

PHOTOMETRIC OBSERVATIONS AND ANALYSIS OF EIGHT ASTEROIDS FROM MALTA, SLOVAKIA AND ESTONIA

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We report the results of our photometric observations of eight main-belt asteroids from six observatories in Malta, Slovakia, and Estonia. We obtained the lightcurves for the following asteroids, which can facilitate future analysis of these objects at different oppositions: 894 Erda; 914 Palisana; 2286 Fesenkov; 2360 Volgo-Don; 3710 Bogoslovskij; 3852 Glennford; 6898 Saint-Marys; and (23552) 1994 NB.

We conducted photometric observations of eight main-belt asteroids from four observatories located on the Maltese mainland, one at Važec, Slovakia and another at Tartu, Estonia. Through these observatories listed in Table 1, we have observed the following asteroids: 894 Erda, 914 Palisana, 2286 Fesenkov, 2360 Volgo-Don, 3710 Bogoslovskij, 3852 Glennford, 6898 Saint-Marys, and (23552) 1994 NB. Except for the images gathered at Tartu Observatory for which a Cousins R-filter was used, we employed a clear filter (unfiltered) with PR (Pan-STARRS r) zero point for all other images. All of our images were calibrated through dark-frame subtraction and flat-field division.

We remotely controlled all of our equipment over the Internet or from a nearby location for each telescope. Operations at Tartu Observatory were performed through direct control on site by C. Galdies. We used *Sequence Generator Pro* (Binary Star Software) for image acquisition by all Maltese Observatories. Luckystar Observatory used the *NINA* image acquisition software (Berg, 2023) while at Tartu Observatory, *Maxim DL* software was

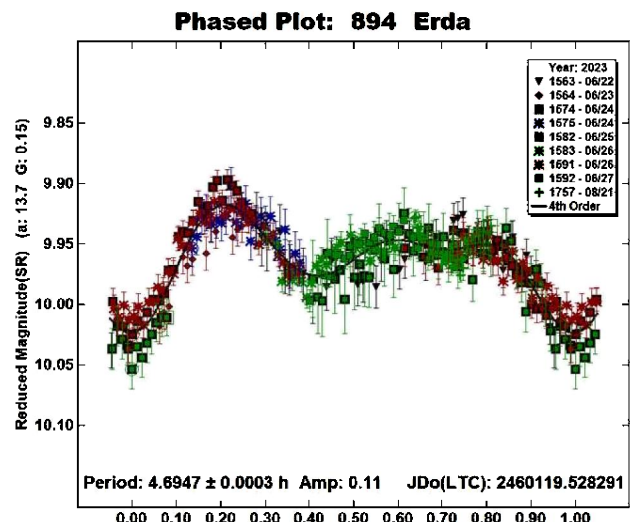
employed. We used *MPO Canopus* software (Warner, 2017) for our image analysis, to obtain differential aperture photometry, and to construct lightcurves. Table I displays the details of the instrumentation and observation runs for each target. We selected near-solar color comparison stars using the Comparison Star Selector (CSS) feature of *MPO Canopus*. We based all brightness measurements on the Asteroid Terrestrial-impact Last Alert System (ATLAS) catalogue (Tonry et al., 2018).

Observatory Country	Ap (m) Type	Camera	Asteroids (#Runs)
Antares MALTA	0.28 SCT	SBIG ST-11	2360 (5)
Flarestar (171) MALTA	0.25 SCT	Moravian G2-1600	894 (7) 914 (5) 2360 (4)
Luckystar (M55) SLOVAKIA	0.25 SCT	Atik 460EX	3710 (3) 6898 (6) 23552 (3)
Manikata MALTA	0.20 SCT	SBIG ST-9	2286 (3)
Tartu (L75) ESTONIA	0.60 Zeiss 600 L	Andor iKon-L 936	894 (1)
Znith Obs. MALTA	0.20 SCT	Moravian G2-1600	3852 (4)

Table I. Instrumentation and Observation Runs. SCT: Schmidt-Cassegrain Telescope; L: Reflector. Observatory column gives the MPC code.

894 Erda is an outer main-belt asteroid that was discovered on 1918 Jun 4 by M. Wolf at Heidelberg. This asteroid was named for the Norse goddess, incarnation of the nature and a seer who knows the origin and the destination of all things (Schmadel, 2003). It has an estimated diameter of 28.3 ± 1.5 km diameter, based on H of 9.87. It orbits the Sun with a semi-major axis of 3.117 au with an eccentricity of 0.11 and period of 5.5 years (JPL, 2023).

This asteroid was previously observed by Behrend (2023web); Stephens (2002); Higgins and Goncalves (2007); and Benishek (2022).



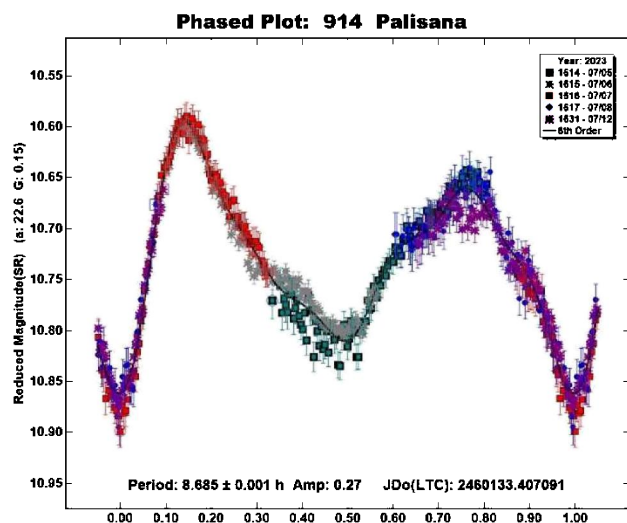
During this observing campaign, Flarestar Observatory observed this target for a period of seven nights from 2023 June 22-27. Tartu Observatory in Estonia also contributed to the data by conducting another observation run of this asteroid on 2023 August 21 using a 0.6-m reflector Zeiss 600. The data obtained from Tartu Observatory merged effectively with the data acquired from Flarestar Observatory.

From our analysis, we derived a synodic period of 4.6947 ± 0.0003 h with an amplitude of 0.11 ± 0.02 magnitude. The period is consistent with the previously published results.

914 Palisana is a carbonaceous asteroid that is taxonomic CU under the Tholen Classification. The letter U is assigned when an object possesses an unusual spectrum for its type. This makes Palisana an interesting object because type CU objects are uncommon. It was discovered on 1919 July 4 by M. Wolf at Heidelberg and is named in honor of the well-known Austrian astronomer Johann Palisana (1848-1925), who was an observer at the Marine Observatory in Pola (now Pula, Croatia) (Schmadel, 2003).

The Small-Body database and JPL (2023) list the asteroid as having a diameter of 76.190 ± 0.486 km by NEOWISE (Masiero et al., 2014) and orbits the Sun with a semi-major axis of 2.457 au. Its orbit has an eccentricity of 0.214 and a period of 3.853 years (JPL, 2023).

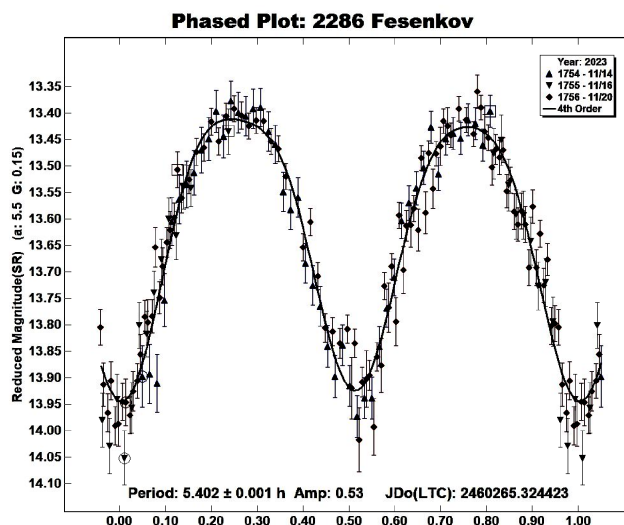
Palisana was observed from Flarestar Observatory on five nights. Our results yielded a synodic period of 8.685 ± 0.001 h with an amplitude of 0.27 ± 0.02 mag, which is consistent with the previously published results by Colazo et al. (2022) and Stephens and Warner's (2020) period 1 of 8.686 ± 0.03 h.



2286 Fesenkov is a main-belt asteroid that was discovered by N.S. Chernykh at the Crimean Astrophysical Observatory on 1977 July 14. The asteroid was named in memory of Vasilej Grigor'evich Fesenkov (1889-1972), one of the founders of the study of astrophysics in the former Soviet Union (Schmadel, 2003). Notably, he served as the editor of the *Astronomicheskij Zhurnal* from 1924 to 1964 and assumed the role of Chairman of the Committee on Meteorites of the U.S.S.R. Academy of Sciences from 1945 onward.

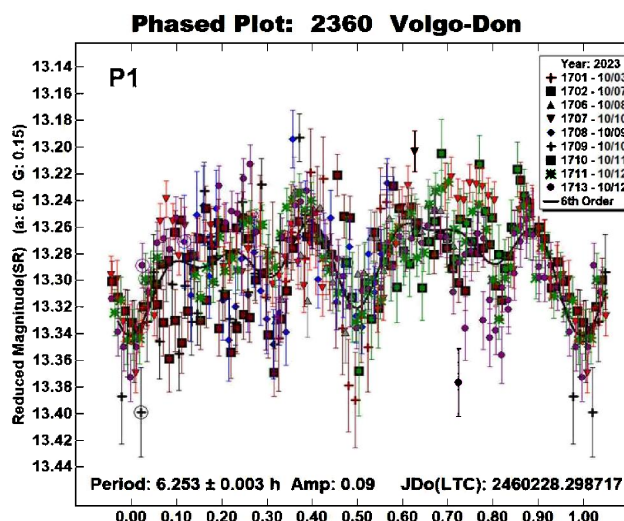
Based on NEOWISE data (Masiero et al., 2012), the estimated diameter is 6.691 ± 0.103 km. The absolute magnitude is $H = 13.11$. This minor planet orbits the Sun with a semi-major axis of 2.193 au, eccentricity of 0.093, and period of 3.25 years (JPL, 2023).

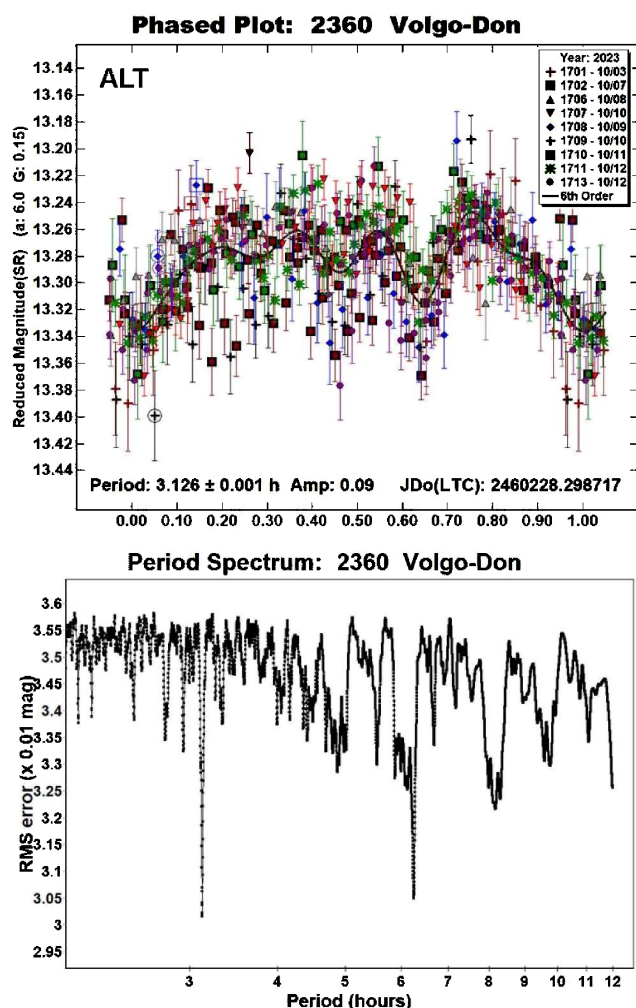
With the aim to improve the quality of the published period by Waszczak et al. (2015) of 5.404 ± 0.0025 h ($U=2$), observations of Fesenkov were acquired from Manikata Observatory over three nights from 2023 November 14 to 20. Our results are consistent with those obtained by Waszczak et al., our synodic period being 5.402 ± 0.001 h with an amplitude of 0.53 ± 0.03 mag.



2360 Volgo-Don (1975 VD3) is a middle main-belt asteroid that was discovered on 1975 November 2 by T. Smirnova at Nauchnyj (Schmadel, 2003). It was named on the occasion of the 30th anniversary of the construction of the Volgo-Don Navigation Canal, which connects the Volga and Don rivers at their closest approach.

NEOWISE data gives an estimated diameter of 9.692 ± 0.071 km (Masiero et al., 2014). This absolute magnitude is $H = 13.05$. The orbit has a semi-major axis of 2.672 au with an eccentricity of 0.196. The orbital period is 3.19 years (JPL, 2023).





Because the asteroid had no published period that we could find, it was picked for observation by Flarestar and Antares Observatories. Our results produced two possible lightcurve solutions, with the preferred one (P_1) being 6.253 ± 0.003 h ($A = 0.09 \pm 0.04$ mag). The alternate solution of 3.126 ± 0.001 h (amp. 0.09 ± 0.04 mag.) is the half-period. Both solutions share a similar RMS with the shorter period having slightly lower residuals.

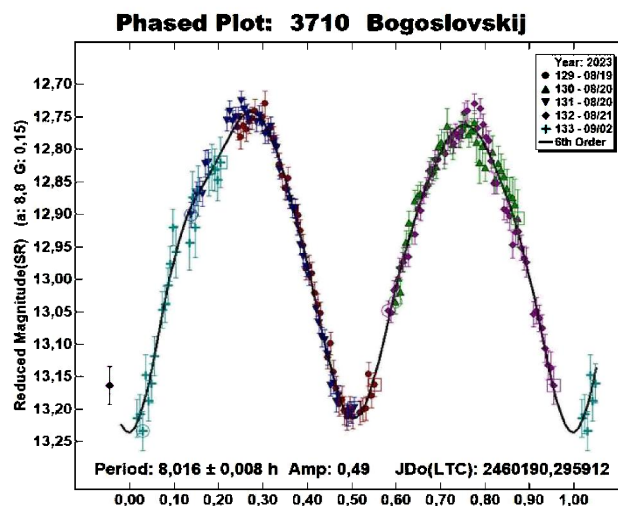
In our opinion, close inspection of the lightcurve reveals that the 6.253 h period is more likely due to a more coherent fitting to a somewhat symmetrical bi-modal solution. Additional follow-up for this asteroid is encouraged to uncover its true period.

3710 Bogoslovskij (1978 RD6) is a main-belt asteroid that was discovered on 1978 September 13 by N. Chernykh at Nauchnyj. It is named in honor of Nikita Bogoslovskij, a well-known contemporary composer and writer, on the occasion of his eightieth birthday (Schmadel, 2003).

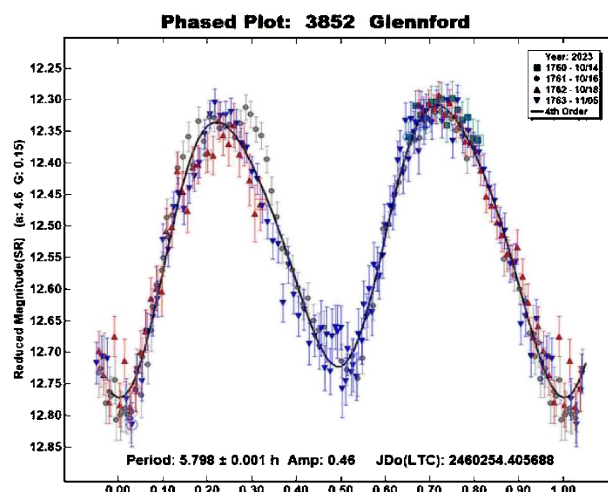
The estimated diameter is 11.625 ± 0.196 km (Masiero et al., 2012). The absolute magnitude is listed as $H = 12.76$. The semi-major axis is 2.74 au and the orbital eccentricity is 0.159. A year for the asteroid is equivalent to 3.17 Earth-years (JPL, 2023).

3710 Bogoslovskij was observed from Luckystar Observatory on three nights from 2023 August 19 to September 7. Our result is consistent with Behrend (2023web), who observed the asteroid

around the same time. He reported the rotation period to be 8.0138 ± 0.0004 h. Our solution was 8.016 ± 0.008 h with an amplitude of 0.49 ± 0.02 mag.



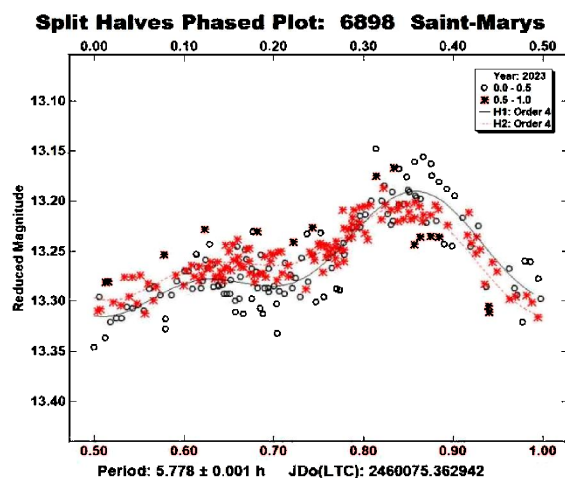
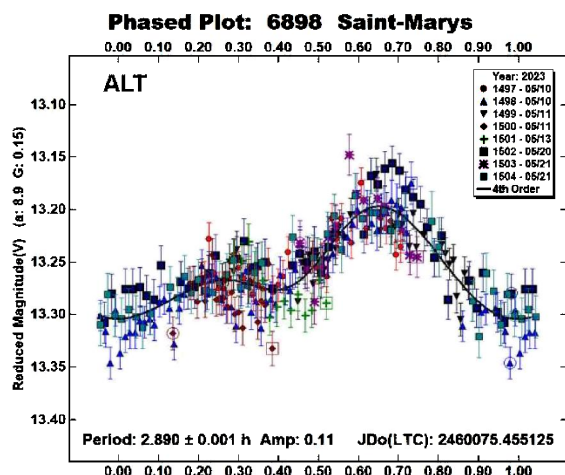
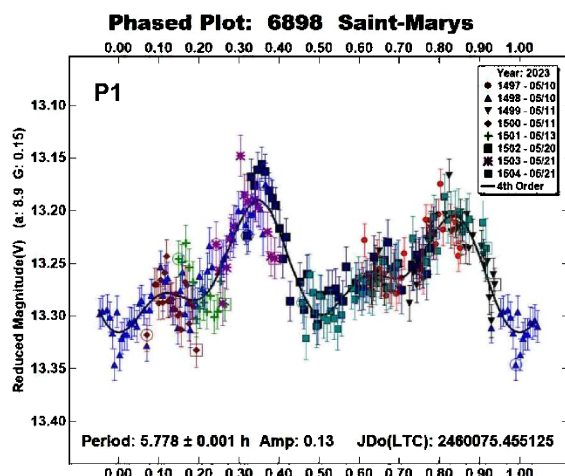
3852 Glennford is a main-belt asteroid that was discovered on 1987 February 24 by H. Debehogne at the European Southern Observatory. The diameter of this asteroid is estimated to be 18.510 ± 0.179 km (Masiero et al., 2011) and has an absolute magnitude of $H = 12.37$. The semi-major axis is 3.105 au, which yields an orbital period of 3.71 years. 3852 Glennford is named after the Canadian-born actor Glenn Ford (1916-2006), who appeared in more than 100 movies covering virtually every genre, from westerns to science fiction (Schmadel, 2003).



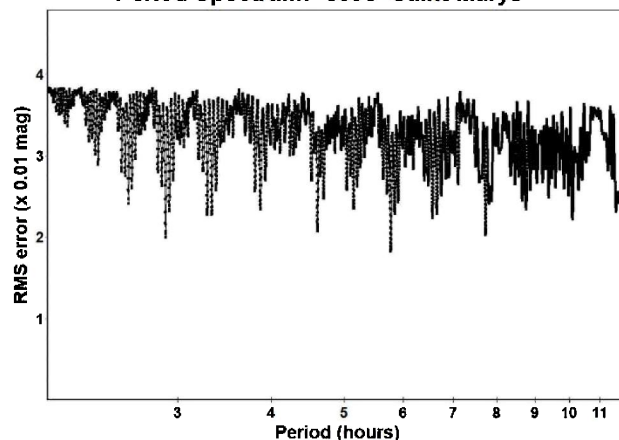
We observed on four nights from Znith Observatory, where we derived the synodic period to be 5.798 ± 0.001 h with an amplitude of 0.46 ± 0.03 mag. Our result is consistent with that published by Ďurech et al. (2019).

6898 Saint-Marys (1998 LE) is a main-belt asteroid that belongs to the 502 Eunomia family (Nesvorný et al., 2015). It was discovered on 1988 June 8 by C.S. Shoemaker at Palomar. Its estimated diameter is 8.447 ± 0.130 km (Masiero et al., 2014). It orbits the Sun with a semi-major axis of 2.665 au and has an eccentricity of 0.123. The asteroid completes one orbit around the sun every 4.35 years (JPL, 2023).

We observed 6898 from Luckystar Observatory on six nights from 2023 May 10-21. Based on these observations, we determined the synodic period to be 5.778 ± 0.001 hours, with an amplitude of 0.13 ± 0.02 mag. The shape of the lightcurve for that period is bimodal. Close inspection of the lightcurve reveals two bumps prior to the peak brightness. Although it is possible that these are real features, this prompted us to check whether or not the half-period was the correction solution.

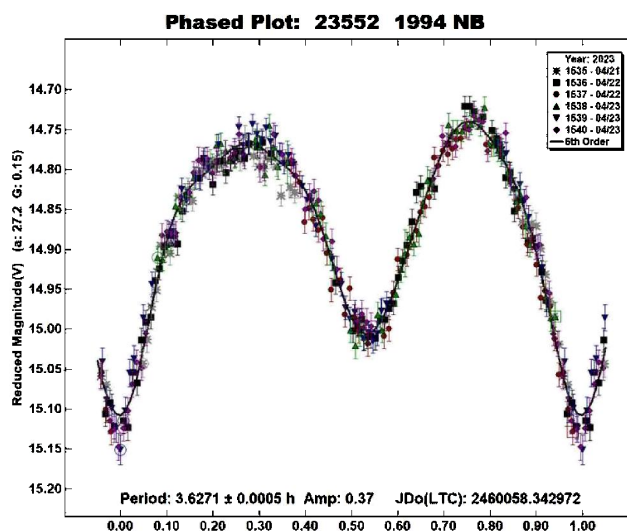


Period Spectrum: 6898 Saint-Marys



The split-halves plot showed a similar distribution with some deviations that did not allow us to confidently determine its true period. Hence, we cannot rule out the alternative period (ALT) of 2.890 ± 0.001 h with an amplitude of 0.11 ± 0.03 mag. The LCDB database did not contain any previous results.

(23552) 1994 NB is a main-belt asteroid that belongs to the Phocaea family. This asteroid was discovered on 1994 July 3 by E.F. Helin, at Palomar Observatory. The absolute magnitude is $H=13.68$. The orbit has a semi-major axis of 2.364 au and eccentricity of 0.277. The orbital period is 3.63 years (JPL, 2023).



(23552) 1994 NB was observed from Luckystar Observatory over three nights from 2023 April 21-23. Our synodic period of 3.6271 ± 0.0005 h is consistent with results from Loera-González et al. (2023) and Skiff et al. (2023). The amplitude is 0.37 ± 0.03 mag.

Number	Name	2023 mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
894	Erda	06/22-08/21	14.0,12.0	302	15	4.6947	0.0003	0.11	0.02	MB
914	Palisana	07/05-07/12	22.8,21.6	309	27	8.685	0.001	0.27	0.02	MB
2286	Fesenkov	11/14-11/20	6.0,2.5	61	0	5.402	0.001	0.53	0.03	MB
2360	Volgo-Don	10/03-10/12	6.5,1.8	20	-2	6.253	0.003	0.09	0.04	MB
						3.126	0.001	0.09	0.04	
3710	Bogoslovskij	08/19-09/02	9.1,7.5	335	14	8.016	0.008	0.49	0.02	MB
3852	Glennford	10/14-11/05	4.6,5.8	30	1	5.798	0.001	0.46	0.03	Themis
6898	Saint-Marys	05/10-05/21	8.8,11.3	223	15	5.778	0.001	0.13	0.02	Eunomia
						2.890	0.001	0.11	0.03	
23552	1994 NB	04/21-04/23	27.0,27.4	197	36	3.6271	0.0005	0.37	0.02	Phocaea

Table II. Observing circumstances and results. The phase angle is given for the first and last date. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009).

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LIGHTCURVE AND ROTATION PERIOD ANALYSIS OF 1887 VIRTON AND 4099 WIGGINS

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Photometric observations of two main-belt asteroids were obtained between 2023 July 13 and 2023 November 11. The following rotational periods were determined: 1887 Virton, 70.165 ± 0.003 h; 4099 Wiggins, 10.985 ± 0.001 h.

Photometric images obtained for this report were obtained from observatories around the globe. Several of the co-authors used their own equipment and some used the iTelescope or Las Cumbres Observatory facilities.

Photometry analysis and period determination were carried out using *TychoTracker Pro* Version 10.8.5. (TT), easily performing both functions. Photometric analysis was done using standard differential techniques on images. The TT software has the facility to allow the user to choose comparison stars, for which the default color range of $+0.50 < (B-V) < +0.90$ was employed. The ATLAS catalog (Tonry et al., 2018) was used as the source of reference stars for both asteroids. TT's period determination operates by finding model light curves - comprising a user-defined number of Fourier components which best fit the asteroid photometric data. The program lists the candidate periods found within a user-defined period range and sampling frequency, based on minimizing Root Mean Square Errors (RMSE), i.e. using the difference between modelled and photometric magnitudes. The candidate periods are listed in increasing RMSE value and the entire suite of RMSE values is plotted as a "periodogram" for quality control.

In these periodograms both objects yielded clear 'best-fit' period solutions having well-defined 'stalactites' as shown in the following Figures. Neither asteroid has a value for its rotational period listed in the current issue of the LCDB (Warner et al., 2009).

Periodograms often exhibit several possible candidate periods, in which case an examination of the rotational phase plot for each of these is then conducted looking for a credible lightcurve. Where the object shape is the dominant factor in producing the observed magnitude changes, (typically having lightcurve amplitudes of >0.2 mag), the rotational phase plot often has two peaks and two troughs (bimodal) and this is usually chosen as the most likely for such asteroids.

In this paper there is no attempt to find an absolute magnitude for any of the asteroids and a value of $G = 0.15$ has been used throughout the calculations. Time-series from different nights and observing locations using a variety of imaging equipment were offset in magnitude to bring them into alignment when producing the raw and rotational-phase plots. The same offset was used for each instance of an individual imaging setup. When this paper is accepted for publication all the observations will be loaded into the ALCDEF database. Some individual datapoints have been combined by stacking during period analysis to improve the signal-to-noise ratio.

The results are summarized in the table below. Column 3 gives the span of dates over which the observations were made. Column 4 is the range of phase angles for each date range, if this is preceded by an asterisk this means the asteroid passed through minimum phase