

CCD PHOTOMETRY OF 35 ASTEROIDS AT Sopot ASTRONOMICAL OBSERVATORY: 2021 NOVEMBER - 2022 JULY

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Lightcurves and synodic rotation periods were established for 35 asteroids using photometric observations carried out at Sopot Astronomical Observatory between 2021 November and 2022 July are presented in this paper.

Photometric observations of 35 asteroids were conducted at Sopot Astronomical Observatory (SAO) from 2021 November through 2022 July 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 were performed using *Perfindia* custom-made software developed in the R statistical programming language (R Core Team, 2020) by the author. 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

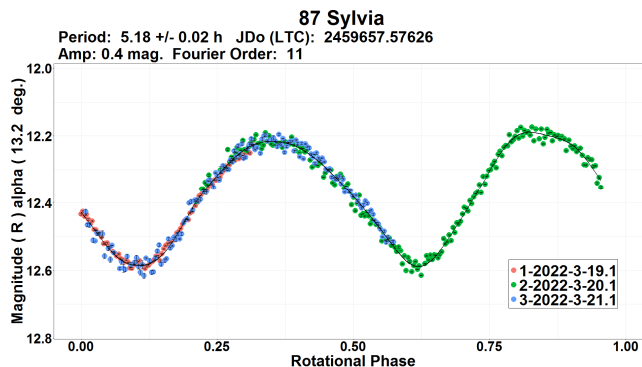
$$\Delta P = (0.02 \cdot P^2) / T$$

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.

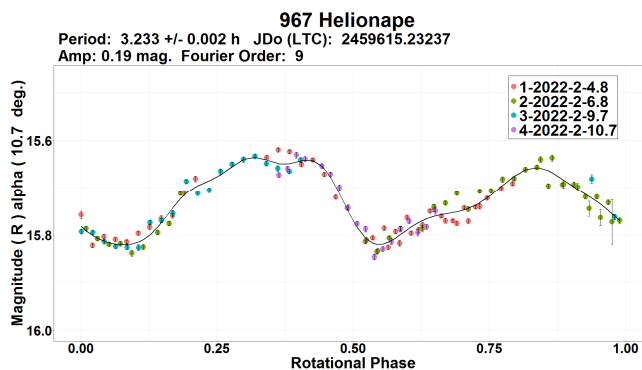
Some of the targets presented in this paper were observed within the Photometric Survey for Asynchronous Binary Asteroids (*BinAstPhot Survey*) under the leadership of Dr. Petr Pravec from Ondřejov Observatory, Czech Republic.

Table I gives the observing circumstances and results.

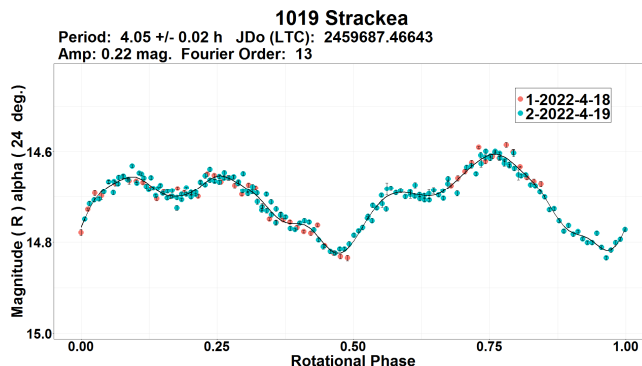
87 Sylvia. The rotation period derived from the 2022 March SAO observations, $P = 5.18 \pm 0.02$ h, is in full agreement with virtually all previously recorded values in the Asteroid Lightcurve Database (LCDB; Warner et al., 2009a), including 5.183 h (Schober and Surdej, 1979), 5.184 h (Foerster and Potthoff, 2001), 5.1833 h (Behrend, 2007web), and 5.1858 h (Behrend 2021web).



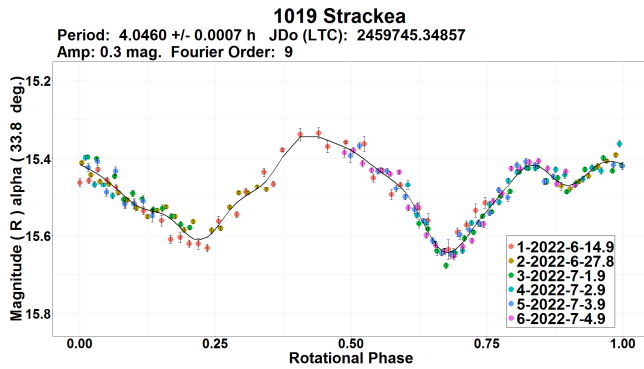
967 Helionape. Photometric data obtained at SAO in early 2022 February over four nights indicate a bimodal lightcurve solution with a corresponding period of $P = 3.233 \pm 0.002$ h, perfectly in line with previous highly-consistent results: 3.234 h (Apostolovska et al., 2009), 3.232 h (Kryszczyńska et al., 2012), and 3.2341 h (Behrend, 2020web).



1019 Strackea. During the 2022 apparition, this Hungaria asteroid was observed at two different viewing geometries resulting in two separate data groups and two composite lightcurves different in shape. The first data group was obtained on two consecutive nights in 2022 April and show a bimodal lightcurve phased to a period of $P = 4.05 \pm 0.02$ h as a plausible solution.

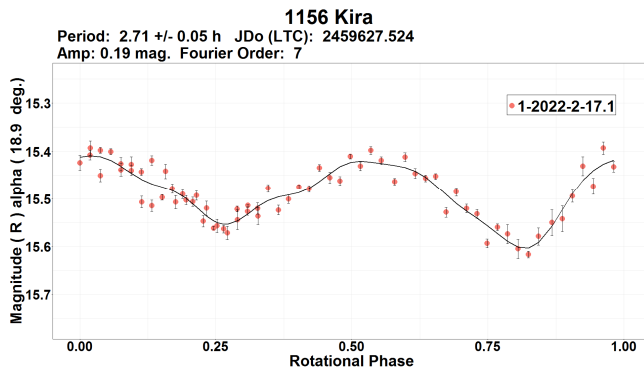


Another group of data acquired over 6 nights from mid-2022 June to early 2022 July also indicates a bimodal solution corresponding to the period of $P = 4.0460 \pm 0.0007$ h.

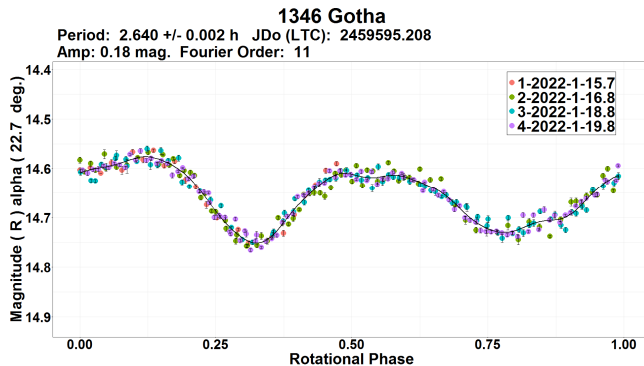


Both results are not only mutually consistent, but are also consistent with most previously established periods: 4.05 h (Behrend, 2006web), 4.044 h (Warner, 2009b), 4.047 h (Warner, 2011), 4.048 h (Stephens and Warner, 2019), and 4.04729 h (Pal, 2020).

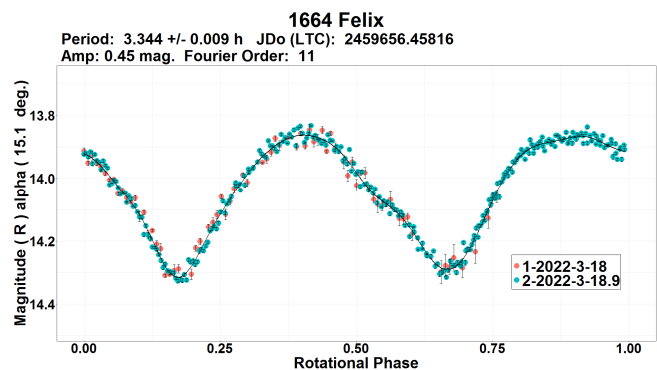
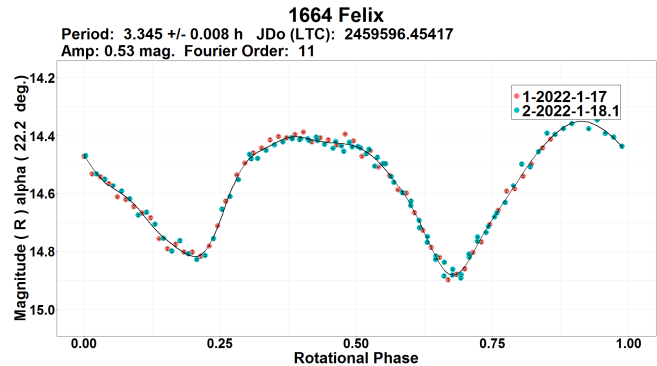
1156 Kira. Data obtained on a single night in 2022 January were sufficient to achieve coverage of more than one rotation cycle and to establish at least a coarse period of $P = 2.71 \pm 0.05$ h. Nevertheless, it matches quite well the previous period results recorded in the LCDB: 2.79103 h, 2.79105 h, and 2.79113 h (Dykhuys et al., 2016), and 2.791 h (Polakis, 2021).



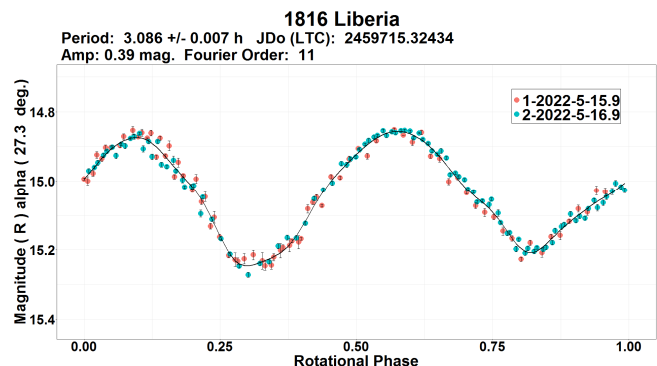
1346 Gotha. A bimodal period of $P = 2.640 \pm 0.002$ h is singled out as the most favorable result in the period analysis conducted upon the data collected over four nights in 2022 January. A search for previously determined periods in the LCDB finds a series of values in very good agreement with the newly established result, for example: 2.6548 h (Behrend, 2006web), 2.64067 h (Behrend, 2011web), 2.640 h (Waszczak et al., 2015), and 2.642 h (Aznar Macias, 2017).



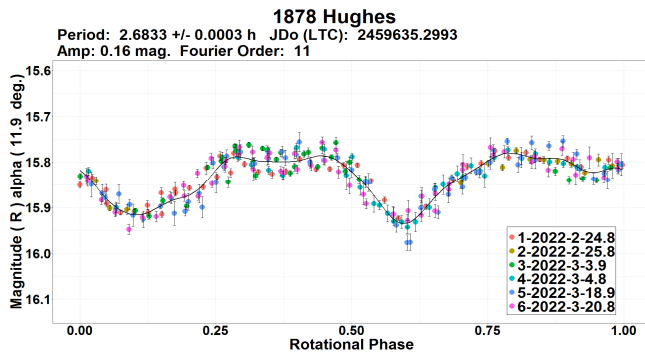
1664 Felix. In this case as well, the data are divided into two groups collected at two different viewing geometries during the same 2022 apparition. The first group was obtained over two consecutive nights in 2022 January while the second one was acquired on two consecutive nights two months later. Consequently, as a result of period analysis, two bimodal lightcurves of different shape phased to statistically identical period values of 3.345 ± 0.008 h and 3.344 ± 0.009 h were constructed. An insight into the LCDB database indicates a very good agreement with the new results and those previously determined by Higgins et al. (2008, 3.3454 h) and a sidereal rotation period by Durech et al. (2020, 3.344855 h).



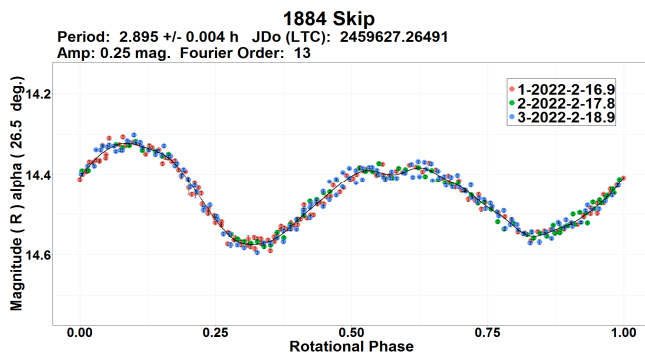
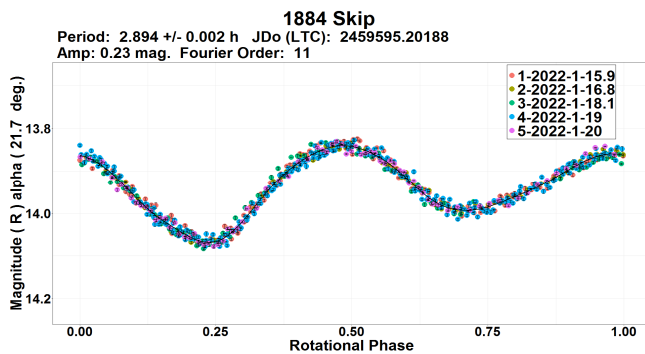
1816 Liberia. Data from two consecutive nights in 2022 May led to an unambiguous bimodal solution with a period of $P = 3.086 \pm 0.007$ h. The SAO data collected in the 2019 apparition showed an identical result of 3.08606 h (Benishek, 2020).



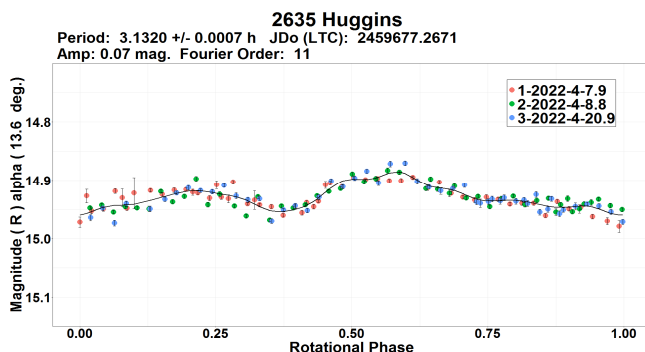
1878 Hughes. This was a *BinAstrom* Survey target. According to the LCDB records on this asteroid, there is only one previously known rotation period, Molnar et al. (2018, 2.683 h). A bimodal period of $P = 2.6833 \pm 0.0003$ h found from the 2022 February-March SAO data apparently confirms the previous finding.



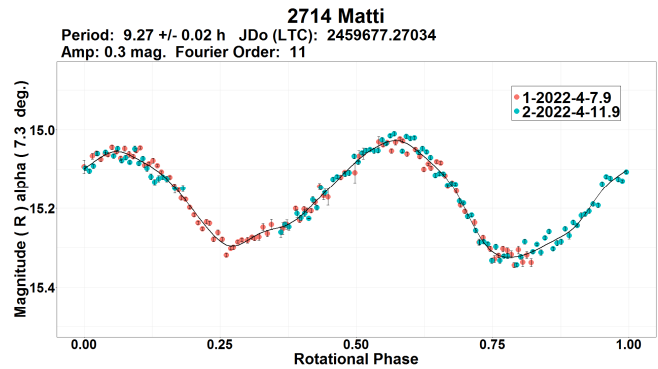
1884 Skip. Previously known rotation periods include Di Martino et al. (1994, 3.079 h), Behrend (2017web, 7.7477 h), Benishek and Rowe (2018, 2.89484 h), Skiff et al. (2019, 2.8887 h), and a sidereal period by Durech et al. (2020, 2.89442 h). The 2022 apparition SAO observations obtained on five nights in January and three nights in February produced two bimodal lightcurves with statistically equal periods of 2.894 ± 0.002 h (January) and 2.895 ± 0.004 h (February).



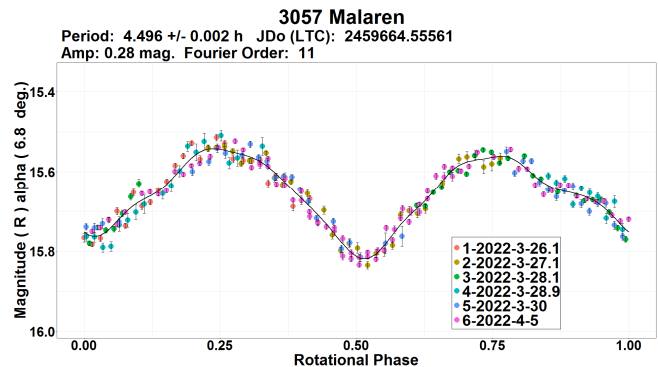
2635 Huggins. A rotation period result of $P = 3.1320 \pm 0.0007$ h, found from SAO data obtained on three nights in 2022 April, corroborates a previous result by Waszczak et al. (2015, 3.129 h).



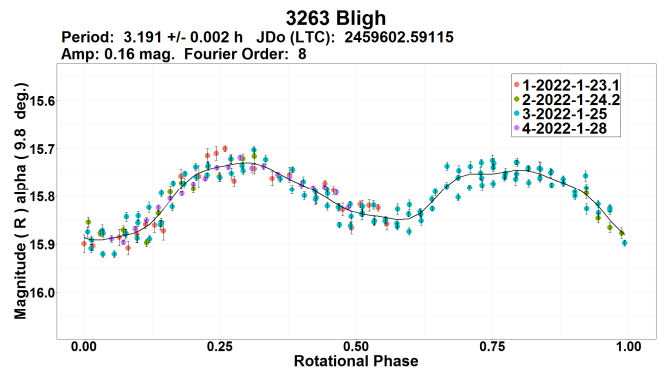
2714 Matti. A bimodal period solution of $P = 9.27 \pm 0.02$ h was obtained from a data set obtained over two nights in 2022 April. Durech et al. (2020) found a sidereal rotation period of 9.27359 h.



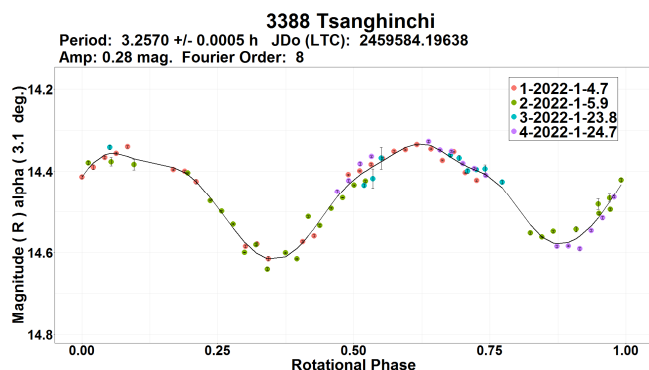
3057 Malaren. A period of 4.496 ± 0.002 h was found from data obtained on six nights in 2022 March-April. The result is identical to the only previous result of 4.496 h by Waszczak et al. (2015).



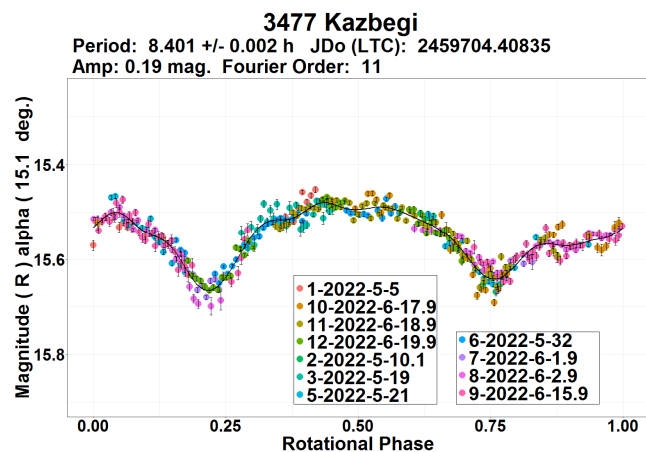
3263 Bligh was observed on four nights in late 2022 January. Period analysis led to a bimodal solution with $P = 3.191 \pm 0.002$ h. This matches very well with the only previously known period determination by Casalnuovo (2014, 3.193 h).



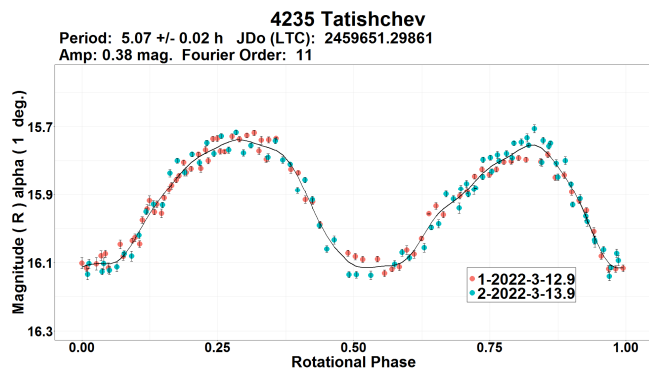
3388 Tsanginchi. A period of $P = 3.2570 \pm 0.0005$ h was determined from observations made on four nights in 2022 January. An excellent match with a rotation period result found by Durkee (2011, 3.257 h) is obvious.



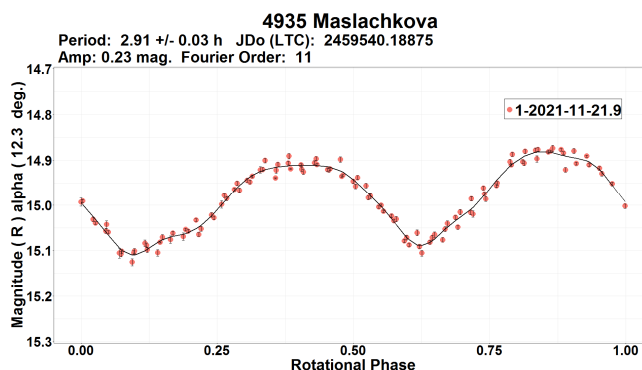
3477 Kazbegi. Period analysis conducted on the 2022 May-June combined data set yielded an unequivocal bimodal period solution of $P = 8.401 \pm 0.002$ h.



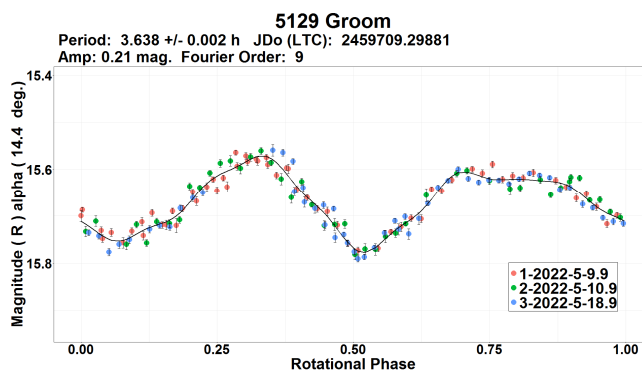
4235 Tatishchev. No records on previous rotation period determinations were found in the LCDB. Photometric observations taken with high cadence on two consecutive nights in 2022 March proved sufficient to unambiguously establish a bimodal lightcurve solution phased to a period of $P = 5.07 \pm 0.02$ h.



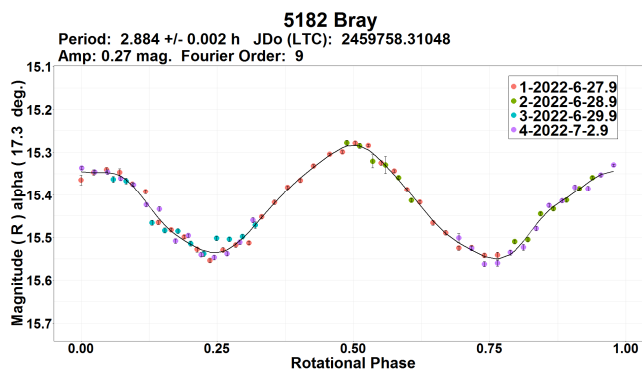
4935 Maslachkova. A period of $P = 2.91 \pm 0.03$ h, determined from a single night of observations in 2021 November, is statistically consistent with the results found by Galad et al. (2009, 2.90192 h) and Waszczak et al. (2015, 2.903 h).



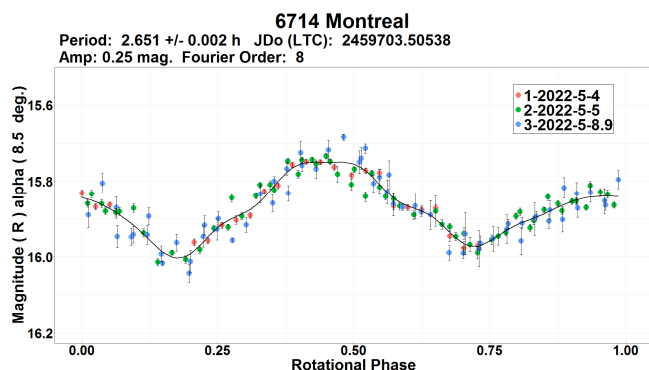
5129 Groom. This asteroid was a *BinAstPhot Survey* returning binary suspect. Data obtained on three nights in 2022 May show a synodic rotation period of $P = 3.638 \pm 0.002$ h, a result that is in very good agreement with the vast majority of previously determined values: 3.636 h (Behrend, 2007web), 3.6378 h (Pravec, 2007web), 3.6374 h (Pravec, 2011web), 3.6362 h (Pravec, 2012web), 3.6371 h (Pravec, 2016web), 3.6376 h (Pravec, 2018web), and a sidereal period of 3.63759 h by Durech et al. (2020). No significant deviations in the lightcurve that could point to the existence of a secondary rotation component or mutual events were detected during the 2022 apparition.



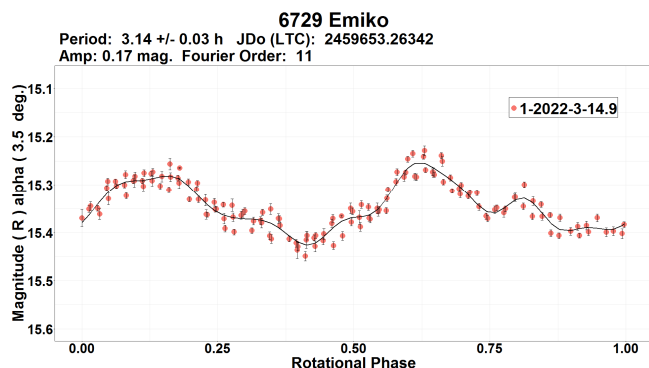
5182 Bray. Analysis of four nights of observations at SAO in 2022 late June to early July indicate a short rotation period bimodal solution of $P = 2.884 \pm 0.002$ h, which is consistent with other values found to date, e.g., 2.883 h (Klinglesmith, 2014web), 2.884 h (Behrend, 2018web), and 2.86 h (Fauerbach, 2019).



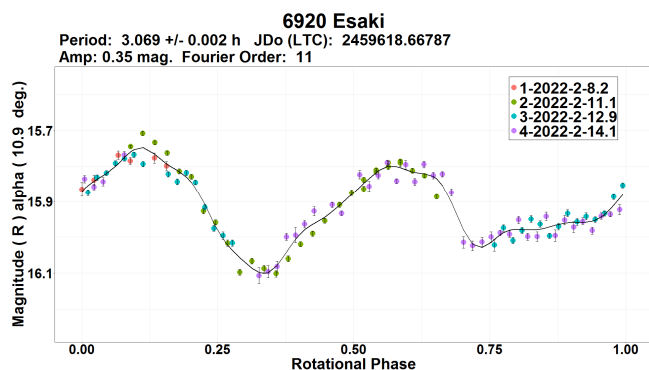
6714 Montreal. Prior to this rotation period determination there was only one sidereal period result reported by Durech (2020, 2.651089 h). Period analysis of the 2022 May SAO data taken on three nights yielded a synodic period of $P = 2.651 \pm 0.002$ h.



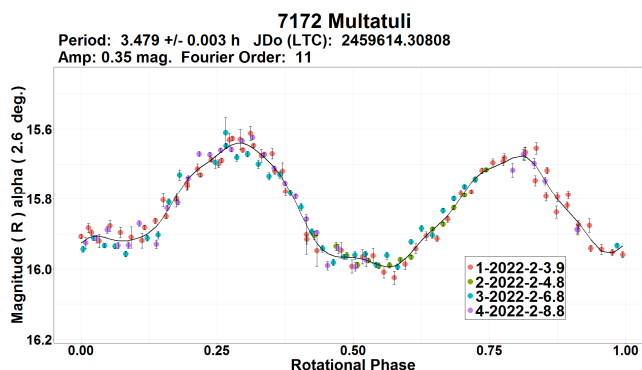
6729 Emiko. The only previously reported rotation period by Behrend (2016web, 3.13 h) is highly consistent with the value of $P = 3.14 \pm 0.03$ h shown here, which was obtained from the single night dense photometric data taken in 2022 mid-March.



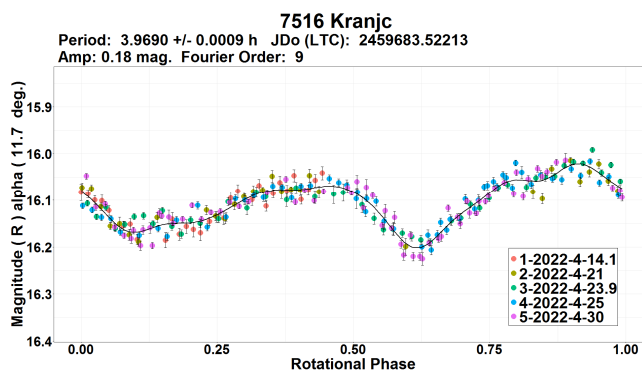
6920 Esaki. This is a Vestoid asteroid with no previously known spin rate. Four data sets obtained at SAO in 2022 February reveal a fairly fast rotation with a period of $P = 3.069 \pm 0.002$ h.



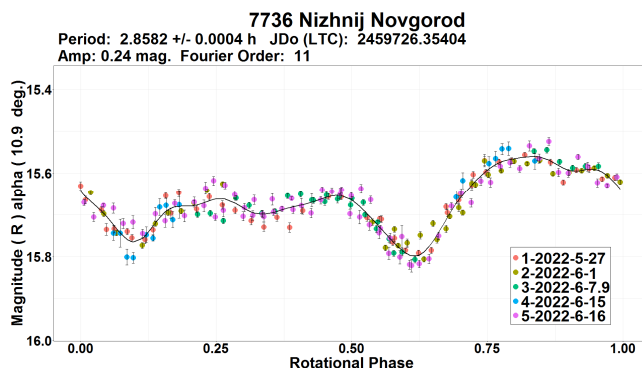
7172 Multatuli. Erasmus et al. (2020) report a value of 3.357 h for rotation period. The uncertainty score of $U = 2$ - assigned in the LCDB indicates that the result, the only one previously reported, is mostly unreliable, i.e., barely statistically valid for rotation rate studies. The 2022 February dense cadence SAO combined data set obtained over four nights shows a somewhat different rotation period of $P = 3.479 \pm 0.003$ h based on a bimodal lightcurve solution.



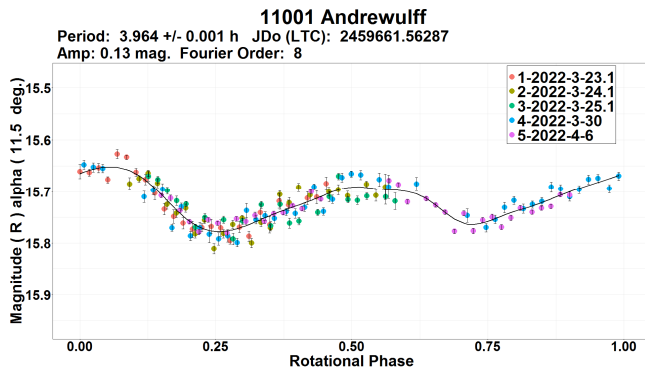
7516 Kranjc. This was a returning *BinAstPhot Survey* suspected binary asteroid. A unique bimodal rotation period solution of $P = 3.9690 \pm 0.0009$ h was determined from the SAO dense combined data set obtained over five nights in 2022 April. The newly found value corresponds very well to those previously known, such as 3.96769 h (Pravec, 2008web), 3.96776 h (Oey, 2009), 3.982 h (Warner, 2009c), and 3.9702 h (Pravec, 2019web). No significant attenuations in the rotational lightcurve that could be a binarity indicator were detected in the 2022 apparition data.



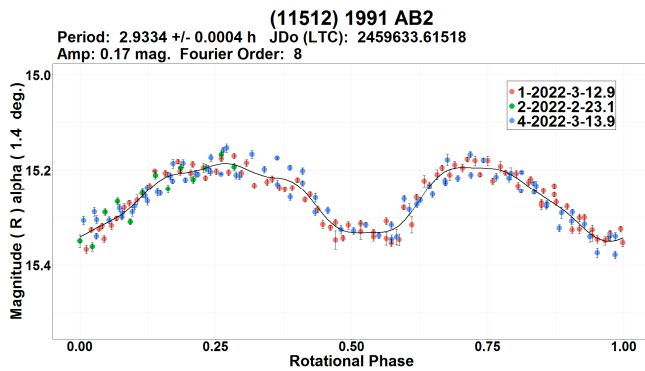
7736 Nizhnij Novgorod. Papini et al. (2019) reported a value of 2.858 h for rotational period. Period analysis of the SAO combined photometric data set obtained over five nights in 2022 May-June yielded a period $P = 2.8582 \pm 0.0004$ h, which is equal to the one previously determined.



11001 Andrewulff. This was another returning *BinAstPhot Survey* binary suspect. The period of $P = 3.964 \pm 0.001$ h derived from the 2022 March-April SAO observations matches well with two previously reported results by Pravec (2012web, 3.9638 h) and Waszczak et al. (2015, 3.965 h). No signs of a possible satellite were observed.



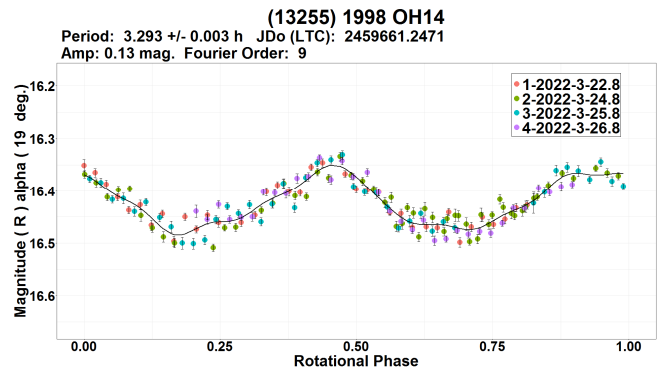
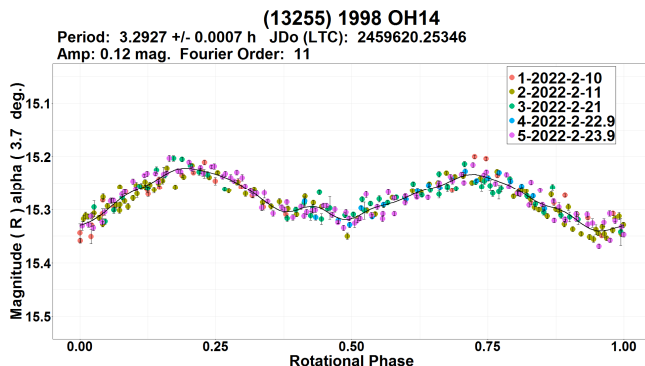
(11512) 1991 AB2. Hess and Dittion (2016) found a period of 2.933 h. The period result obtained using 2022 February-March SAO data collected on three nights is $P = 2.9334 \pm 0.0004$ h.



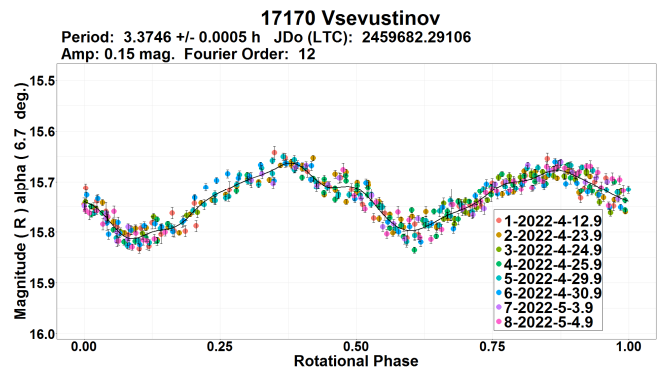
(13255) 1998 OH14. This was a *BinAstrPhot Survey* target. The rotation period found in 2017 from the BinAstrPhot Survey observations by Donald Pray is 3.2941 h (Pravec, 2017web). Any significant rotational lightcurve deviations were not detected at that time.

During the 2022 apparition, this target was observed at SAO in February and March. Due to viewing geometry changes over the time span of observations, the data were split into two separate groups, each producing a lightcurve of different shape from the other.

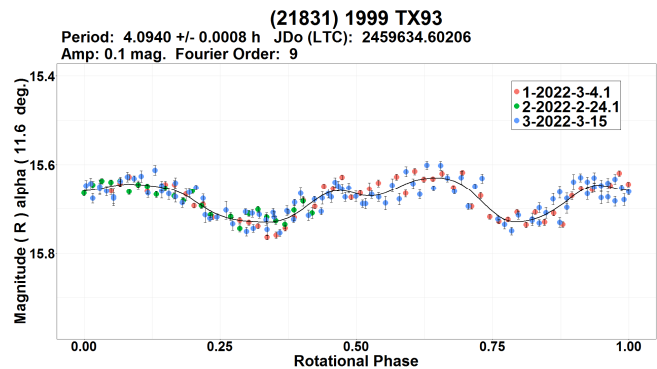
No significant deviations that could indicate the presence of a satellite were observed in either of the lightcurves. Results for rotation period obtained from both combined data sets in independent period analyzes are highly consistent with each other: 3.2927 ± 0.0007 h (2022 February, five nights) and 3.293 ± 0.003 h (2022 March, four nights).



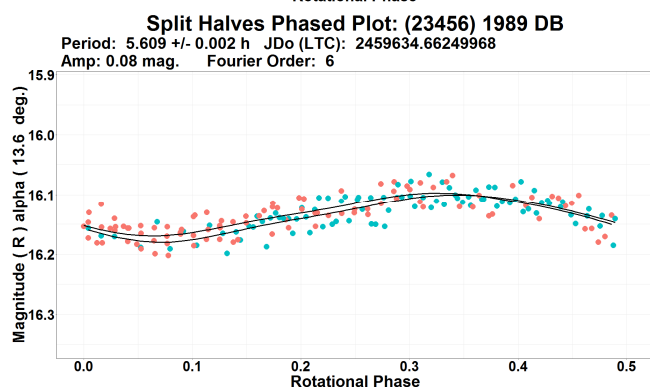
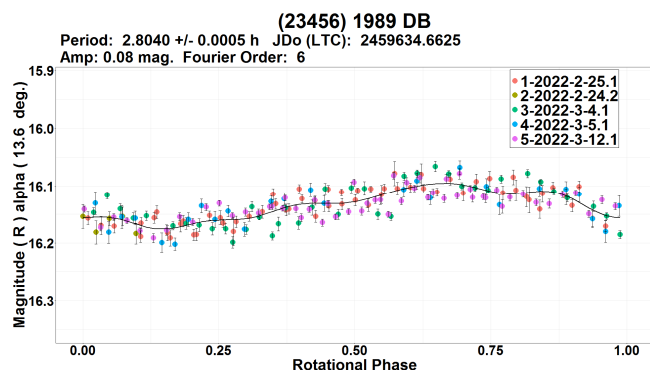
17170 Vsevastinov. This returning *BinAstrPhot Survey* suspected binary asteroid was observed in the 2012 apparition without any sign of a satellite. During the 2022 apparition, observations were made in April and May for a total of eight nights. The 2012 result for a rotation period of 3.3750 h (Pravec, 2012web) is almost identical to the newly established result of $P = 3.3746 \pm 0.0005$ h derived from the 2022 data. As in 2012, the 2022 observations found no lightcurve deviations that would indicate a satellite.



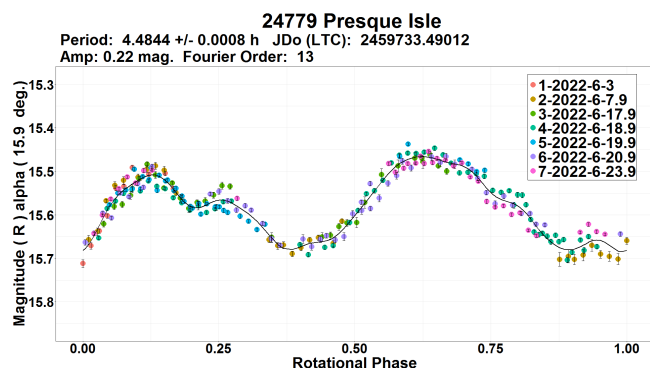
(21831) 1999 TX93. No previous rotation period reports were found in the LCDB. Photometric observations with dense cadence were carried out at SAO on three nights in 2022 February-March. Although the data analysis indicates a small lightcurve amplitude of only 0.1 mag, a reliable unique period of $P = 4.0940 \pm 0.0008$ h was established.



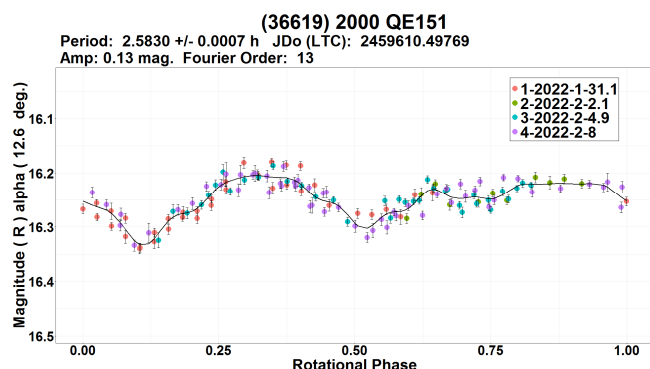
(23456) 1989 DB. A plausible rotation period of $P = 2.8040 \pm 0.0005$ h was found from the 2022 February-March combined data set obtained over five nights. The possibility of a harmonically related bimodal period solution of 5.609 ± 0.002 h, i.e., $2P$, within the period error, was ruled out since the two halves of the corresponding bimodal lightcurve were essentially equal. According to the LCDB, this is the first reported period for the asteroid.



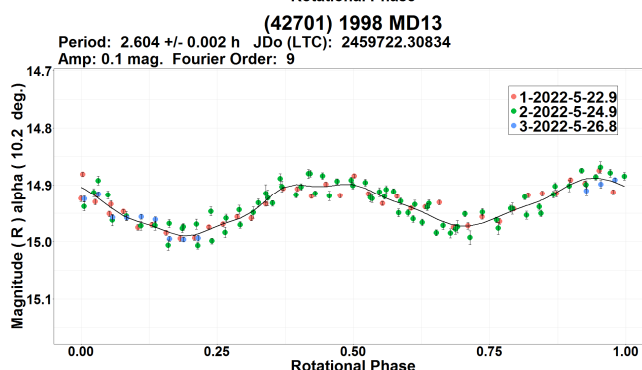
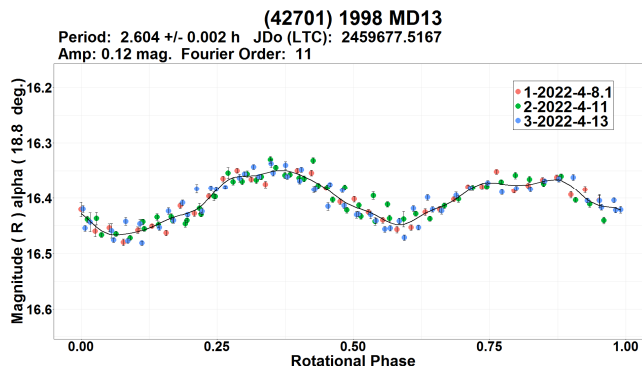
(24779) Presque Isle. A search for of the LCDB found no previous results. Period analysis conducted on the 2022 June SAO combined data set shows a secure bimodal lightcurve with a period of $P = 4.4844 \pm 0.0008$ h.



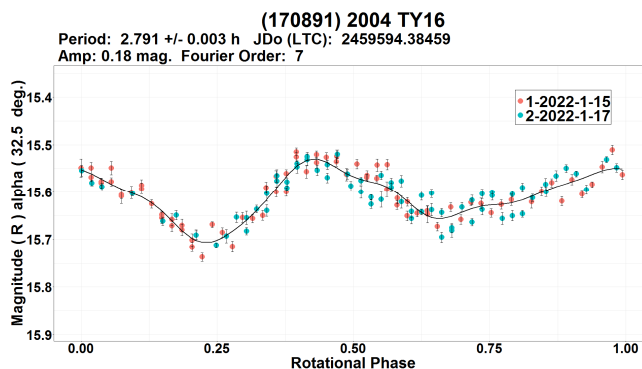
(36619) 2000 QE151. A period of $P = 2.5830 \pm 0.0007$ h was found from the 2022 January-February combined data set. This closely matches the only previous result of 2.58294 h found by Pal et al. (2020).



(42701) 1998 MD13. As in some cases described above, the data were divided into two groups and analyzed separately due to the changing viewing geometry and lightcurve shape over the observing span (2022 April-May). The established period values are exactly the same for both data groups (including the period errors): $P = 2.604 \pm 0.002$ h. Previously known period determinations include 2.602 h (Klinglesmith and Lovata, 2018), 2.603 h (Papini et al., 2019), and 2.603 h (Rowe, 2019).



(170891) 2004 TY16. The rotation period presented here for this near-Earth asteroid ($P = 2.791 \pm 0.003$ h) is fully accordant with the only previously reported result by Carbognani (2008, 2.795 h).



Acknowledgements

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References

Apostolovska, G.; Ivanova, V.; Kostov, A. (2009). "CCD Photometry of 967 Helionape, 3415 Danby, (85275) 1994 LY, 2007 DT103, and 2007 TU24." *Minor Planet Bull.* **36**, 27-28.

Number	Name	20yy/mm/dd	Phase	L _{PAB}	B _{PAB}	Period (h)	P.E.	Amp	A.E.	Grp
87	Sylvia	22/03/19-03/21	13.2,12.9	227	7	5.18	0.02	0.40	0.02	SYL
967	Helionape	22/02/04-02/10	10.7,13.1	112	4	3.233	0.002	0.19	0.02	FLOR
1019	Strackea	22/04/17-04/19	24.0,24.3	189	32	4.05	0.02	0.22	0.01	HUN
1019	Strackea	22/06/14-07/04	33.8,34.4	207	32	4.0460	0.0007	0.30	0.02	HUN
1156	Kira	22/02/17-02/17	18.9,18.9	186	2	2.71	0.05	0.19	0.03	MB-I
1346	Gotha	22/01/15-01/19	22.7,23.5	70	-17	2.640	0.002	0.18	0.02	EUN
1664	Felix	22/01/16-01/18	22.2,21.8	149	9	3.345	0.008	0.53	0.02	MB-I
		22/03/17-03/19	15.1,15.7	158	8	3.344	0.009	0.45	0.02	MB-I
1816	Liberia	22/05/15-05/17	27.3,27.4	184	24	3.086	0.007	0.39	0.02	PHO
1878	Hughes	22/02/24-03/20	12.0,18.1	127	-2	2.6833	0.0003	0.16	0.03	KOR
1884	Skip	22/01/15-01/20	21.7,22	106	30	2.894	0.002	0.23	0.02	MB-I
		22/02/16-02/19	26.5,26.9	113	24	2.895	0.004	0.25	0.02	MB-I
2635	Huggins	22/04/07-04/20	13.6,19.4	177	-6	3.1320	0.0007	0.07	0.02	FLOR
2714	Matti	22/04/07-04/12	7.3,9.4	188	7	2.604	0.002	0.12	0.02	MB-I
3057	Malaren	22/03/26-04-05	*6.8,6.4	191	10	4.496	0.002	0.28	0.02	MB-I
3263	Bligh	22/01/23-01/28	9.8,7.8	139	9	3.191	0.002	0.16	0.03	V
3388	Tsanghinchi	22/01/04-01/24	3.1,13.8	106	7	3.2570	0.0005	0.28	0.02	PHO
3477	Kazbegi	22/05/04-06/20	*15.1,11.5	251	9	8.401	0.002	0.19	0.02	V
4235	Tatishchev	22/03/12-03/14	1.0,1.4	170	0	5.07	0.02	0.38	0.03	MB-O
4935	Maslachkova	21/11/21-11/22	12.3,12.5	44	-8	2.91	0.03	0.23	0.02	FLOR
5129	Groom	22/05/09-05/18	14.4,17.8	205	10	3.638	0.002	0.21	0.01	MB-O
5182	Bray	22/06/27-07/02	17.3,18.7	250	19	2.884	0.002	0.27	0.01	MB-I
6714	Montreal	22/05/04-05/09	*8.5,7.9	231	17	2.651	0.002	0.25	0.03	MB-I
6729	Emiko	22/03/14-03/15	3.5,3.4	175	7	3.14	0.03	0.17	0.02	EUN
6920	Esaki	22/02/08-02/14	10.9,8.4	157	9	3.069	0.002	0.35	0.03	V
7172	Multatuli	22/02/03-02/08	2.6,5.2	132	3	3.479	0.003	0.35	0.02	HER
7516	Kranjc	22/04/14-04/30	11.7,6.0	222	8	3.9690	0.0009	0.18	0.03	MB-I
7736	Nizhnij Novgorod	22/05/26-06/16	*10.9,11.8	254	19	2.8582	0.0004	0.24	0.03	EUN
11001	Andrewulff	22/03/23-04/06	11.5,4.9	198	5	3.964	0.001	0.13	0.02	MB-I
11512	1991 AB2	22/02/23-03/14	*9.4,2.2	169	-1	2.9334	0.0004	0.17	0.03	MB
13255	1998 OH14	22/02/09-02/24	*3.7,6.0	146	3	3.2927	0.0007	0.12	0.02	MB-I
		22/03/22-03/26	19.0,20.5	150	4	3.293	0.003	0.13	0.03	MB-I
17170	Vsevastinov	22/04/12-05/05	6.7,15.7	201	9	3.3746	0.0005	0.15	0.02	FLOR
21831	1999 TX93	22/02/24-03/15	15.2,6.0	184	2	4.0940	0.0008	0.10	0.02	MB-I
23456	1989 DB	22/02/24-03/12	14.0,5.3	178	3	2.8040	0.0005	0.08	0.02	MB-I
24779	Presque Isle	22/06/02-06/24	15.9,10.8	273	18	4.4844	0.0008	0.22	0.03	MB-I
36619	2000 QE151	22/01/30-02/08	12.6,8.2	152	-2	2.5830	0.0007	0.13	0.03	FLOR
42701	1998 MD13	22/04/08-04/13	18.8,16.8	227	10	2.604	0.002	0.12	0.02	MB-I
		22/05/22-05/26	10.2,11.6	232	12	2.604	0.002	0.10	0.02	MB-I
170891	2004 TY16	22/01/14-01/17	32.5,31.9	138	10	2.791	0.003	0.18	0.03	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.*, 2009a): SYL = Sylvia, HUN = Hungaria, FLOR = Flora, MB-I/O = main-belt inner / outer, PHO = Phocaea, V = Vestoid, NEA = near-Earth asteroid, HER = Hertha, EUN = Eunomia, KOR = Koronis.

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