LIGHTCURVE ANALYSIS FOR EIGHT MAIN-BELT AND THREE NEAR-EARTH ASTEROIDS

Gonzalo Fornas, AVA - J57, CAAT
Centro Astronómico del Alto Turia, SPAIN
gon@iicv.es

Fernando Huet, AVA - Z93

Enrique Arce, AVA - J67

Rafael Barberá, AVA - J57, CAAT
Centro Astronómico del Alto Turia, SPAIN

Álvaro Fornas AVA - J57, CAAT
Centro Astronómico del Alto Turia, SPAIN

Gonzalo Fornas Jr.

Vicente Mas, AVA - J57, CAAT,
Centro Astronómico del Alto Turia, SPAIN

(Received: 2024 January 9)

Photometric observations of eight main-belt asteroids and three NEAs were obtained between 2023/8 - 2023/12. We derived the following rotational synodic periods: 353 Ruperto-Carola, 2.7389 ± 0.000016 h; 452 Hamiltonia, 2.88119 ± 0.00007 h; 914 Palisana, 8.68062 ± 0.00017 h; 1554 Yugoslavia, 3.8873 ± 0.0002 h; 2729 Urumqi, 3.127840 ± 0.000024 h; 4917 Yurilvovia, 10.169 ± 0.018 h; 8142 Zolotov, 4.32388 ± 0.00005 h; (6037) 1988 EG, 2.75724 ± 0.00036 h; 15817 Lucianotesi, 12.687 ± 0.005 h; (41437) 2000 GT122, 2.99011 ± 0.00035 h; (154244) 2002 KL6, 4.60721 ± 0.00002 h. And the following sidereal periods: 452 Hamiltonia: 2.881314 ± 0.000002 h; 1554 Yugoslavia: 3.88762 ± 0.000003; 8142 Zolotov: 4.323410 ± 0.000003 h.

We report on the photometric analysis results for eight main-belt and three NEAs by Asociación Valenciana de Astronomía (AVA). The data were obtained during the last months of 2023. We present graphic results of data analysis, mainly lightcurves, with the plot phased to a given period. We managed to obtain a number of accurate and complete lightcurves and calculating as accurately as possible their rotation periods.

Observatory	Telescope (meters)	CCD
C.A.A.T. J57	43 cm DK	QHY- 600
C.A.A.T. J57	200 mm NW	ZWO ASI 1600
Z93	SC 8”	SBIG ST8300
J67	SC 10”	SBIG ST7

Table I. List of instruments used for the observations.

We focused on asteroids with no reported period and those where the reported period was poorly established and needed confirmation. All the targets were selected from the Collaborative Asteroid Lightcurve (CALL) website (*http://www.minorplanet.info/call.html)* and the Minor Planet Center (*http://www.minorplanet.net*). The Asteroid Lightcurve Database (LCDB; Warner et al., 2009) was consulted to locate previously published results.

Work Methods

Images were measured using *MPO Canopus* (Bdw Publishing) with the differential photometry technique. The comparison stars were restricted to near solar-color to minimize color dependencies, especially at larger air masses. The lightcurves show the synodic rotation period. The amplitude (peak-to-peak) that is shown is that for the Fourier model curve and not necessarily the true amplitude.

If we have enough data in ALCDEF in addition to our own data, we can try a second step with the software *LC INVERT* (Bdw Publishing), which uses the inversion method described by Kaasalainen (2001). This software uses the code written by J. Durech based on the original FORTRAN code written by Kaasalainen: “Period Scan”. The advantage of this method is that it allows the use of "dense" data such as the ones we have obtained in our measurements together with "sparse" data type, available in databases from Catalina, USNO, Atlas, Palomar, etc.

This is an iterative method that, based on an initial estimate of the period given by the lightcurve, finds the local minimum of χ^2 and gives the corresponding solution. The procedure starts with six initial poles for each trial period and selects the period that gives the lowest χ^2. If there is a clear minimum in χ^2 when plotted as a function of the period, we can assume it as a correct solution. Not always we get a clear solution. We have referenced only those asteroids with an unambiguous calculation.

When calculating we use weighting coefficients to take into account the density of the data. We assign to "dense" data a value of 1 and to "sparse" data a value of 0.3 as an empiric rule.

Error estimates for inversion method are not obvious. The smallest separation ΔP of local minima (Kaasalainen and Torppa, 2001; Kaasalainen et al., 2001), in the period parameter space is roughly given by

$$\Delta P \approx 0.5 * P^2/\Delta t$$

where Δt is the full epoch range of the data set. This derives from the fact that the maxima and minima of a double sinusoidal lightcurve for periods P and P ± ΔP are at the same epochs after Δt time.

As we can read at M. Kaasalainen and Torppa (2001), “The period error is mostly governed by the epochs of the lightcurves. If the best local χ^2minimum of the period spectrum is clearly lower than the others, one can obtain an error estimate of, say, a hundredth part of the smallest minimum width ΔP since the edge of a local minimum ravine always lies much higher than its bottom.”

J. Durech proposes an estimate of error of

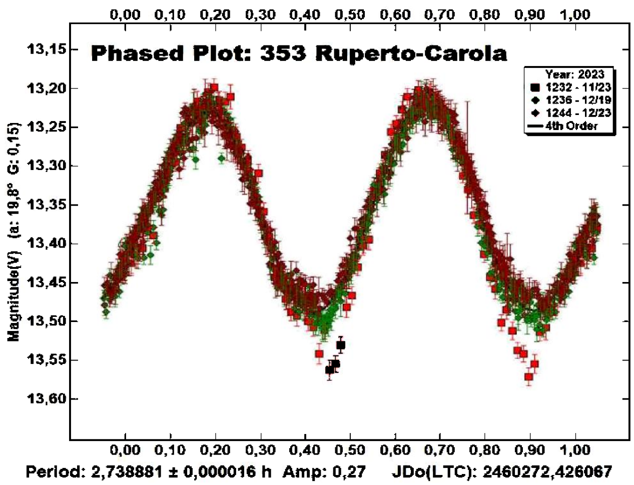
$$\Delta P \approx (1/10 * 0.5) * P^2/\Delta t$$

The factor 1/10 means that the period accuracy is 1/10 of the difference between local minima in the periodogram.

In case we get an unambiguous result with the inversion Method, we can check our result with the calculation method given by Slivan (2012, 2013; Eqs. 3-5), as implemented in *http://www.koronisfamily.com*). With this method, from the maximum lux of different apparitions, we try to delimit the error intervals to know an exact number of rotations of the asteroid, which univocally leads us to know its sidereal period. This is a valid method for data of the "dense" type, obtained continuously during an entire observation session.

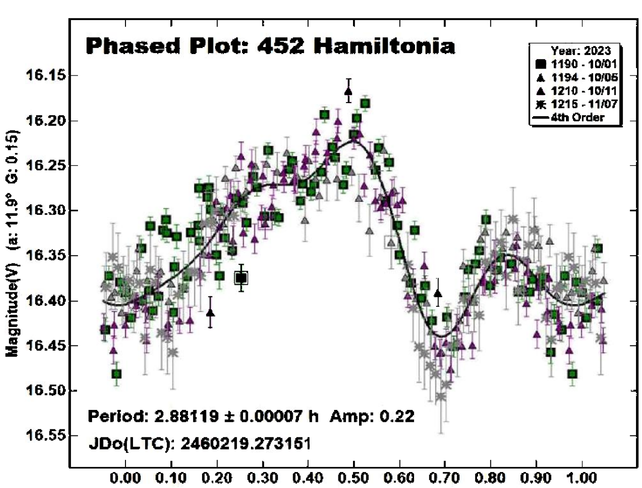
Results

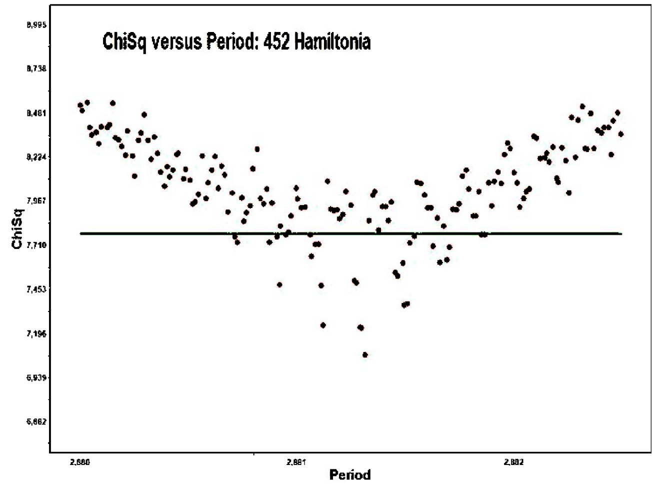
353 Ruperto-Carola. This middle main-belt asteroid was discovered on 1893 Jan 16 by M.F. Wolf at Heidelberg. We made observations from 2023 Nov 23 - Dec 23. From our data we derive a rotation period of 2.7389 ± 0.000016 h and an amplitude of 0.27 mag. Our result matches with Behrend (2020web) who got 2.7396 h, Warner (2006) with 2.73898 h, Hanus et al. (2016) and Durech et al. (2016) with the result of 2.73896 h. Pal et al. (2020) got 2.73912 h and Martikainen et al. (2021) got 2.738970 h.



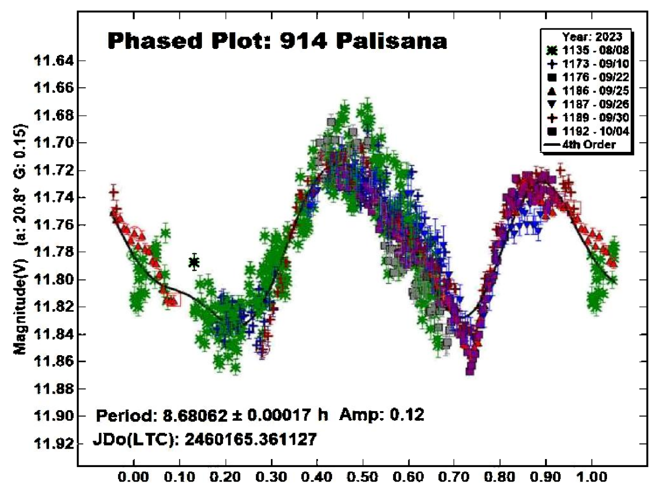
452 Hamiltonia. This outer main-belt asteroid was discovered on 1899 Dec 6 by J.E. Keeler at Mount Hamilton. We made observations from 2023 Oct 1 to Nov 7. From our data we derive a rotation period of 2.88119 ± 0.00007 h and an amplitude of 0.22 mag. Our result matches with Pilcher (2010) who found a period of 2.8813 h and Aznar et al. (2018), who found 2.88 h. Beherend (2011web) found 3.8 h.

We use data from LCDB, Pilcher (2010), in conjunction with our own dense data and sparse data from ATLAS (672 points: 2017/6/15 - 2022/2/28), Catalina (383 points: 2006/12/1 - 2023/5/29), LONEOS (20 points: 1999/8/12 - 2007/6/10), Palomar (128 points: 2018/1/20 - 2022/7/16) and USNO (124 points: 1998/4/21 - 2011/2/23). With the inversion method we calculate a sidereal rotation period of 2,881314 ± 0.000002 h. For the error estimation we have used the interval 2005-2023. In the lower graph we show the χ^2 value as a function of the period, which clearly shows the convergence of the iterative method used.



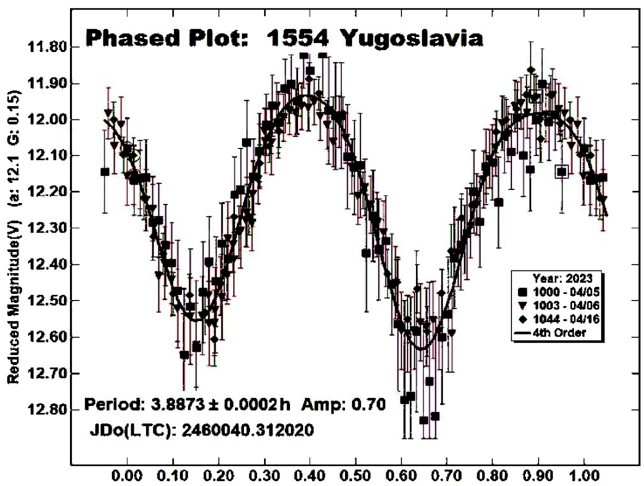


914 Palisana. This inner main-belt asteroid was discovered on 1919 Jul 4 by M.F. Wolf at Heidelberg We made observations on 2023 from Aug 8 to Oct 4. From our data, we derive a rotation period of 8.68062 ± 0.00017 h and an amplitude of 0.12 mag. This is consistent with Behrend (2019web) who got 8.68113 h and Stephens and Warner (2020) with 8.686 h. Colazo et al. (2022) got too 8.681 h. In the other side, Riccioli et al. (1995) got a period of 15.62 h and Warner (2009) got 15.922 h.

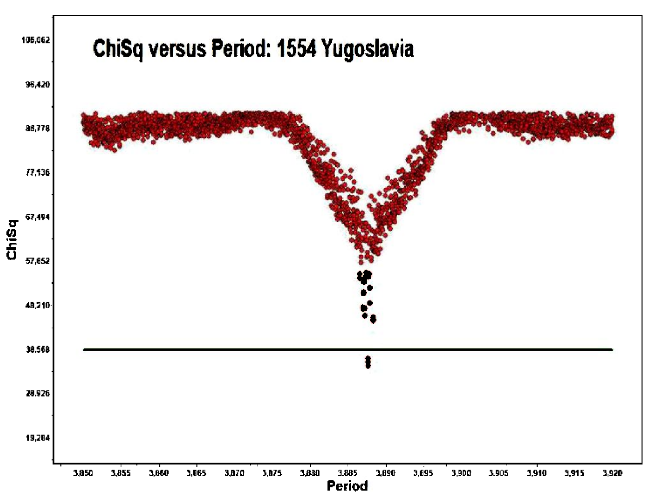


1554 Yugoslavia. This middle main-belt asteroid of the Eumonia family was discovered on 1940 Sep 6 by M.B. Protic at Belgrade. We made observations on 2023 April 5-16. From our data we derive a rotation period of 3.8873 ± 0.0002 h and an amplitude of 0.7 mag.

The asteroid 1554 Yugoslavia has already been studied and there are several calculations of its synodic period in the LCDB. It is worth highlighting the data available in ALCDEF: Higgins (2008), 2007/04/9-15 who got a period of 3.8879 h; Benishek (2013) 2012/08/28-09/08, with a period of 3.8876 h; Brines et al. (2017), 2016/07/04, with a period of 3.8876 h; J. Delgado 2021/12/3-6; S. Hopkings 2021/12/22-31.



We use this data from LCDB in conjunction with our own dense data and sparse data from ATLAS (934 points: 2017/10/19 - 2023/3/25), Catalina (382 points: 2005/12/2 - 2023/4/9), Palomar (73 points: 2014/5/18 - 2022/2/19) and USNO (97 points: 1999/5/31 - 2013/12/30). With the inversion method we calculate a sidereal rotation period of 3.887673 ± 0.000003 h. For the error estimation we have used the interval 2005-2023. In the lower graph we show the χ^2 value as a function of the period, which clearly shows the convergence of the iterative method used.

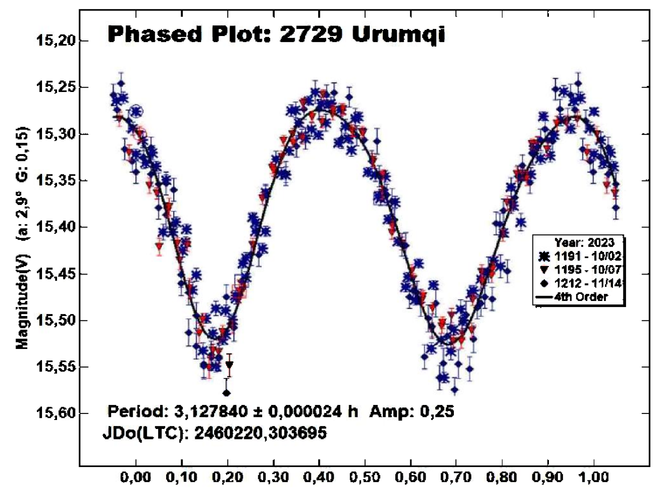


We use the calculation method given by Slivan. The times of the maximum values in the lightcurves are:

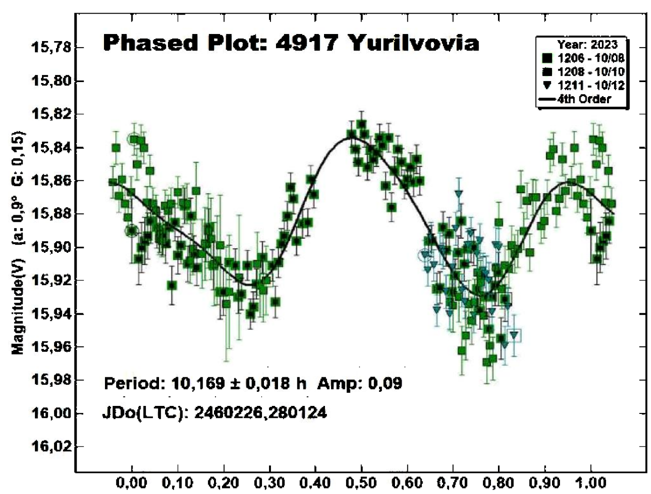
2023/4/06: JD 2460041.3475
2021/4/12: JD 2459570.8182

With an error estimation of .00001 h, we do get an ambiguous solution: 3.887682 ± $7*10^{-6}$ h with an amplitude of 0.24 mag. Martikainen et al. (2021) found a period of 3.887670 h.

2729 Urumqi. This outer main-belt asteroid was discovered on 1979 Oct 19 by the Purple Mountain Obs. at Nanking. We made observations on 2023 Oct 2 to Nov 14. From our data we derive a rotation period of 3.127840 ± 0.000024 h and an amplitude of 0.25 mag. Slivan et al. (2008) and Gao and Tan (2020) got a period of 3.127 h, Liu (2016) got 3.1274 h.



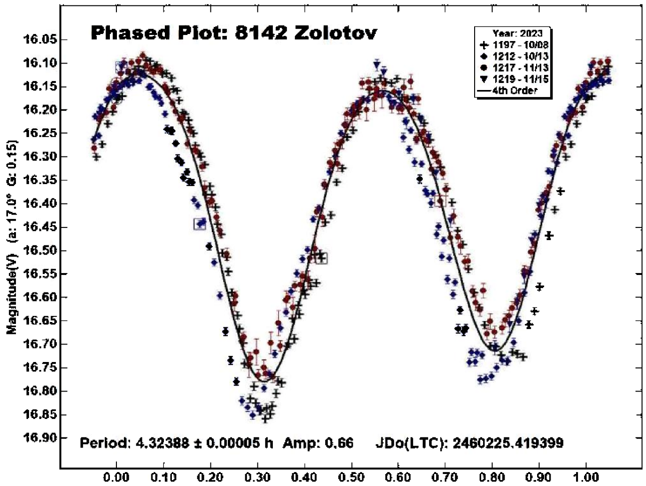
4917 Yurilvovia. This middle main-belt asteroid was discovered on 1973 Sep 28 by the Crimean Astrophysical Obs. at Nauchnij. We made observations on 2023 Oct 8-12. From our data we derive a rotation period of 10.169 ± 0.018 h and an amplitude of 0.09 mag. Hanus et al. (2016) got a sidereal period of 4.17744 h with the inversion method.

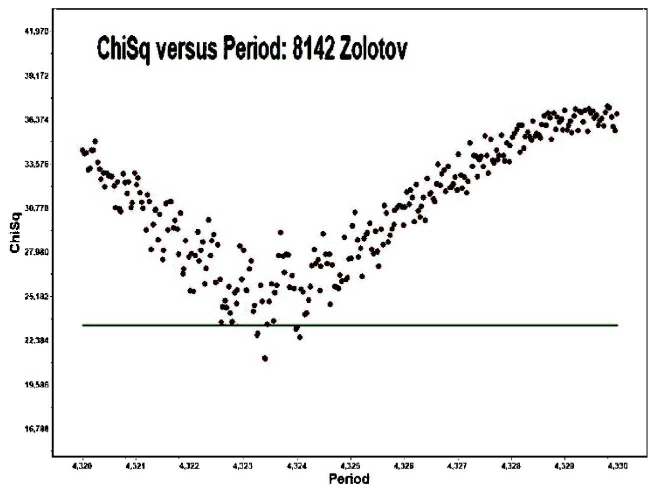


8142 Zolotov. This inner main-belt asteroid was discovered on 1982 Oct 20 by L.G. Karachkina at Nauchnij. We made observations on 2023 Oct 8 to Nov 15. From our data we derive a rotation period of 4.32388 ± 0.00005 h and an amplitude of 0.66 mag. Erasmus et al. (2020) got a period of 4.323 h.

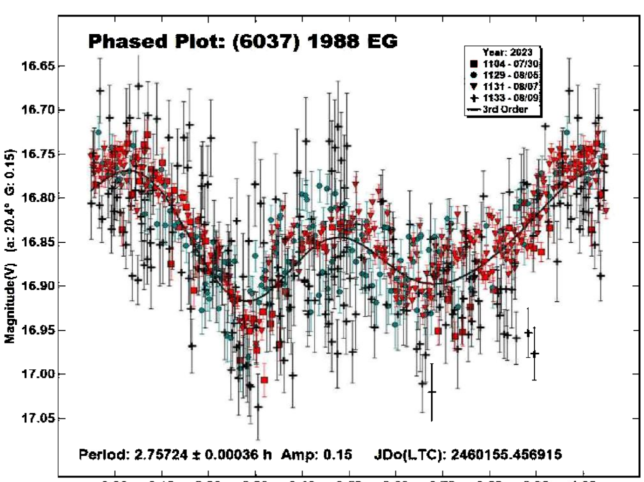
We use our dense data and sparse data from ATLAS (469 points: 2018/3/29 - 2023/9/10), Catalina (415 points: 2003/4/22 - 2023/6/19), Palomar (80 points: 2016/11/7 - 2022/7/2) and LONEOS (28 points: 1999/3-/19 - 207/5/16). With the inversion method we calculate a sidereal rotation period of 4.323410 ± 0.000003 h. For the error estimation we have used the interval 2003 - 2023. In the lower graph we show the χ^2 value as a function of the period, which clearly shows the convergence of the iterative method used.

We haven't data from previous observations to try the Slivan method with this asteroid.

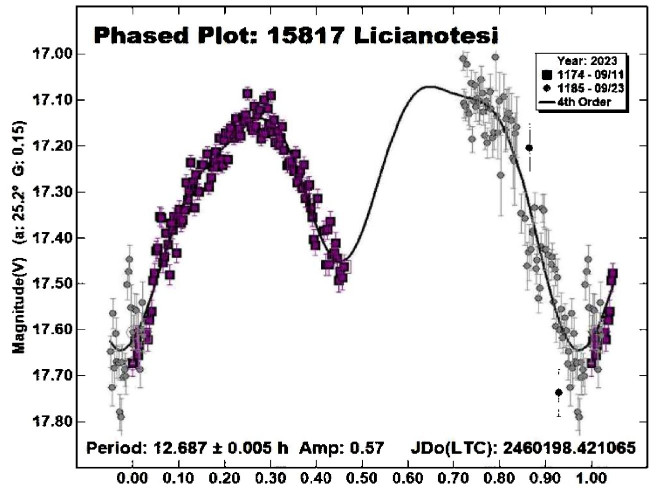




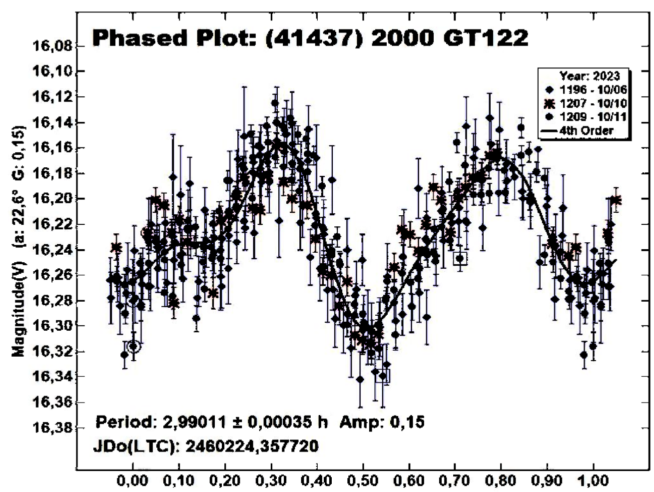
(6037) 1988 EG. This near-Earth object was discovered on 1988 March 22 by J. Alu at Palomar. We made observations on 2023 Jul 30 to Aug 9. Data analysis found a rotation period of 2.75724 ± 0.00036 h and an amplitude of 0.15 mag. Pravec et al. (1998web and 2021web) got 2.76 h and 2.7602 h.



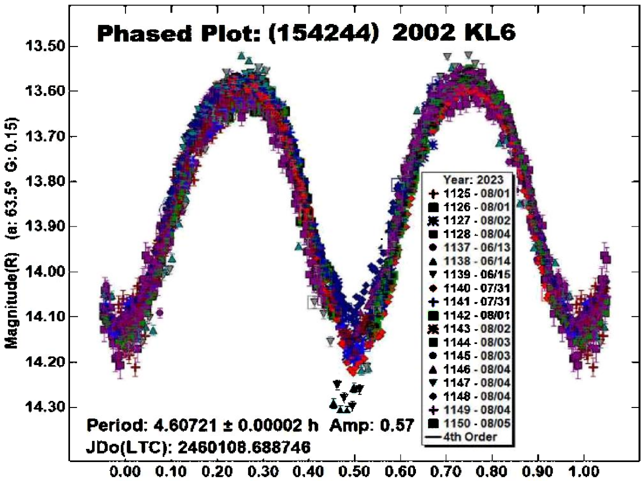
15817 Lucianotesi. This near-Earth object was discovered on 1994 Aug 28 by A. Boattini and M. Tombelli at San Marcello. We made observations on 2023 Sep 11 to 23. From our data we derive a rotation period of 12.687 ± 0.005 h and an amplitude of 0.57 mag. We have not previous information about its rotation period.



(41437) 2000 GT122. This middle main-belt asteroid was discovered on 2000 Apr 11 by C.J. Juels at Fountain Hills. We made observations on 2023 Oct 6 to11. From our data we derive a rotation period of 2.99011 ± 0.00035 h and an amplitude of 0.15 mag. Waszczak et al. (2015) got a period of 2.991 h.



(154244) 2002 KL6. This near-Earth object was discovered on 2002 May 27 by NEAT at Haleakala. We made observations in 2023 Aug 8-21. In LCDB there are observations from Benishek, 2023 Jul 31 to Aug 5 and from Warner, 2023 Jun 13 to Jun 15. We use all of the 2023 data to get a rotation period of 4.60721 ± 0.00002 h and an amplitude of 0.57 mag. Our calculation is compatible with data from LCDB.



Number	Name	Sidereal Period (h)	P. Error (h)
452	Hamiltonia	2.881314	0.000002
1554	Yugoslavia	3.887682	0.000003
8142	Zolotov	4.323401	0.000003

Table II. Sidereal rotation period obtained from LCINVERT, when available

Acknowledgements

We would like to express our gratitude to Brian Warner for supporting the CALL web site and his suggestions. To Dr. Stephen Slivan for his advice.

References

Aznar, A.M.; Cornea, R.; Suciu, O. (2018). "Photometric Analysis and Physical Parameters for Six Mars-crossing and Ten Main-belt Asteroids from APT Observatory Group: 2017 April- September." *Minor Planet Bull.* **45**, 92-96.

Behrend, R. (2011web, 2019web, 2020web). Observatoire de Geneve web site.
http://obswww.unige.ch/~behrend/page_cou.html

Benishek, V. (2013). "Lightcurves for 366 Vincentina, 592 Bathseba, and 1544 Yugoslavia from Belgrade Astronomical Observatory." *Minor Planet Bull.* **40**, 100-101.

Brines, P.; Lozano, J.; Rodrigo, O.; Fornas, A.; Herrero, D.; Mas, V.; Fornas, G.; Carreño, A.; Arce, E. (2017). "Sixteen Asteroids Lightcurves at Asteroids Observers (OBAS) - MPPD: 2016 June - November.". *Minor Planet Bull.* **44**, 145-149.

Colazo, M.; Damián, S.; Montelenoe, B.; Morals, M.; Ciancia, G.; García, A.; Melia, R.; Suárez, N.; Wilberger, A.; Fornari, C.; Nolte, R.; Bellocchio, E.; Mottino, A.; Colazo, C. (2022). "Asteroid Photometry and Lightcurve Analysis for Six Asteroids." *Minor Planet Bull.* **49**, 304-306.

Durech, J.; Hanus, J.; Oszkiewicz, D.; Vanco, R. (2016). "Asteroid models from the Lowell photometric database." *Astron. Astrophys*. **587**, A48.

Erasmus, N.; Navarro-Meza, S.; McNeill, A.; Trilling, D.E.; Sickafoose, A.A.; Denneau, L.; Flewelling, H.; Heinze, A.; Tonry, J.L. (2020). "Investigating Taxonomic Diversity within Asteroid Families through ATLAS Dual-band Photometry." *Ap. J. Suppl. Ser.* **247**, A13.

Gao, X.; Tan, H. (2020). "Photometry of 2729 Urumqi at the Xingming Observatory in Urumqi City." *Minor Planet Bull.* **47**, 151.

Hanus, J.; Durech, J.; Oszkiewicz, D.A.; Behrend, R.; and 165 colleagues (2016). "New and updated convex shape models of asteroids based on optical data from a large collaboration network." *Astron. Astrophys*. **586**, A108.

Harris, A.W.; Young, J.W.; Scaltriti, F.; Zappala, V. (1984). "Lightcurves and phase relations of the asteroids 82 Alkmene and 444 Gyptis." *Icarus* **57(2)**, 251-258.

Higgins, D. (2008). "Asteroid Lightcurve Analysis at Hunters Hill Observatory and Collaborating Stations: April 2007 - June 2007." *Minor Planet Bull.* **35**, 30-32.

Kaasalainen, M. (2001). "Interpretation of lightcurves of precessing Asteroids." *Astron. and Astrophysics* **376**, 302-309. doi:10.1051/0004-6361:20010935.

Kaasalainen, M.; Torppa, J. (2001). "Optimization Methods for Asteroid Lightcurve Inversion. I Shape detemination." *Icarus* **143**, 24-36.

Number	Name	mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
353	Ruperto-Carola	2023/11/23-12/23	20.2,15.2	91.9	-2.8	2.7389	0.000016	0.27	0.05	MB-M
452	Hamiltonia	2023/10/1-11/7	9.5,18.4	345.1	-3.7	2.88119	0.00007	0.22	0.05	MB-O
914	Palisana	2023/8/8-10/4	20.6,27.7	318.3	32.0	8.68062	0.00017	0.12	0.02	MB-I
1554	Yugoslavia	2023/4/5-16	12.1,14.6	160.7	-10.8	3.8873	0.0002	0.7	0.05	MB-M
2729	Urumqi	2023/10/02-11/14	2.8,14.7	4.0	-3.3	3.127840	0.000024	0.25	0.05	MB-O
4917	Yurilvovia	2023/10/8-12	3.3, 5.3	7.6	-0.8	10.169	0.018	0.09	0.02	MB-M
8142	Zolotov	2023/10/8-11/15	16.5, 6.3	40.2	-0.6	4.32388	0.00005	0.66	0.05	MB-I
6037	1988 EG	2023/7/30-8/9	20.0,21.0	318.0	11.1	2.75724	0.00036	0.15	0.02	NEA
15817	Lucianotesi	2023/9/11-23	10.2,11.9	354.8	-7.0	12.687	0.005	0.57	0.05	NEA
41437	2000 GT122	2023/10/6-11	11.6, 9.2	31.4	6.7	2.99011	0.00035	0.15	0.02	MB-M
154244	2002 KL6	2023/8/8-21	62.1,53.8	336.2	27.5	4.60721	0.00002	0.57	0.05	NEA
	(From Benishek, V.)	2023/7/31-8/05								
	(From Warner, B.)	2023/6/13-7/15								

Table III. Synodic Periods. Observing circumstances and results. The phase angle values are 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). MB-I/O: Main-belt inner/outer; NEA: Near Earth Asteroid.

Kaasalainen, M.; Torppa, J.; Muinonen, K. (2001). "Optimization Methods for Asteroid Lightcurve Inversion. II The complete Inversion Problem." *Icarus* **153**, 37-51.

Liu, J. (2016). "Rotation Period Analysis for 2729 Urumqi." *Minor Planet Bull.* **43**, 204.

Martikainen, J.; Muinonen, K.; Penttila, A.; Cellino, A.; Wang, X.-B. (2021). "Asteroid absolute magnitudes and phase curve parameters from Gaia photometry." *Astron. & Astrophys.* **649**, A98.

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. Suppl Ser.* **247**, id. 26.

Pilcher, F. (2010). "Rotation Period Determinations for 81 Terpsichore, 419 Aurelia, 452 Hamiltonia, 610 Valeska, 649 Josefa, and 652 Jubilatrix,". *Minor Planet Bull.* **37**, 45-46.

Pravec, P.; Wolf, M.; Sarounova, L. (1998web, 2021web). Ondrejov Asteroid Photometry Project. *http://www.asu.cas.cz/~ppravec/neo.htm*

Riccioli, D.; Blanco, C.; Di Martino, M.; De Sanctis, G. (1995). "Lightcurves and rotational periods of main belt asteroids. III." *Astron. Astrophys. Suppl. Ser.* **111**, 297-303.

Slivan, S.M.; Binzel, R.P.; Boroumand, S.C.; Pan, M.W.; Simpson, C.M.; Tanabe, J.T.; Villastrigo, R.M.; Yen, L.L.; Ditteon, R.P.; Pray, D.P.; Stephens, R.D. (2008). "Rotation rates in the Koronis family, complete to H≈11.2." *Icarus* **195**, 226-276.

Slivan, S.M. (2012). "Epoch Data in Sidereal Period Determination. I. Initial Constraint from Closest Epochs." *Minor Planet Bull.* **39**, 204-206.

Slivan, S.M. (2013). "Epoch Data in Sidereal Period Determination II. combining Epochs from Different Apparitions." *Minor Planet Bull.* **40**, 45-48.

Stephens, R.D.; Warner, B.D. (2020). "Main-belt Asteroids Observed from CS3: 2020 January to March." *Minor Planet Bull.* **47**, 224-230.

Warner, B.D. (2006). "Asteroid lightcurve analysis at the Palmer Divide Observatory - February - March 2006." *Minor Planet Bull.* **33**, 82-84.

Warner, B.D. (2009). "Asteroid Lightcurve Analysis at the Palmer Divide Observatory: 2008 September – December." *Minor Planet Bull.* **36**, 70-73.

Warner, B.D.; Harris, A.W.; Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. *https://minplanobs.org/alcdef/index.php*

Waszczak, A.; Chang, C.; Ofek, E.; Laher, R.; Masci, F.; Levitan, D.; Surace, J.; Cheng, Y.; Ip, W.; Kinoshita, D.; Helou, G.; Prince, T.; Kulkarni, S. (2015). "Asteroid Light Curves from the Palomar Transient Factory Survey: Rotation Periods and Phase Functions from Sparse Photometry." *Astron. J.* **150**, A75.

SYNODIC ROTATION PERIOD FOR KORONIS FAMILY OBJECT (452) HAMILTONIA

Francis P. Wilkin, Joseph J. Maier
Union College, Department of Physics and Astronomy,
807 Union St., Schenectady, NY 12308
wilkinf@union.edu

(Received: 2024 January 15)

We present new lightcurves for (452) Hamiltonia in 2023. Observations of Hamiltonia were made at the Union College Observatory and two remote facilities. We derived a single apparition period 2.8813±0.0001 h.

Previously measured periods for (452) Hamiltonia include 2.8813 ± 0.0001 h (Pilcher, 2010), and 2.88 ± 0.01 h (Aznar Macías et al., (2018). We observed (452) Hamiltonia as part of our project at the Union College Observatory (UCO) to characterize Koronis family asteroids (e.g. Wilkin et al., 2022; Crowley and Wilkin, 2023) and to extend the sample completeness (Slivan et al., 2003; Slivan et al., 2024). Specifically, our goal for (452) Hamiltonia is to lengthen the overall time span of observations during the 2023 apparition, so that when combined with earlier observations of Slivan et al. (2023) in July and August, we obtain a more precise synodic rotation period than those previously available.

Observational planning was done using the *Koronisfamily.com* web tool (Slivan, 2003). We recorded lightcurves on a total of five nights using telescopes at three observatories. Telescope and camera properties are given in Table I. All observing runs had similar spans of 2.8-3.8 h. The final run on CHI-1 used exposure time 300 s, in distinction to those listed in Table I. Bias, dark, and twilight-flat field corrections were performed in *AstroImage J* (AIJ; Collins et al., 2017) for the UCO images, and photometry was performed on all images in AIJ. Corrections for light-travel time were applied using ephemerides from the NASA Horizons app (NASA, 2024).

Similar lightcurve shapes were obtained on all nights, although some variation is seen (Fig. 1). To determine a period value, we used the final run, on Oct 20, and the two runs on Sep 17, which as seen in Fig. 1, have considerably higher quality than the earliest run, at UCO. Relative magnitude values of each night were shifted in brightness to produce a self-consistent composite (Fig. 2). Based upon our observations spanning 44 nights, we obtain period 2.8813±0.0001 h and amplitude 0.19±0.02 mag. Note that the datapoints for both figures are identical. Observations reported here are further analyzed by Slivan et al. (2024) together with lightcurves that they recorded earlier in the apparition, to determine the improved synodic period needed for sidereal period determination.