Tonry, J.L.; Denneau, L.; Flewelling, H.; Heinze, A.N.; Onken, C.A.; Smartt, S.J.; Stalder, B.; Weiland, H.J.; Wolf, C. (2018). "The ATLAS All-Sky Stellar Reference Catalog." *Ap. J.* **867**, A105.

Vachier, F.; Pravec, P.; Kucakova, H.; Hornoch, K.; Kusnirak, P.; Pray, D.; Cooney, W.; Gross, J.; Terrell, D.; Flanagan, B.; Pellerin, B.; Durkee, R.; Benishek, V.; Berthier, J.; Klotz, A.; Teng, J.-P.; Peyrot, A.; Thierry, P. (2019). *CBET* **4628**.

Warner, B.D. (2007). "Initial Results of a Dedicated H-G Program." *Minor Planet Bul.* **34**, 113-119.

Warner, B.D. (2013). "Lightcurve Photometry Opportunities: 2013 April-June." *Minor Planet Bull*. **40**, 119-121.

Warner, B.D. (2016). "Three Additional Candidates for the Group of Very Wide Binaries." *Minor Planet Bul.* **43**, 306-309.

Warner, B.D.; Coley, D. (2013). "16525 Shumarinaiko: A New Nysa Binary." *Minor Planet Bull*. **40**, 124-125.

Warner, B.D.; Harris, A.W.; Pravec, P. (2009). "The Asteroid Lightcurve Database." Icarus **202**, 134-146. Updated 2020 Aug. *http://www.minorplanet.info/lightcurvedatabase.html*

LIGHTCURVE AND ROTATION PERIOD DETERMINATIONS FOR 25 ASTEROIDS

Vladimir Benishek
Belgrade Astronomical Observatory
Volgina 7, 11060 Belgrade 38, SERBIA
vlaben@yahoo.com

(Received: 2021 April 15)

Lightcurves and synodic rotation periods for 25 asteroids determined from CCD photometric data acquired at Sopot Astronomical Observatory (SAO) over the time span 2020 July - 2021 April are summarized in this paper.

Photometric observations of 25 asteroids were conducted at Sopot Astronomical Observatory (SAO) from 2020 July through 2021 April 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 ≤ 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, 2021) 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.

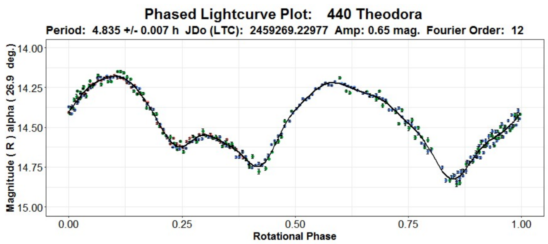
Lightcurve construction and period analysis was performed using *Perfindia* custom-made software developed in the R statistical programming language (R Core Team, 2020) by the author. The essence of its algorithm is reflected in finding the most favorable solution for rotational period by minimizing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

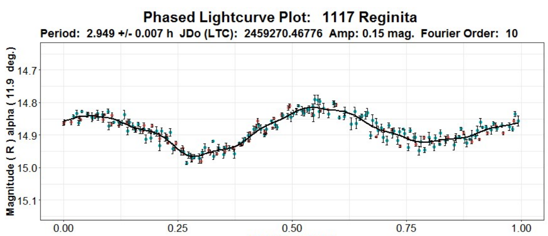
Some of the targets presented in this paper were observed within the Photometric Survey for Asynchronous Binary Asteroids (*BinAstPhot Survey*) under the leadership of Dr. Petr Pravec from Ondřejov Observatory, Czech Republic.

Table I gives the observing circumstances and results.

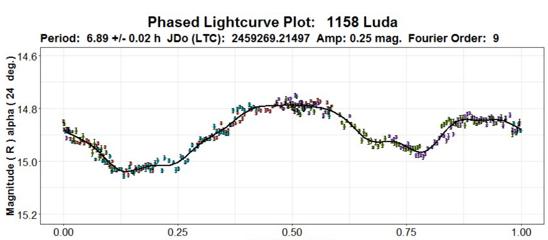
440 Theodora was a fairly bright target, favorable for observing during a waxing Moon approaching full at the end of 2021 February. A secure rotation period value has been established for it over several apparitions throughout previous decades. A search of the LCDB database (Warner et al., 2009) yielded the following previously found periods: 4.828 h (Florczak et al., 1997), a sidereal period of 4.83658 h by Hanuš et al. (2011) and two determinations by Behrend (4.82821 h, 2010; 4.83612 h, 2018). A synodic rotation period of $P = 4.835 \pm 0.007$ h, derived from the SAO data obtained over three nights is in good agreement with the previously found results.



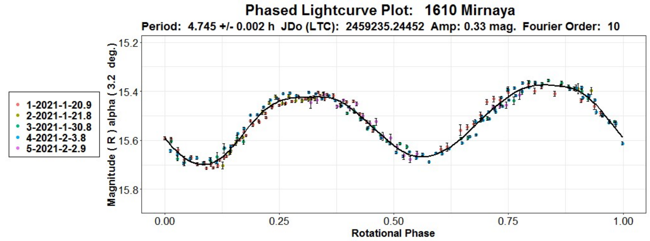
1117 Reginita. As in the preceding case, there are several fairly consistent rotation periods found over previous decades. Among some of them are 2.9463 h (Wisniewski et al., 1997), 2.9458 h (Behrend, 2007), 2.9464 h (Kryszczynska et al., 2012), 2.928 h (Waszczak et al., 2015), and 2.9467 h (Franco et al., 2018). Again, the SAO result ($P = 2.949 \pm 0.007$ h) obtained from the 2021 February observations conducted on two consecutive nights is consistent with the previous ones.



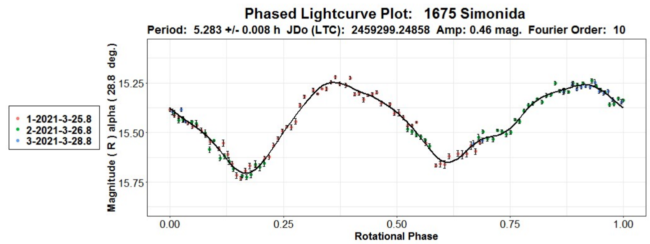
1158 Luda. Several previous rotation period results are quite uniform: 6.863 h (Behrend, 2005), 6.90 h (Warner, 2005), 6.870 h (Warner, 2011a), and 6.86 h (Kim et al., 2014). The exception is that of Alvarez-Candal et al. (7.44 h, 2004). The 2021 February SAO data collected on four consecutive nights confirm the consistent previously determined values, yielding a result of $P = 6.89 \pm 0.02$ h.



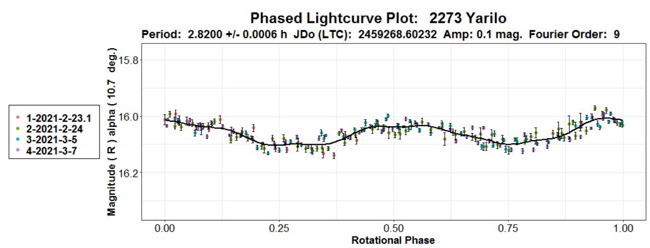
1610 Mirnaya. This was a *BinAstPhot Survey* target with no previously known rotation period. The SAO observations carried out on five nights in 2021 January-February show an unequivocal bimodal period result of $P = 4.745 \pm 0.002$ h.



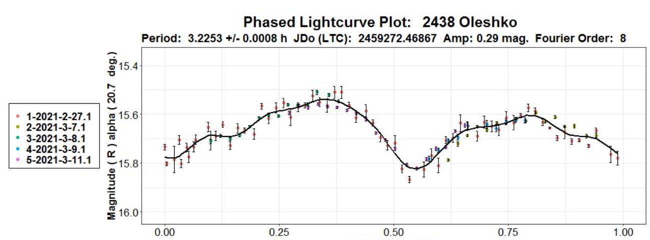
1675 Simonida. This is another minor planet with a well-established rotation period. These include 5.3 h (Wisniewski et al., 1997), 5.29 h (Behrend, 2008), 5.2885 h (Kryszczynska et al., 2012), and 5.28779 h (Pal et al., 2020). A bimodal lightcurve with a fairly large amplitude (0.46 mag.) phased to a period of $P = 5.283 \pm 0.008$ h was the result of period analysis using SAO photometric data collected on three nights in late 2021 March.



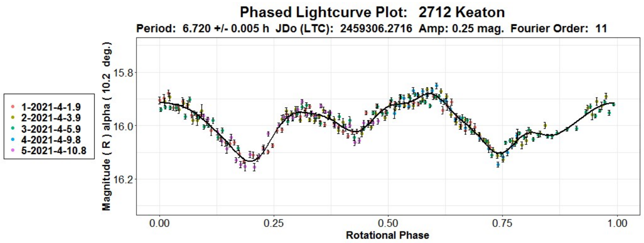
2273 Yarilo. No prior period results were known for this *BinAstPhot Survey* inner main-belt target. Period analysis upon four photometric data sets obtained at SAO in 2021 February-March led to a synodic rotational period of $P = 2.8200 \pm 0.0006$ h.



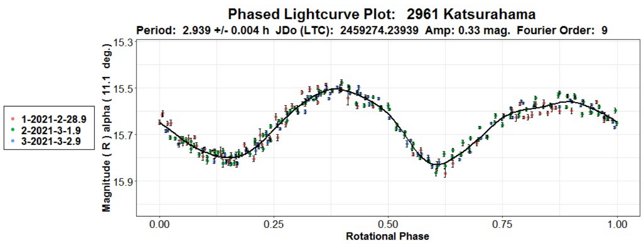
2438 Oleshko. The only previously found rotation perion by Behrend (2011) of 3.227 h is corroborated by the SAO rotation period determination ($P = 3.2253 \pm 0.0008$ h) based on five datasets obtained in 2021 February-March.



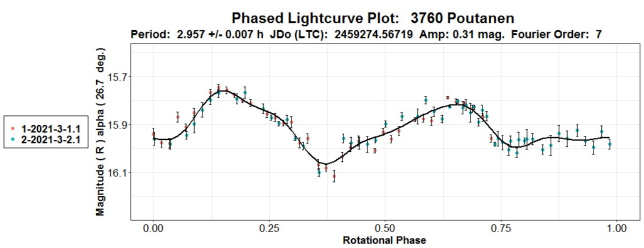
2712 Keaton. The only previously found rotation period by Chang et al. (5.87 h, 2019) significantly differs from the new result derived from dense SAO photometry that indicates an unambiguous period of $P = 6.720 \pm 0.005$ h. As a program target within *BinAstPhot Survey*, this inner main-belt asteroid was observed on five nights in early 2021 April.



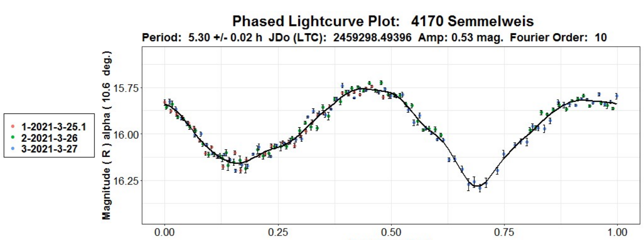
2961 Katsurahama. Several consistent previously found rotation periods such as those by Warner (2.936 h, 2011b) and Kryszczynska et al. (2.937 h, 2012) are in excellent agreement with a bimodal solution of P = 2.939 ± 0.004 h found from the SAO 2021 February-March data.



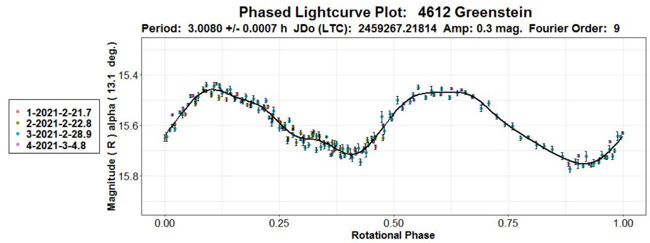
3760 Poutanen. A newly found period of P = 2.957 ± 0.007 h from the 2021 March SAO data is fully consistent with three previous results: 2.956 h (Salvaggio et al., 2017), 2.9554 h (Benishek, 2018), and 2.95588 h (Pal et al., 2020).



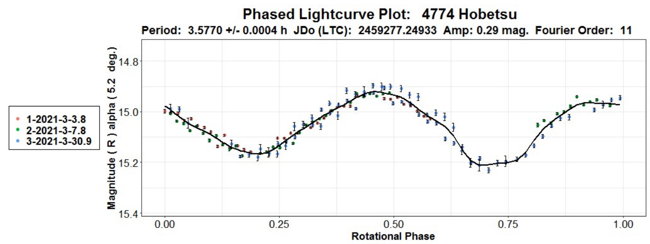
4170 Semmelweis. Data taken on three consecutive nights in late 2021 March yielded a bimodal lightcurve of fairly high amplitude (0.53 mag) and a corresponding period of P = 5.30 ± 0.02 h, which affirms previous results by Waszczak et al. (2015, 5.302 h and 5.305 h), Aznar Macias (2016, 5.31 h), and Pal et al. (2020, 5.3054 h).



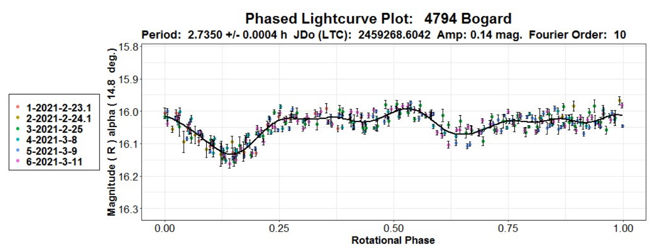
4612 Greenstein. No period results prior to this determination were found in the LCDB. Photometric observations over four nights at SAO in 2021 February-March resulted in a bimodal lightcurve phased to an unambiguous solution period of P = 3.0080 ± 0.0007 h.



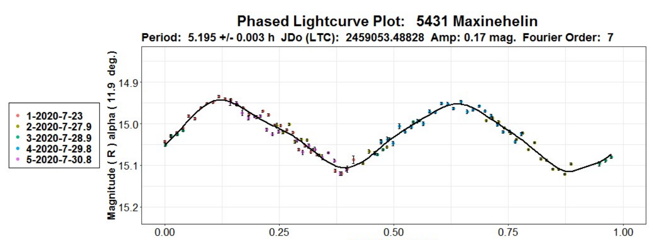
4774 Hobetsu. A bimodal period solution found from the 2021 apparition SAO data (P = 3.5770 ± 0.0004 h) slightly differs from the value determined from the 2019 SAO observations of 3.564 h (Benishek, 2020) and matches exactly the period obtained during the 2004 apparition by Pray (2005, 3.577 h).



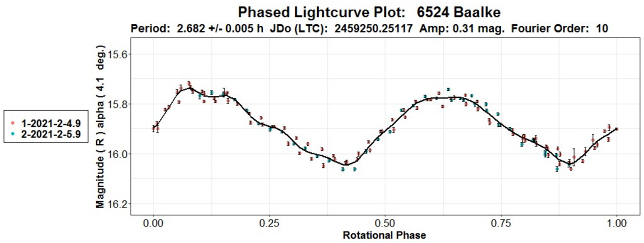
4794 Bogard. An insight into the LCDB showed this to be the very first period determination for this *BinAstPhot Survey* target. The SAO observations taken on six nights in 2021 February-March led to a period of P = 2.7350 ± 0.0004 h as the statistically most favorable one.

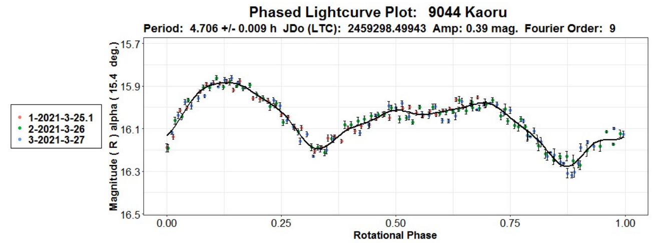


5431 Maxinehelin. The new result for synodic rotation period (P = 5.195 ± 0.003 h) obtained from the SAO observations carried out over five nights in the second half of 2020 July is identical to the previous values reported by Pravec (2013, 5.1951 h) and Stephens (2014, 5.195 h) but differs quite noticeably from the period found by Klinglesmith III et al. (2014, 4.888 h).

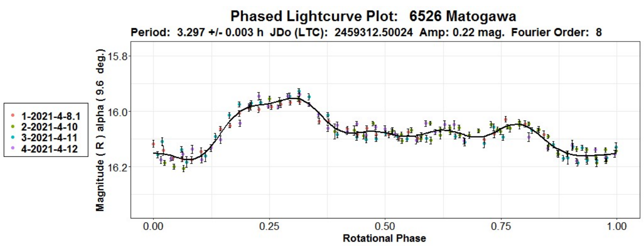


6524 Baalke. As it turned out, the rotational cycle of this inner main-belt asteroid is quite short, photometric observations at SAO on two consecutive nights in early 2021 February at low solar phase angles were sufficient to establish a lightcurve and to find a plausible rotation period. A bimodal lightcurve with an amplitude of 0.31 mag and phased to a period of P = 2.682 ± 0.005 h was constructed from the acquired data. According to the LCDB, this is the first reported rotation period this asteroid.

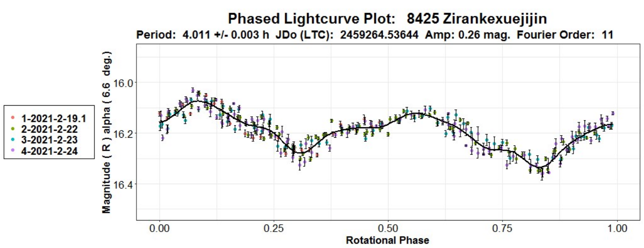




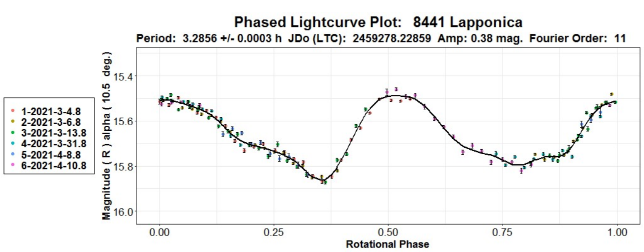
<u>6526 Matogawa</u>. There were no reports on rotation periods for this *BinAstPhot Survey* target prior to this work. Period analysis points to a value of $P = 3.297 \pm 0.003$ h as a reliable solution. The relevant photometric data were collected at SAO on four nights in early 2021 April.



<u>8425 Zirankexuejijin</u>. No previous reports on rotation period determinations for this asteroid are known. Photometric data were obtained at SAO on four nights in the second half of 2021 February yielding a bimodal lightcurve phased to a period of $P = 4.011 \pm 0.003$ h and an amplitude of 0.26 mag.

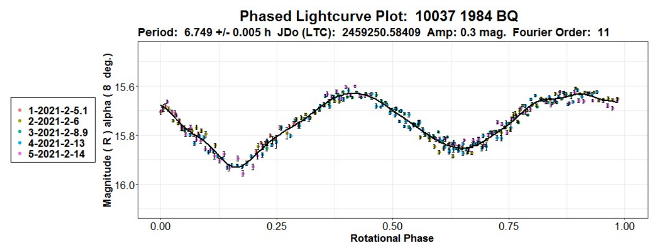


<u>8441 Lapponica</u>. The two previously determined periods by Behrend (2008, 3.27 h) and Clark (2008, 3.275 h) are consistent with the result of $P = 3.2856 \pm 0.0003$ h found from the SAO data collected on six nights in 2021 March-April.

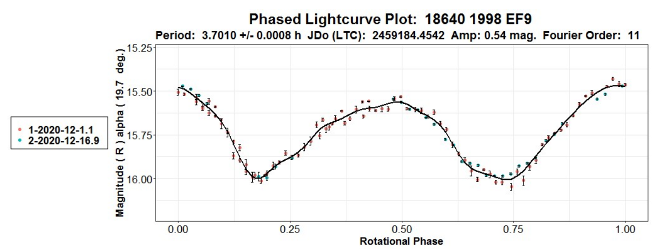


<u>9044 Kaoru</u>. This was a *BinAstPhot Survey* target with no previously known rotation period. Period analysis conducted over data collected on three consecutive nights in late 2021 March indicates an unambiguous rotation period solution of $P = 4.706 \pm 0.009$ h.

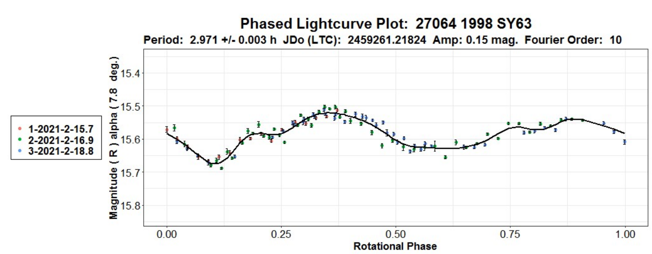
<u>(10037) 1984 BQ</u>. This Vesta family asteroid was also a *BinAstPhot Survey* target with no rotation period determination results in the LCDB. An unambiguous bimodal period solution of $P = 6.749 \pm 0.005$ h was found from the data collected on five nights in the first half of 2021 February.



<u>(18640) 1998 EF9</u>. No previous rotation periods were found in this case as well. Data taken on two nights in 2021 December led to a bimodal period solution of $P = 3.7010 \pm 0.0008$ h.



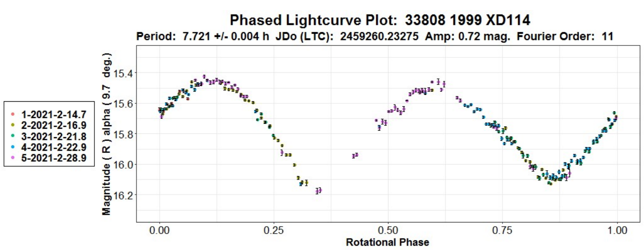
<u>(27064) 1998 SY63</u>. A check of the LCDB records points this to being the first rotation period determination for 1998 SY63. A unique period solution of $P = 2.971 \pm 0.003$ h was found analyzing the data collected on three nights in 2021 February.

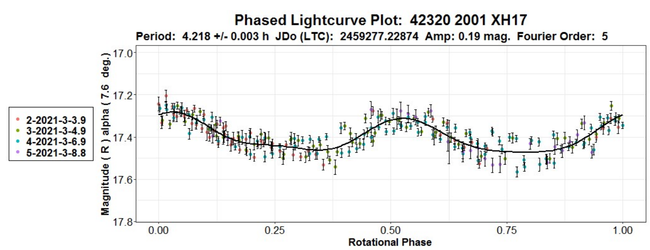


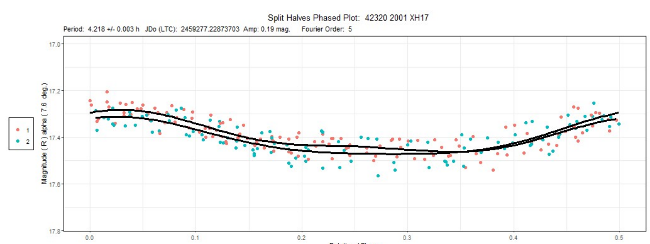
<u>(33808) 1999 XD114</u>. A high-amplitude (0.72 mag.) lightcurve associated with a period of $P = 7.721 \pm 0.004$ h arises as an unequivocal solution in period analysis performed upon the combined dataset made up of observations from 2021 February at low solar phase angles, shedding light for the first time at hitherto unknown spin rate of this inner main-belt asteroid.

Number	Name	20yy/mm/dd	Phase	L_{PAB}	B_{PAB}	Period (h)	P.E.	Amp	A.E.	Grp
440	Theodora	21/02/23-21/02/26	26.9,27.5	104	0	4.835	0.007	0.65	0.02	FLOR
1117	Reginita	21/02/24-21/02/26	11.9,11.4	181	3	2.949	0.007	0.15	0.02	FLOR
1158	Luda	21/02/23-21/02/26	24.0,24.2	89	15	6.89	0.02	0.25	0.03	EUN
1610	Mirnaya	21/01/20-21/02/03	3.2,10.4	116	3	4.745	0.002	0.33	0.03	FLOR
1675	Simonida	21/03/25-21/03/28	28.8,28.9	119	8	5.283	0.008	0.46	0.02	FLOR
2273	Yarilo	21/02/23-21/03/07	10.7,4.3	197	-1	2.8200	0.0006	0.10	0.02	MB-I
2438	Oleshko	21/02/26-21/03/11	20.7,16.0	196	5	3.2253	0.0008	0.29	0.03	FLOR
2712	Keaton	21/04/01-21/04/10	10.2,14.8	176	0	6.720	0.005	0.25	0.03	MB-I
2961	Katsurahama	21/02/28-21/03/03	11.1,12.1	141	-6	2.939	0.004	0.33	0.02	FLOR
3760	Poutanen	21/03/01-21/03/02	26.7,26.5	216	13	2.957	0.007	0.31	0.03	MB-I
4170	Semmelweis	21/03/24-21/03/27	10.6,9.9	211	7	5.30	0.02	0.53	0.02	EOS
4612	Greenstein	21/02/21-21/03/04	13.1,17.7	131	7	3.0080	0.0007	0.30	0.02	MB-I
4774	Hobetsu	21/03/03-21/03/30	5.2,18.8	157	-4	3.5770	0.0004	0.29	0.03	FLOR
4794	Bogard	21/02/23-21/03/11	14.8,6.0	179	0	2.7350	0.0004	0.14	0.02	FLOR
5431	Maxinehelin	20/07/22-20/07/30	11.9,10.5	314	14	5.195	0.003	0.17	0.02	PHO
6524	Baalke	21/02/04-21/02/06	4.1,4.9	128	2	2.682	0.005	0.31	0.02	MB-I
6526	Matogawa	21/04/08-21/04/12	9.7,7.8	213	7	3.297	0.003	0.22	0.03	FLOR
8425	Zirankexuejijin	21/02/19-21/02/24	6.6,3.7	161	0	4.011	0.003	0.26	0.03	FLOR
8441	Lapponica	21/03/04-21/04/10	10.5,26.7	152	6	3.2856	0.0003	0.38	0.02	FLOR
9044	Kaoru	21/03/24-21/03/27	15.4,14.5	209	7	4.706	0.009	0.39	0.02	FLOR
10037	1984 BQ	21/02/05-21/02/14	*8.0,6.0	146	11	6.749	0.005	0.30	0.02	V
18640	1998 EF9	20/11/30-20/12/16	19.7,13.1	102	6	3.7010	0.0008	0.54	0.02	PHO
27064	1998 SY63	21/02/15-21/02/18	7.8,9.1	137	10	2.971	0.003	0.15	0.02	FLOR
33808	1999 XD114	21/02/14-21/03/01	9.7,14.0	136	15	7.721	0.004	0.72	0.03	MB-I
42320	2001 XH17	21/03/03-21/03/08	7.8,9.2	156	14	4.218	0.003	0.19	0.06	MB-I

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, FLOR = Flora, MB-I = main-belt inner, PHO = Phocaea, EOS = Eos, V = Vestoid.







(42320) 2001 XH17 was another inner main-belt minor planet without a previously known rotation period. Despite its fairly low brightness (fainter than 17th magnitude) at the time it was observed in early 2021 March, this asteroid was selected for photometry because it was in the same CCD field of view for several nights with another much brighter newly discovered binary asteroid, 3523 Arina, and followed systematically within the *BinAstPhot Survey*.

Despite the larger data scatter, a bimodal period of P = 4.218 ± 0.003 h stands out as a statistically dominant solution in period analysis. A harmonically related half-period monomodal period value (P/2), although somewhat less statistically favorable, could not be ruled out as a possibility given the relatively small lightcurve amplitude (0.19 mag.).

This alternative solution is supported by a considerable overlap of the two lightcurve halves for the bimodal period within the data scatter, which is significant compared to the lightcurve amplitude, and so it is hard to reach a definitive conclusion based on the "split halves" test. The longer period of 4.218 h is formally adopted as a solution in this paper but further observations are highly recommended in future apparitions to verify the result.

Acknowledgements

Observational work at Sopot Astronomical Observatory is supported by a 2018 Gene Shoemaker NEO Grant from The Planetary Society.

References

Alvarez-Candal, A.; Duffard, R.; Angeli, C.A.; Lazzaro, D.; Fernandez, S. (2004). "Rotational Lightcurves of Asteroids Belonging to Families." *Icarus* **172**, 388-401.

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. (2005, 2007, 2008, 2010, 2018). Observatoire de Geneve web site. *http://obswww.unige.ch/~behrend/page_cou.html*

Benishek, V. (2018). "Lightcurve and Rotation Period Determinations for 29 Asteroids." *Minor Planet Bull.* **45**, 82-91.

Benishek, V. (2020). "Asteroid Photometry at Sopot Astronomical Observatory: 2019 June-October." *Minor Planet Bull.* **47**, 75-83.

Chang, C.-K.; Lin, H.-W.; Ip, W.-H.; Chen, W.-P.; Yeh, T.-S.; Chambers, K.C.; Magnier, E.A.; Huber, M.E.; Flewelling, H.A.; Waters, C.Z.; Wainscoat, R.J.; Schultz, A.S.B. (2019). "Searching for Super-fast Rotators Using the Pan-STARRS 1." *Astrophys. J. Suppl. Series* **241**, 6.

Clark, M. (2008). "Asteroid Lightcurve Observations." *Minor Planet Bull.* **35**, 152-154.

Florczak, M.; Dotto, E.; Barucci, M.A.; Birlan, M.; Erikson, A.; Fulchignoni, M.; Nathues, A; Perret, L.; Thebault, P. (1997). "Rotational properties of main belt asteroids: photoelectric and CCD observations of 15 objects." *Planetary and Space Science*, **45**, 1423-1435.

Franco, L.; Marchini, A.; Baj, G.; Scarfi, G.; Succi, G.; Bachini, M.; Arena, C. (2018). "Lightcurves for 91 Aegina, 235 Carolina, 1117 Reginita, and (505657) 2014 SR339." *Minor Planet Bull.* **45**, 399-400.

Hanuš, J.; Durech, J.; Broz, M.; Warner, B.D.; Pilcher, F.; Stephens, R.; Oey, J.; Bernasconi, L.; Casulli, S.; Behrend, R.; Polishook, D.; Henych, T.; Lehký, M.; Yoshida, F.; Ito, T. (2011). "A study of asteroid pole-latitude distribution based on an extended set of shape models derived by the lightcurve inversion method." *Astron. Astrophys.* **530**, A134.

Kim, M.-J.; Choi, Y.-J.; Moon, H.-K.; Byun, Y.-I.; Brosch, N.; Kaplan, M.; Kaynar, S.; Uysal, O.; Guzel, E.; Behrend, R.; Yoon, J.-N.; Mottola, S.; Hellmich, S.; Hinse, T.C.; Eker, Z.; Park, J.-H. (2014). "Rotational Properties of the Maria Asteroid Family." *Astron. J.* **147**, A56.

Klinglesmith III, D.A.; Hanowell, J.; Risley, E.; Turk, J.; Vargas, A.; Warren, C.A. (2014). "Asteroid Observations at the Etscorn Campus Observatory." *Minor Planet Bull.* **41**, 82-84.

Kryszczynska, A.; Colas, F.; Polinska, M.; Hirsch, R.; Ivanova, V.; Apostolovska, G.; Bilkina, B.; Velichko, F.P.; Kwiatkowski, T.; Kankiewicz, P. and 20 colleagues. (2012). "Do Slivan states exist in the Flora family? I. Photometric survey of the Flora region." *Astron. Astrophys.* **546**, A72.

Pal, A.; Szakáts, R.; Kiss, C.; Bódi, A.; Bognár, Z.; Kalup, C.; Kiss, L.L.; Marton, G.; Molnár, L.; Plachy, E.; Sárneczky, K.; Szabó, G.M.; Szabó, R. (2020). "Solar System Objects Observed with TESS - First Data Release: Bright Main-belt and Trojan Asteroids from the Southern Survey." *Ap. J. Supl. Ser*. **247**, 26-34.

Pravec, P. (2013). Photometric Survey for Asynchronous Binary Asteroids web site. *http://www.asu.cas.cz/~ppravec/newres.txt*

Pray, D.P. (2005). "Lightcurve Analysis of Asteroids 276, 539, 1014, 1067, 3693, and 4774." *Minor Planet Bull.* **32**, 8-9.

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. *https://www.R-project.org/*

Salvaggio, F.; Marchini, A.; Papini, R. (2017). "Rotation Period Determination for 3760 Poutanen and 14309 Defoy." *Minor Planet Bull.* **44**, 354-355.

Stephens, R.D. (2014). "Asteroids Observed from CS3: 2013 July-September." *Minor Planet Bull.* **41**, 13-15.

VizieR (2021). *http://vizier.u-strasbg.fr/viz-bin/VizieR*

Warner, B.D. (2005). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory - Winter 2004-2005." *Minor Planet Bull.* **32**, 54-58.

Warner, B.D.; Harris, A.W.; Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2020 Oct 22. *http://www.minorplanet.info/lightcurvedatabase.html*

Warner, B.D. (2011a). "Upon Further Review: III. An Examination of Previous Lightcurve Analysis from the Palmer Divide Observatory." *Minor Planet Bull.* **38**, 21-23.

Warner, B.D. (2011b). "Upon Further Review: V. An Examination of Previous Lightcurve Analysis from the Palmer Divide Observatory." *Minor Planet Bull.* **38**, 63-65.

Warner, B.D. (2012). The MPO Users Guide: A Companion Guide to the MPO Canopus/PhotoRed Reference Manuals. BDW Publishing, Colorado Springs, CO.

Warner, B.D. (2018). *MPO Canopus* software, version 10.7.11.3. *http://www.bdwpublishing.com*

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.

Wisniewski, W.Z.; Michalowski, T.M.; Harris, A.W.; McMillan, R.S. (1997). "Photometric Observations of 125 Asteroids." *Icarus* **126**, 395-449.