

PHOTOMETRIC INVESTIGATION AND ROTATIONAL CHARACTERIZATION OF SEVEN MAIN-BELT ASTEROIDS

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This study presents photometric measurements and lightcurve analysis for seven main-belt asteroids using observatories in Malta, Slovakia, Canada, and the United States. Synodic rotation periods and amplitudes were determined for 612 Veronika, 1532 Inari, 2240 Tsai, 4288 Tokyotech, 9333 Hiraimasa, (13042) 1990 QE, and (26187) 1996 XA27. These results enhance the understanding of the asteroids' rotational properties and highlight the importance of multi-site observations.

Photometric observations of seven main-belt asteroids were carried out from six observatories located on the Maltese mainland, Slovakia, Canada and the United States. Observations of asteroids for 612 Veronika, 1532 Inari, 2240 Tsai, 4288 Tokyotech, 9333 Hiraimasa, (13042) 1990 QE, and (26187) 1996 XA27 were

obtained from the observatories shown in Table I. All of our images were taken through a clear filter (or unfiltered) with Rc zero-point and calibrated through dark and flat-field subtraction.

Our equipment was either controlled remotely over the Internet or from a location near each telescope. Image acquisition was conducted via *Sequence Generator Pro* (Binary Star Software) by all Maltese Observatories. The Slovakian and Canadian observatories employed the *NINA* telescope control software (Berg, 2023) to acquire their images and for telescope automation. RIT Observatory employed *Maxim DL* (Ver. 6.16) for their observatory operations and image acquisition. For our image analysis, we used version 10 of *MPO Canopus* software (Warner, 2017), to gather differential aperture photometry and for lightcurve construction. Table I shows details of the instrumentation used and observation runs for each respective target. We used the Comparison Star Selector (CSS) feature developed by *MPO Canopus* to choose near-solar color comparison stars. All brightness measurements were based on the Asteroid Terrestrial-impact Last Alert System (ATLAS) catalogue (Tonry et al., 2018).

Observatory	Tel and Type	Camera	Observed Asteroids (#Runs)
Antares Obs.	0.28-m SCT	SBIG ST-11	9333 (6)
Flarestar Obs. (MPC: 171)	0.25-m SCT	Moravian G2-1600	612 (5) 1532 (9) 4288 (3)
Luckystar Obs. (MPC: M55)	0.25-m SCT	Atik 460EX	13042 (2) 26187 (4)
Stellar Horizon Obs.	0.30-m SCT	ASI 6200MM	1532 (1)
RIT Obs. (MPC: 920)	0.30-m SCT	ASI 6200MM	1532 (2)
A la belle étoile Obs.	0.2-m MK	Moravian G2-1600	1532 (3)
Znith Obs.	0.2-m SCT	Moravian G2-1600	1532 (1) 2240 (3)

Table I. Instrumentation and Observation Runs. SCT: Schmidt-Cassegrain; MK: Maksutov-Cassegrain

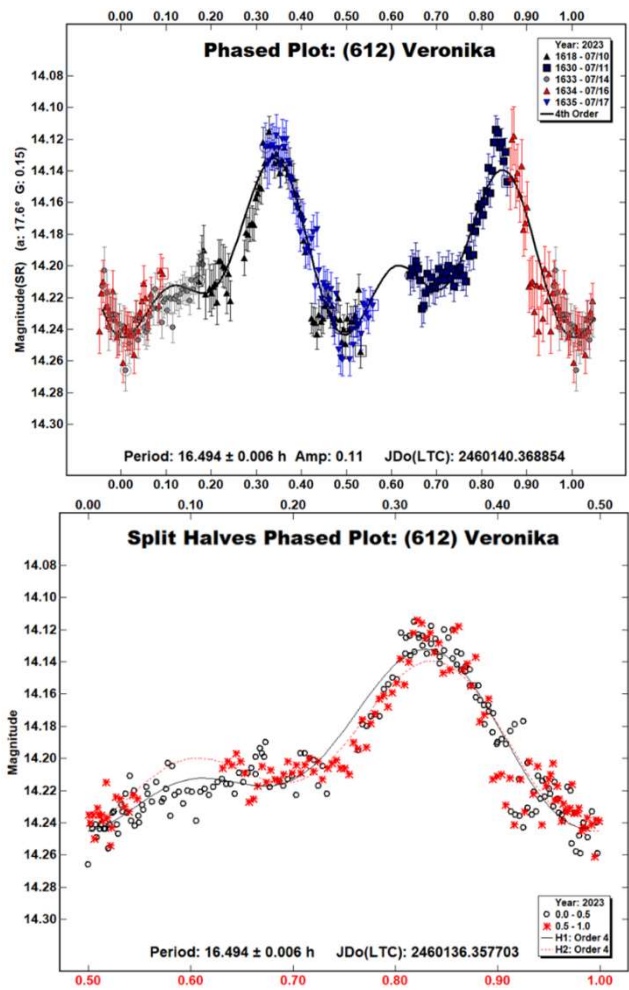
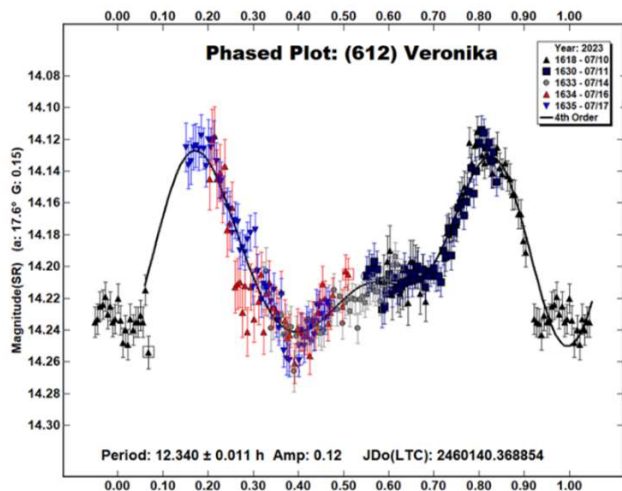
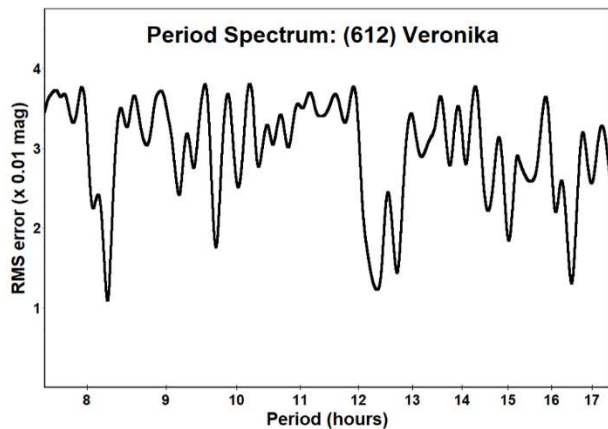
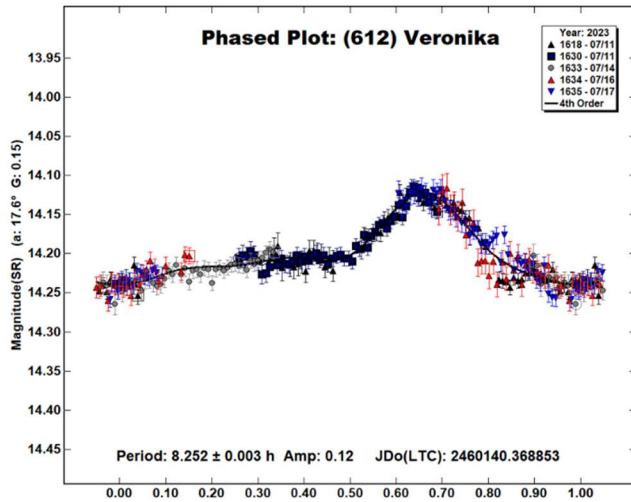
612 Veronika is a main-belt asteroid that was discovered on 1906 October 8 by A. Kopff at Heidelberg. Although this asteroid was named after “Veronika,” Schmadel (2012) states that the reference to this name to a person or occurrence is unknown.

According to the Small-Body Database at JPL, asteroid Veronika has an estimated diameter of 138.767 ± 0.519 km based on an absolute magnitude (H) of 10.93. It orbits the sun with a semi-major axis of 3.153 AU with an eccentricity of 0.259 and period of 5.559 years (JPL, 2024). The Asteroid Lightcurve Database (LCDB; Warner et al., 2009) lists asteroid 612 Veronika as having a rotation period of 8.243 h with an amplitude that ranges from 0.09 to 0.14 mag.

(612) Veronika was observed from Flarestar Observatory over five nights from 2023 July 11-17. Data analysis derived its synodic rotation period as 8.252 ± 0.003 h with an amplitude of 0.12 ± 0.03 mag. This solution is in line with the results published in the LCDB database. The resultant period spectrum reveals two other possible periods of 12.340 ± 0.011 h with an amplitude of 0.12 mag and

another at double the period of the 8.252 h solution at 16.494 ± 0.006 h with an amplitude of 0.11 mag.

The split-halves plot of the 16.494 h period shows that the two halves of the double period are morphologically quite similar, thus allowing for the published period of 8.252 h. Hence, we believe that the 8.252 h is the correct period. The period spectrum distinctly shows a possible solution of 12.340 h, but this likely a half-rotation period alias since it is half-way between 8.25 h and 16.50 h.



1532 Inari is a stony main-belt asteroid that belongs to the 606 Eos Family and was discovered on 1938 September 16 by Y. Vaisala at Turku. This asteroid was named after one of the principal lakes of Finland (Schmadel, 2012).

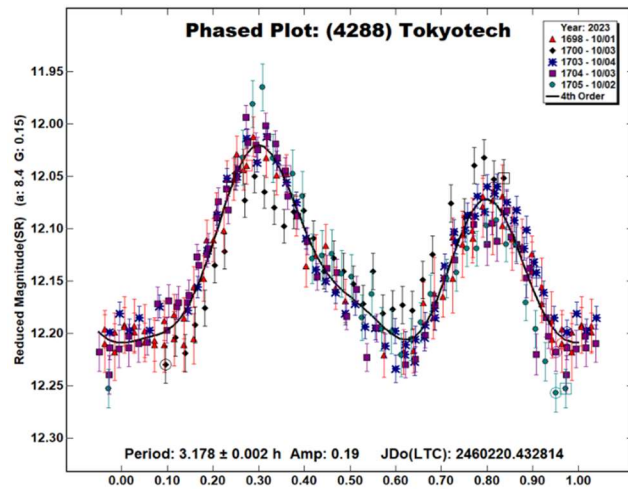
The LCBD (Warner et al., 2009) lists Inari as having an average estimated diameter of 28.42 km with an absolute magnitude of $H = 10.75$. The asteroid orbits the sun at a semi-major axis of 3.004 AU. Its orbit has an eccentricity of 0.047 and a period of 5.207 years (JPL, 2024).

Prior to this observation campaign, the LCBD database listed the rotation period of this asteroid as around 25 hours with a maximum amplitude of 0.09 with a U quality value of 1+ (Behrend, 2008web). The year 2024 was marked by presenting an opportunity to observe this asteroid during an apparition that exhibits one of five brighter observation opportunities from 1995-2050. As the 25-hour period is nearly commensurate with Earth's rotation period, we sent a call for observations to international observatories away from our usual central European locations.

In addition to the data supplied by the European Observatories (Flarestar Observatory: Stellar Horizon Observatory and Znith Observatory), we received data from *Observatoire à la belle étoile* in Canada and from the Rochester Institute of Technology University (RIT Observatory) in the US.

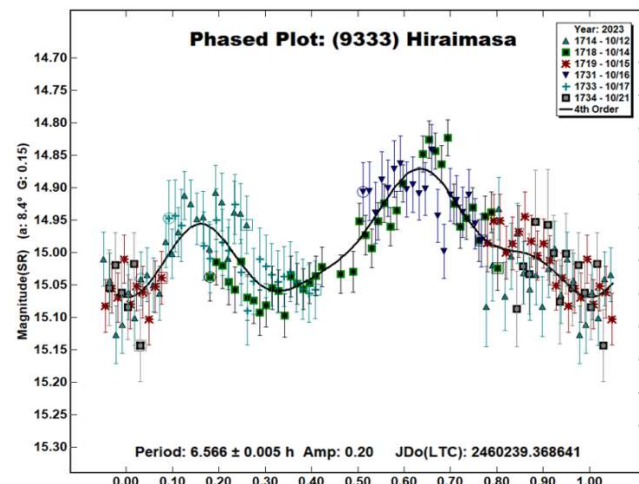
4288 Tokyotech has been reported to be a binary system (Augustin et al., 2019). As observed during 2019, 2.6-hr-long mutual phenomena were detected by the authors. Their results show that the body rotates at a period of 3.18 ± 0.00024 h and has an amplitude of 0.18 magnitude. Attenuations up to 0.15 mag were observed with a period of 30.276 h that were the result of the satellite making mutual phenomena.

The asteroid was observed over three nights from 2023 October 1-4. Our results yielded a composite rotation period of 3.178 ± 0.002 h and amplitude of 0.19 ± 0.03 mag. Our derived period is consistent with that of Augustin et al. (2019) published as 3.1800 ± 0.0003 h in the LCDB.



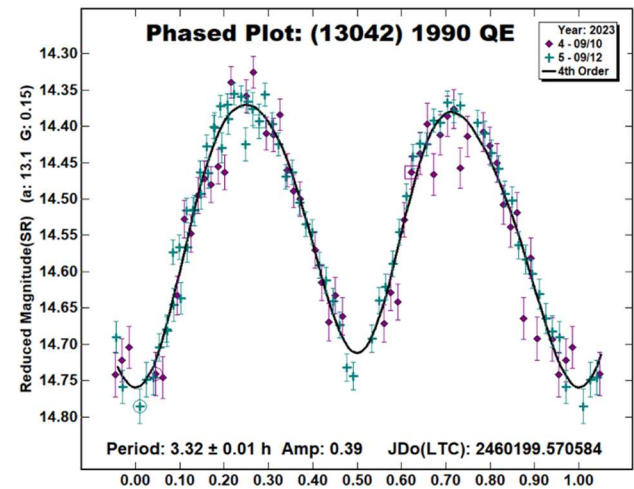
(9333) Hiraimasa is an inner main-belt asteroid that was discovered on 1990 Oct 15 by K. Endate and K. Watanabe at Kitami, Japan. This asteroid has been named in honor of Professor Masanori Hirai (b. 1943) who has specialized in stellar spectroscopic studies of cool stars with a focus on carbon stars. The estimated diameter was derived to be 9.651 ± 0.161 km based on an absolute magnitude $H = 12.93$; it orbits the sun with a semi-major axis of 2.581 AU. The orbit has an eccentricity of 0.176 and period of 4.15 years (JPL, 2024).

9333 Hiraimasa was observed from Antares Observatory on six nights between 2023 October 12 and October 21. We determined the period of asteroid Hiraimasa to be 6.566 ± 0.005 h with an amplitude of 0.20 ± 0.04 mag. Our period is near the published period of 6.911 h that was based on a $U = 2+$ value (Polakis, 2020).

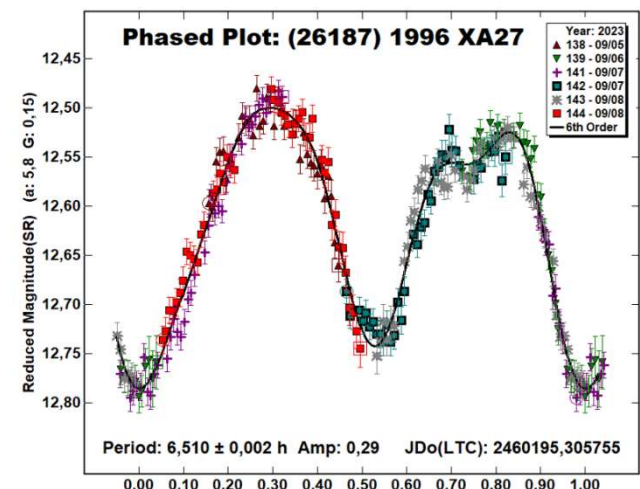


(13042) 1990 QE is a middle main-belt asteroid that belongs to the 2007 Prokne Family. This asteroid was discovered on 1990 August 18 by E.F. Helin at Palomar. The LCDB lists the diameter of this asteroid as 5.69 km with an absolute magnitude of $H = 13.94$. The asteroid orbits at a semi-major axis of 2.568 AU with an eccentricity of 0.240. The orbital period of this asteroid is 4.12 years (JPL, 2024).

1990 QE was observed on two nights from Luckystar Observatory. The derived synodic period was found to be 3.32 ± 0.01 h with an amplitude of 0.39 ± 0.03 mag. No published period could be found for (13042) 1990 QE in the LCDB.



(26187) 1996 XA27 is a main inner-belt asteroid that belongs to the 2011 Klumpkea family. This asteroid was discovered on 1996 December 12 by the Beijing Schmidt CCD Asteroid Program at Xinglong. The LCDB lists an estimated diameter of 9.6 ± 0.2 km based on an absolute magnitude $H = 12.29$. This asteroid orbits the Sun at a semi-major axis of 3.109 AU with an eccentricity of 0.247. The orbital period is 4.48 years (JPL, 2024).



(26187) 1996 XA27 was observed from Luckystar Observatory on four nights from 2023 September 5-8, from which we derived the synodic period to be 6.510 ± 0.002 h with an amplitude of 0.29 ± 0.02 mag. No published period could be found the LCDB for this asteroid.

Number	Name	yyyy mm/dd	Phase	L _{PAB}	B _{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
612	Veronika	2023 07/11-07/17	24.8, 24.7	333	14	8.252	0.003	0.12	0.03	MB
1532	Inari	2024 02/04-04/08	5.8, 16.4	150	0	266.6	0.2	1.48	0.06	Eos
2240	Tsai	2024 01/23-02/06	4.9, 10.4	112	1	4.284	0.001	0.23	0.06	Themis
4288	Tokyotech	2023 10/01-10/04	8.4, 9.0	2	-13	3.178	0.002	0.19	0.03	Eunomia
9333	Hiraimasa	2023 10/12-10/21	8.4, 11.7	8	9	6.566	0.005	0.20	0.04	MB
13042	1990 QE	2023 09/10-09/12	13.1, 12.9	355	18	3.32	0.01	0.39	0.03	Prokne
26187	1996 XA27	2023 09/05-09/08	5.7, 6.4	340	11	6.510	0.002	0.29	0.02	Klumpkea

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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