	5.41	0.03	0.18	0.03	MAR
14031	Rozyo	23/09/28–23/09/29	19.7, 19.6	36	–17	2.89	0.03	0.36	0.03	EUN
15007	Edoardo pozio	23/10/03–23/10/05	12.1, 11.6	28	10	4.30	0.02	0.30	0.02	MB-I
16591	1992 SY17	23/06/28–23/07/10	23.3, 19.0	305	12	2.7372	0.0006	0.24	0.03	MC
17204	2000 AR75	23/08/22–23/08/25	9.4, 7.6	340	–2	2.845	0.003	0.09	0.02	MB-I
24417	2000 BK5	23/10/07–23/11/09	16.9, 1.0	47	0	3.7830	0.0004	0.31	0.03	MB-I
24643	MacCready	23/09/26–23/09/28	20.5, 19.7	26	15	2.828	0.005	0.13	0.03	PHO
36360	2000 OH3	23/10/11–23/10/24	18.6, 13.3	43	13	2.4620	0.0004	0.15	0.03	MB-I
41044	1999 VW6	23/07/24–23/07/30	*6.2, 5.8	305	10	2.731	0.002	0.19	0.03	MB-I
48601	1995 BL	23/08/13–23/08/14	4.2, 4.9	315	4	4.63	0.02	0.41	0.04	HUN
50403	2000 CB114	23/09/30–23/10/11	25.4, 21.1	52	–1	2.5669	0.0005	0.15	0.03	PHO
53523	2000 AC153	23/04/28–23/05/10	*6.0, 6.2	223	7	2.8309	0.0006	0.11	0.02	FLOR
60300	1999 XV176	23/09/03–23/08/12	27.3, 25.5	17	29	2.7083	0.0007	0.08	0.02	PHO
64676	2001 XE68	23/10/26–23/11/12	15.5, 5.4	52	–7	2.4340	0.0003	0.07	0.02	MB-I
81300	2000 GW2	23/07/07–23/07/29	*12.9, 4.6	301	7	2.9629	0.0004	0.24	0.03	MB-I
154244	2002 KL6	23/07/31–23/08/05	*63.6, 63.0	305	35	4.605	0.005	0.60	0.03	NEA
154244	2002 KL6	23/09/01–23/09/03	42.3, 41.1	2	13	4.61	0.02	0.82	0.02	NEA

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. L_{PAB} and B_{PAB} are the average phase angle bisector longitude and latitude. Grp is the asteroid family/group (Warner et al., 2009): EUN = Eunomia, MB-I/M = main-belt inner/middle, NEA = near-Earth asteroid, MAR = Maria, V = Vestoid, HUN = Hungaria, MC = Mars Crosser, V = Vestoid, FLOR = Flora, PHO = Phocaea.

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PHOTOMETRIC OBSERVATIONS OF ASTEROIDS 1631 KOPFF, 2244 TESLA, 2967 VLADISVYAT AND 9628 SENDAIOTSUNA

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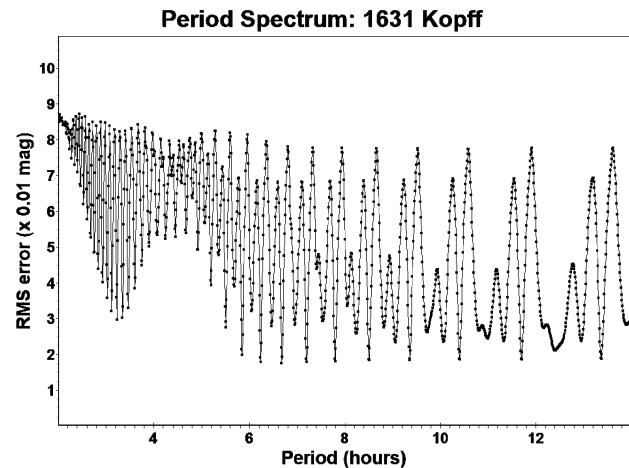
Photometric observations of four main-belt asteroids were conducted to determine their synodic rotation periods. We found: for 1631 Kopff, $P = 6.682 \pm 0.002$ h with $A = 0.28 \pm 0.02$ mag; for 2244 Tesla, $P = 24.65 \pm 0.04$ h with $A = 0.13 \pm 0.03$ mag; for 2967 Vladisvyat, $P = 8.374 \pm 0.001$ h with $A = 0.59 \pm 0.02$ mag, for 9628 Sendaiotsuna, $P = 2.664 \pm 0.001$ h with $A = 0.07 \pm 0.02$ mag.

CCD photometric observations of four main-belt asteroids were carried out in October - December 2023 at the Astronomical Observatory of the University of Siena (K54). We used a 0.30-m $f/5.6$ Maksutov-Cassegrain telescope, SBIG STL-6303E NABG CCD camera, and clear filter; the pixel scale was 2.30 arcsec when binned at 2×2 pixels and all exposures were 300 seconds.

Data processing and analysis were done with *MPO Canopus* (Warner, 2018). All images were calibrated with dark and flat-field frames and the instrumental magnitudes converted to R magnitudes using solar-colored field stars from a version of the CMC-15 catalogue distributed with *MPO Canopus*. Table I shows the observing circumstances and results.

1631 Kopff (1936 UC) was discovered on 1936 October 11 by Y. Vaisala at Turku and named in memory of August Kopff (1882-1960), who as Wolf's assistant in Heidelberg discovered and observed many minor planets. It is an inner main-belt asteroid with a semi-major axis of 2.236 AU, eccentricity 0.214, inclination 7.491° , and an orbital period of 3.34 years. Its absolute magnitude is $H = 12.29$ (JPL, 2023). The NEOWISE satellite infrared radiometry survey (Mainzer et al., 2019) found a diameter $D = 8.636 \pm 0.395$ km using an absolute magnitude $H = 12.10$.

Observations were conducted over two nights and collected 78 data points. The period analysis shows a rotational period of $P = 6.682 \pm 0.002$ h with an amplitude $A = 0.28 \pm 0.02$ mag, in good agreement with the previously results published in the LCDB (Sada et al., 2004; Āurech et al., 2020).



Number	Name	2023/mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
1631	Kopff	11/07-11/11	*4.0, 3.8	48	6	6.682	0.002	0.28	0.02	MB-I
2244	Tesla	12/03-12/19	3.4, 9.0	70	-6	24.65	0.04	0.13	0.03	MB-O
2967	Vladisvyat	11/07-11/18	*3.0, 4.3	48	6	8.374	0.001	0.59	0.02	URS
9628	Sendaiotsuna	10/03-10/14	*11.2, 10.8	16	17	2.664	0.001	0.07	0.02	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 extremum 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).