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

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Photometric observations for thirteen main-belt, and three near-Earth asteroids. We derived synodic periods for 838 Seraphina, 1762 Rusell, 2047 Smetana, 2383 Bradley, 2692 Chkalov, 3895 Earhart, (23512) 1992 PC3, (23880) Tongil, (25330) 1999 KV4, (31545) 1999 DN6, (32459) 2000 SK87, (39489) 1981 EU6, (42449) 3496 T-3, (84833) 2003 AF9, (96720) 1999 LP, (352143) 1999 LP. In addition, we found sidereal periods for 838 Seraphina, 1762 Rusell, 2047 Smetana, 2383 Bradley, 2692 Chkalov, and 3895 Earhart.

We report on the photometric analysis for results thirteen main-belt and three near-earth asteroids by Asociación Valenciana de Astronomía (AVA). The data were obtained during the third quarter of 2024. We present graphic results of data analysis, mainly lightcurves, with the plot phased to a given period. We managed to obtain several accurate and complete lightcurves and calculating as accurately as possible their rotation periods.

Observatory	Telescope	CCD
C.A.A.T. J57	43 cm DK	QHY- 600
C.A.A.T. J57	250 mm NW	ZWO ASI 1600
Z93	0.20 m SC	SBIG ST8300
J67	0.25 m SC	SBIG ST7
Tros Alt Y78	0.20 m SC	ZWO ASI 294 MM PRO

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. The targets were selected from the Collaborative Asteroid Lightcurve website (*https://minorplanet.info/php/call.php*), the Minor Planet Center (*https://www.minorplanetcenter.net/*), and Warner et at. (2024). The Asteroid Lightcurve Database (LCDB; Warner et al., 2009) was consulted to locate previously published results.

Images were measured using *MPO Canopus* (Bdw Publishing) with a 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 found sufficient data in the ALCDEF database (*https://alcdef.org*) in addition to our own data, we used *LCInvert* (Bdw Publishing) to try to model the asteroid. The program uses the inversion method described by Kaasalainen and Torppa (2001) written by J. Durech based on the original FORTRAN code by Kaasalainen. The method allows using *dense* data such as we obtained together with *sparse* data from all-sky programs such as Catalina, USNO, Atlas, Palomar, etc. We use weighting coefficients to account for the density of the data. We usually assign a value of 1 to *dense* data and 0.3 to *sparse* data.

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.

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

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

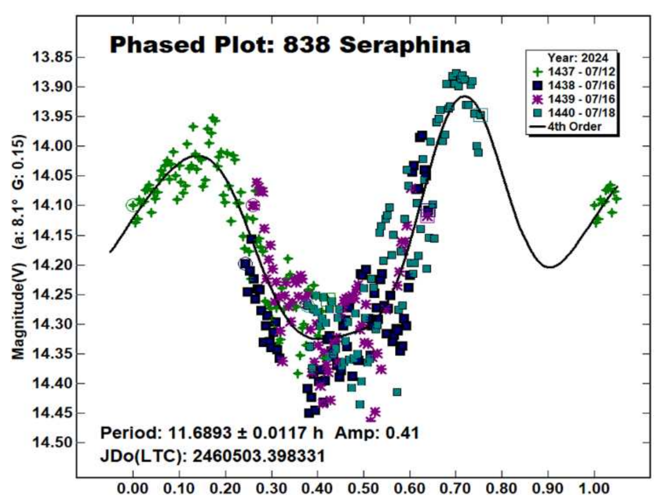
Where Δt is the full epoch range of the dataset. This derives from the fact that the maxima and minima of a double sinusoidal lightcurve for periods P and P±ΔP are at the same epochs after Δt time. As we can read at Kaasalainen et al. (2001), "The period error is mostly governed by the epochs of the 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."

Durech proposes an estimate of error of

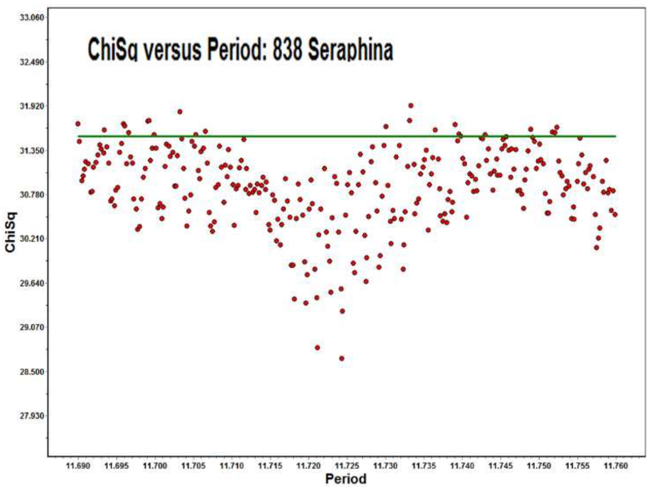
$$\Delta P \approx (1/10 * 0.5)\ P^2/\Delta t$$

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

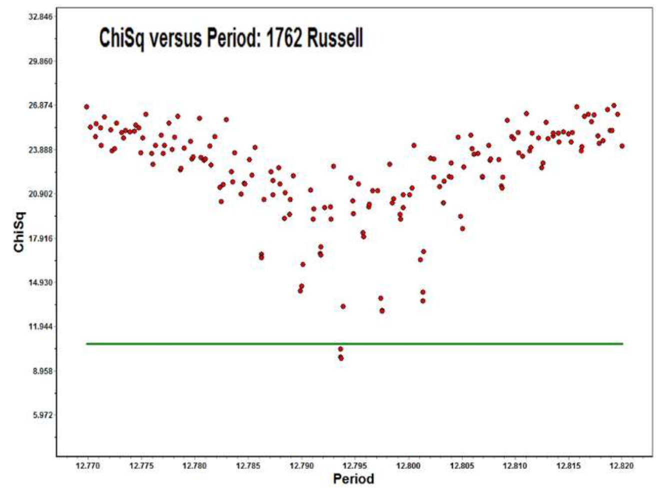
<u>838 Seraphina</u>. This outer main-belt asteroid was discovered on 1916 September 24 at Heidelberg by M.F. Wolf.



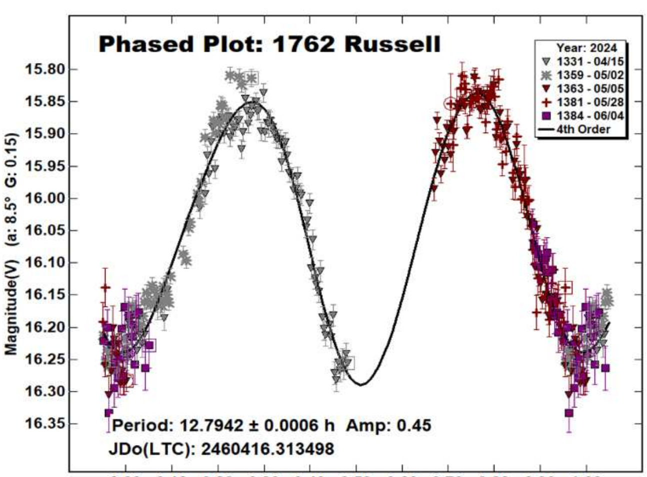
We used our dense data obtained from 2015 November 4-17 and sparse data from ATLAS (887 pts; 2017/9/29-2024/7/9), Catalina (502 pts; 2005/9/30-2024/7/9), LONEOS (24 pts; 2000/9/8-2007/1/16), Palomar (149 pts; 2019/8/23-2022/5/15), and USNO (191 pts; 1998/2/26-2014/5/17) to find a sidereal rotation period of 11.72437 ± 0.00005 h, the error being based on data from 2015-2024. Durech and Hanus (2018) found a sidereal period of 11.7245 h and refined this (Durech et al., 2019) to 11.72446 h. The graph shows the χ^2 value as a function of the period. The large number of points below the 10% error (green line) would make any shape model suspect.



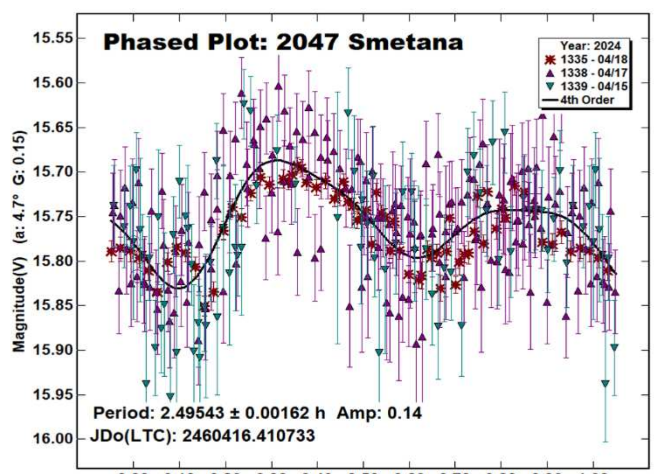
For modeling, we used our *dense* data and those from Klinglesmith (2014/3/23-2014/5/5) found on the ALCDEF site and *sparse* data from ATLAS (1215 pts; 2017/10/19-2024/7/5), Catalina (297 pts; 2003/10/26-2022/1/28), LONEOS (57 pts; 1998/10/12-2007/12/5), Palomar (80 pts; 2019/4/2-2022/8/16), and USNO (107 pts; 1997/9/23-2011/11/1) to determine a sidereal rotation period of 12.793707 ± 0.00005 h. The error estimated error is based on a data ranging from 2004-2024. The plot shows the convergence of the results and only one or two periods meeting the 10% rule. Durech and Hanus (2018) and Durech et al. (2018b) found sidereal periods of 12.79374 h and 12.7933 h, respectively.

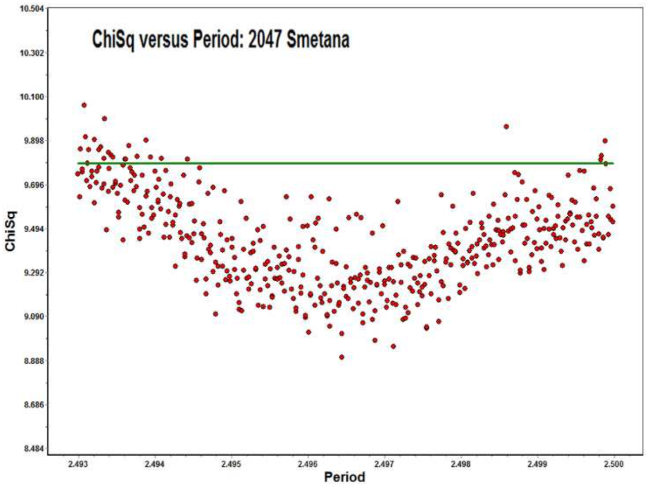


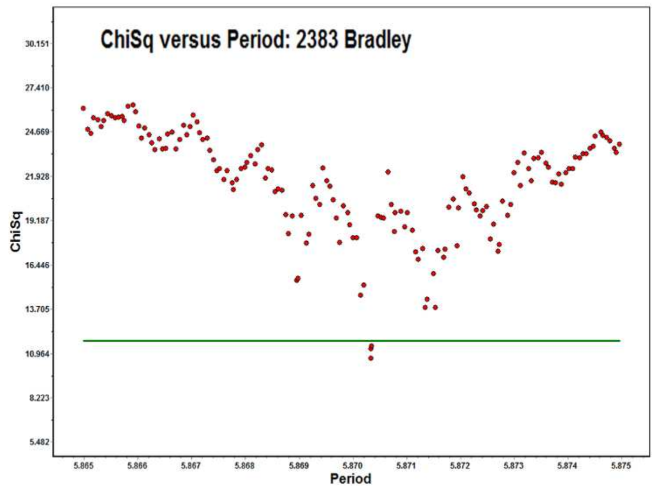
1762 Russell. This outer main-belt asteroid of the Koronis family was discovered on 1953 October 8 at Brooklyn Observatory, Indiana University. We made observations from 2024 April 15 to June 4. Our analysis found a synodic period of 12.7942 ± 0.0006 h with an amplitude of 0.45 mag. Cooney Jr. et al. (2015) found 12.797 h. Slivan et al. (2022) found 12.7946 h, which is consistent with our calculations.



2047 Smetana. We made observations of this Hungaria group member in 2024 April 15-18. From our data, found a synodic rotation period of 2.4954 ± 0.0016 h with an amplitude of 0.14 mag. There were several entries from Warner (2006; 2.4969 h), (2011; 2.4801 h), (2013; 2.4970 h), (2016; 2.498 h). All of these are within the error of our result. This asteroid is a binary (Warner, 2013), but our data do not allow us to verify this.



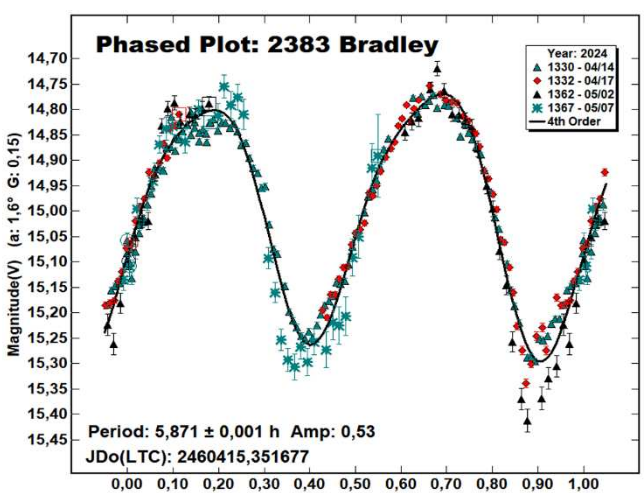




We use our *dense* data those from Warner that were in the ALCDEF database along with *sparse* data from ATLAS (708 pts; 2017/8/3-2024/6/1), Catalina (603 pts; 2005/13/27-2024/5/14), and Palomar (156 pts; 2018/11/21-2022/12/19) to find a sidereal rotation period.

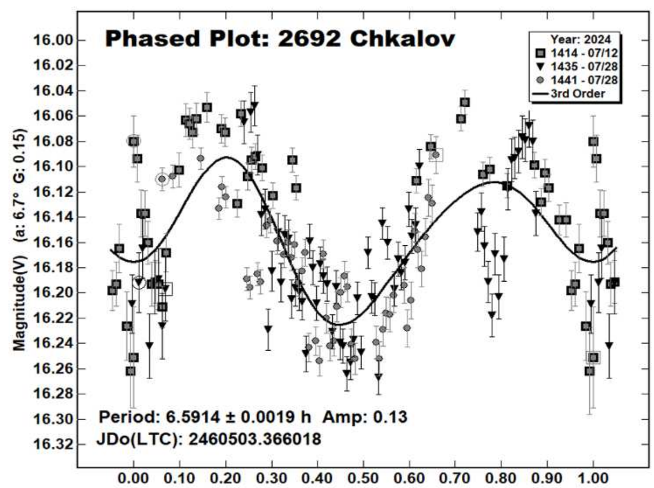
The period with the lowest χ^2 value is 2.4927947 ± 0.000001 h; the error is based on data over the interval between 2006-2024. We think that the binary character of the asteroid prevents a clear convergence. There are not previous data about the sidereal period of this asteroid.

2383 Bradley. This inner main-belt asteroid was discovered on 1981April 5 at Aderson Mesa by E. Bowell. We made observations from 2024 April 4 to May 7. From our data we derived a rotation period of 5.871 ± 0.001 h and an amplitude of 0.53 mag. Warell (2017) found a period of 5.823 h.

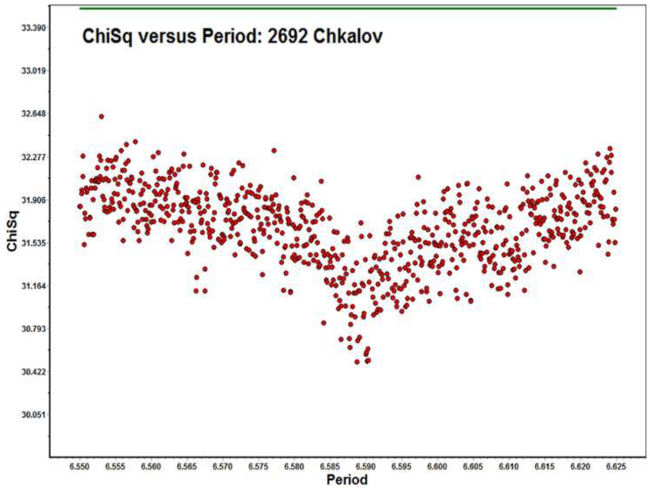


Dense data found in the ALCDEF database were obtained by Farfan, Elias, and Botana from 2024/4/16 to 2024/5/9 were combined with our data and *sparse* data from ATLAS (842 pts; 2018/3/6-2024/7/11), Catalina (444 pts; 2003/12/5-2023/12/31), and Palomar (57 p pts; 2019/1/7-2020/12/21). These led to a sidereal rotation period of 5.8703 ± 0.0002 h, the error being based on the interval 2024 April 16 to September 5. The graph shows a very limited number of results below the 10% line, adding some confidence to our finding. We found no previously reported sidereal periods.

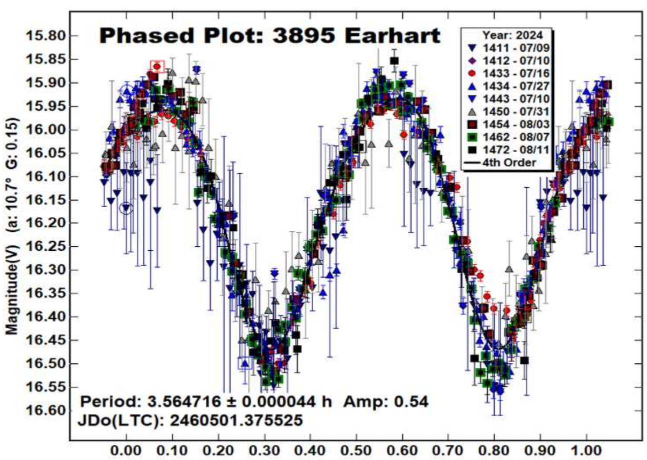
2692 Chkalov. This outer main-belt asteroid was discovered on 1976 December 16 by L.I. Chernykh at Nauchnyj. We made observations from 2024 Jul 12-28. From our data, we derived a rotation period of 6.5914 ± 0.0019 h and an amplitude of 0.13 mag. Garcerán et al. (2016) reported a period of 6.11 h while Pal et al. (2020) determined a sidereal period of 13.1901 h with ATLAS dual band photometry.

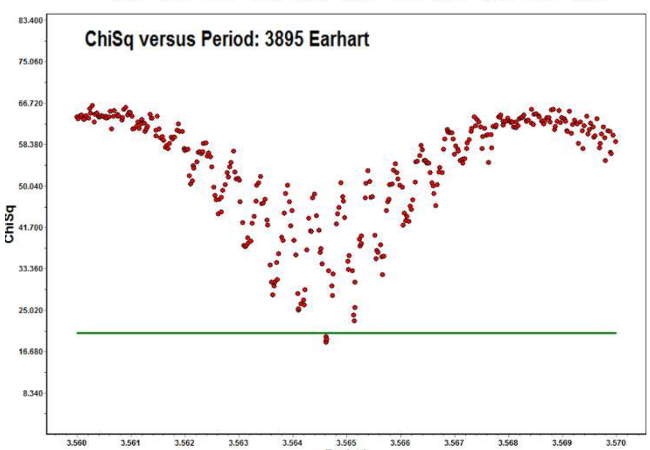


Our *dense* data from 2024 and 2015/7/30-2015/5/8, and those in ALCDEF from Pal et al. (2029/3/2-20219/3/25) were combined with *sparse* data from ATLAS (1038 pts; 2017/8/24-2024/7/11), Catalina (492 pts; 2008/7/21-2023/7/21), and Palomar (75 pts; 2013/12/2-2021/11/24). The inversion method found a sidereal rotation period of 6.587720 ± 0.000002 h. The error is based on data from 2015 September to 2024 June. Note that all of the data points are below the 10% line (found at the very top of the plot). The best that can be said is that at least the sidereal and synodic periods are similar and not aliases of one another.



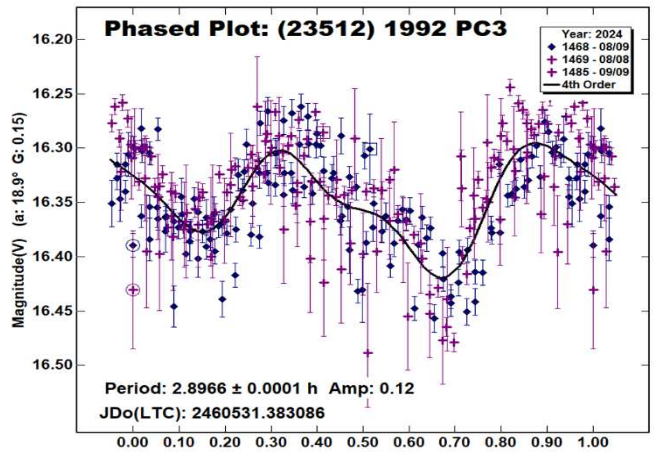
<u>3895 Earhart</u>. This inner main-belt asteroid of the Phocaea family was discovered on 1987 February 23 by C.S. Shoemaker at Palomar. We made observations from 2024 July 9 to August 11. From our data, we derived a synodic rotation period of 3.564716 ± 0.000044 h and an amplitude of 0.54 mag. Behrend (2009web; 2016web; 2020web) found a period of 3.56451 h, 3.56445 h and 3.56501 h, respectively. Skiff (2016web) found 3.5645 h. Other results are Warner (2009, 3.564 h), Aznar Macias et al. (2016, 3.556 h), Stephens and Warner (2021, 3.567 h), and Benishek (2021, 3.5646 h).





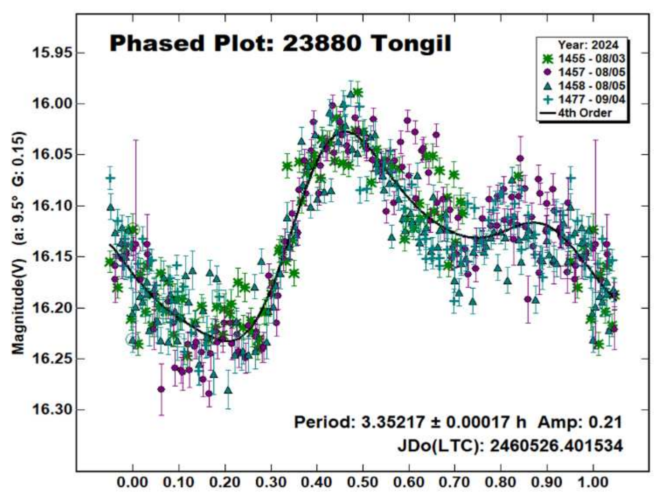
Our *dense* data from 2024 and 2023 1/25 to 4/7 and those in ALCDEF from Warner (2009/4/20-21) and Stephens and Warner (2020/7/26- 29) and *sparse* data from ATLAS (1268 pts; 2017/6/23-2024/7/11), Catalina (485 pts; 2003/12/28-2023/5/8), and Palomar (68 pts; 2018/9/10-2022/2/15) were used in the inversion method to find a sidereal rotation period of 3.56461854 ± 0.000002 h with the error based on data in the interval between 2009 May and 2024 Aug. The plot shows a good convergence by having only two data points below the 10% line. Durech et al. (2020) found a sidereal period of 3.564614 h.

<u>(23512) 1992 PC3</u>. This outer main belt asteroid was discovered on 1992 August 6 at Palomar by H.E. Holt.

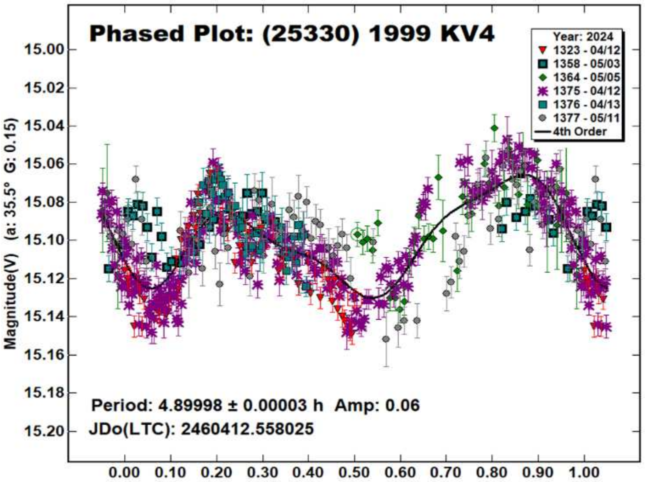


We made observations on 2024 August 9 to September 9. From our data we derive a rotation period of 2.8966 ± 0.0001 h and an amplitude of 0.12 mag. We have not previous information about its rotation period.

<u>(23880) Tongil</u>. This middle main-belt asteroid was discovered on 1998 September 18 at Younchun by T.H. Lee. Our observations from 2024 August 3 to September 4 led to a period of 3.35217 ± 0.00017 h and an amplitude of 0.21mag. We found no other reported rotation period.

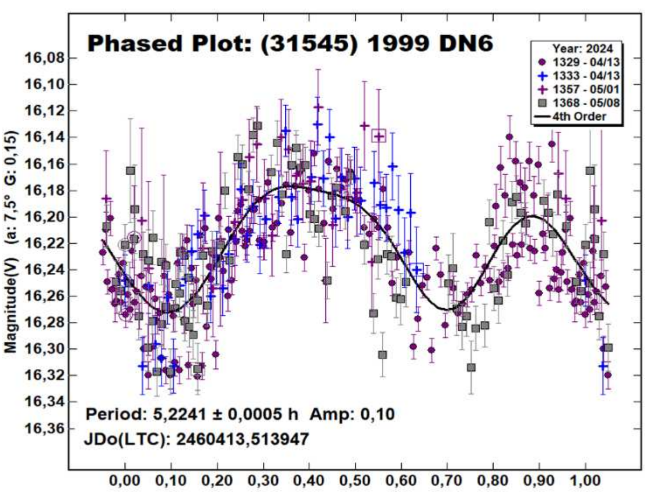


(25330) 1999 KV4. This near-Earth Apollo asteroid was discovered on 1999 May 17 at Catalina. Analysis of observations from 2024 April 12 to May 11 found a period of 4.89998 ± 0.00003 h and an amplitude of 0.06 mag. Pravec et al. (2002web) reported 4.919 h.

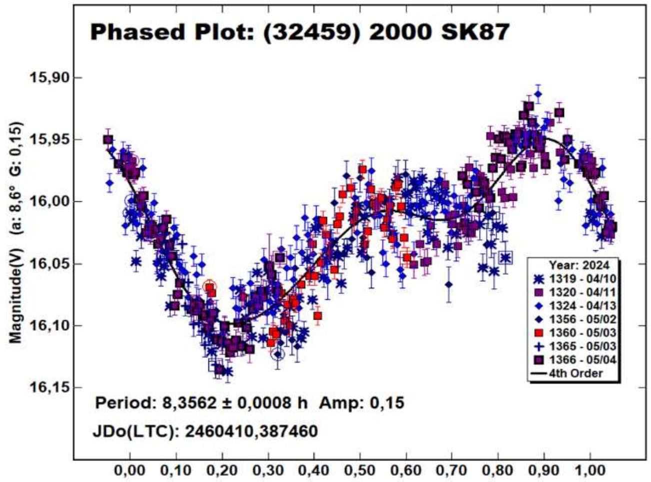


(31545) 1999 DN6. This middle main-belt asteroid was discovered on 1999 February 20 at Socorro by LINEAR. We made observations on 2024 April 13 to May 8. From our data we derived a rotation period of 5.2241 ± 0.0005 h and an amplitude of 0.10 mag. We did not find any previous information about its rotation period.

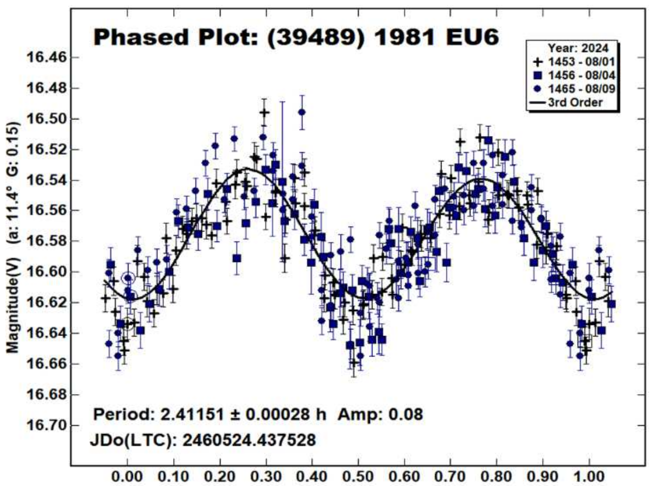
The large scatter in the low amplitude lightcurve reduces confidence in the solution, despite the asymmetrical shape. As noted by Harris et al. (2014), very low amplitude lightcurves at relatively small phase angles cannot be assumed to be bimodal. There is a *small* possibility that shape really is more symmetrical and that the variations are due to a satellite. A higher quality data set, both noise and more consecutive observing sessions are needed.



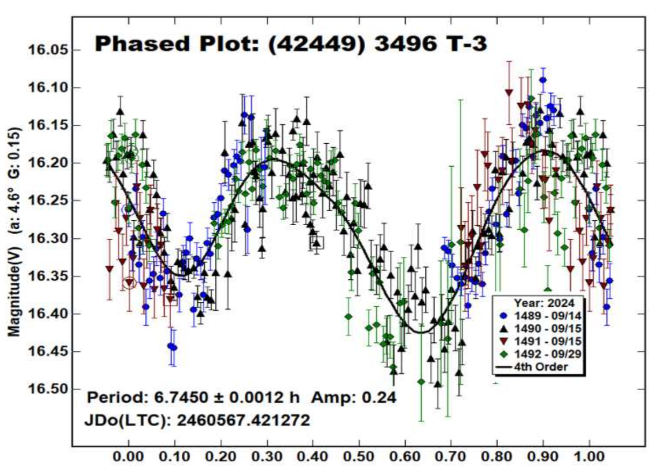
(32459) 2000 SK87 is a middle main-belt asteroid that we observed from 2024 April 10 to May 4. Data analysis a period of 8.3562 ± 0.0008 h with an amplitude of 0.15 mag. A double period of 16.7 h is also a possibility. This appears to be the first period to be reported.



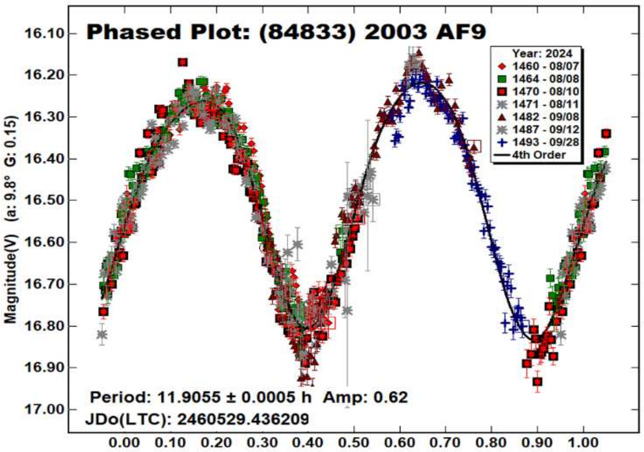
(39489) 1981 EU6. This near-Earth asteroid was discovered in 1981 March at Siding Spring by S.J. Bus. Our observations from 2024 August 1-9 led to a rotation period of 2.41151 ± 0.00028 h and an amplitude of 0.08 mag. Waszczak et al. (2015) found 2.258 h.



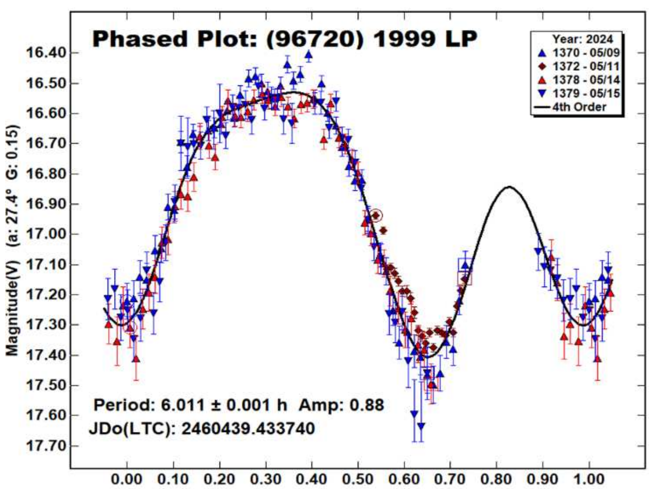
(42449) 3496 T-3. This middle main belt asteroid was discovered in 1977 at Palomar by C.J. van Houten. Analysis of observations made from 2024 September 14-29 determined a period 6.7450 ± 0.0012 h and an amplitude of 0.24 mag. This may be the first period reported.



(84833) 2003 AF9. We made observations of this inner main-belt asteroid from 2024 August 7 to September 28 and found a period of 11.9055 ± 0.0005 h and an amplitude of 0.62 mag. We have not previous information about its rotation period.



(96720) 1999 LP. This inner main belt asteroid was discovered on 1999 June 4 by LINEAR at Socorro.

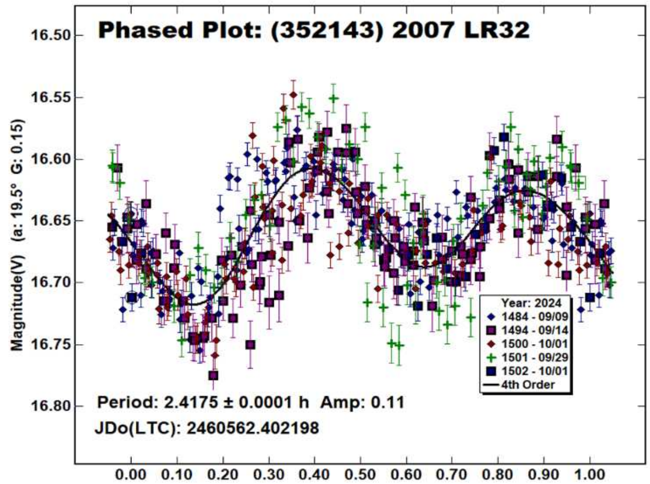


We made observations on 2024 May 9 to 15. From our data we derive a rotation period of 6.011 ± 0.001 h and an amplitude of 0.88 mag. We have not previous information about its rotation period.

(352143) 2007 LR32. This near-Earth asteroid was discovered on 2007 June 15 by LINEAR at Socorro. We made observations on 2024 September 9 to October 1. From our data we derived a rotation period of 2.4175 ± 0.0001 h and an amplitude of 0.11 mag. Behrend (2007web) reported a period of 2.4162 h.

Number	Name	Sidereal Period (h)	P. Error
838	Seraphina	11.724370	0.00005
1762	Rusell	12.793707	0.00005
2047	Smetana	2.4927947	0.000001
2383	Bradley	5.8703	0.0002
2692	Chkalov	6.587720	0.000002
3895	Earhart	3.56461854	0.000002

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



Acknowledgements

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Number	Name	2024/mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
838	Seraphina	07/12-07/18	18.1, 6.5	303	12	11.6893	0.0117	0.41	0.05	MB-O
1762	Rusell	04/15-06/04	8.1,18.6	184	1	12.7942	0.0006	0.45	0.05	MB-O
2047	Smetana	04/15-04/18	7.5, 4.7	214	42	2.4954	0.0016	0.14	0.02	MB-M
2383	Bradley	04/14-05/07	1.0,14.2	204	-1	5.871	0.001	0.53	0.05	MB-I
2692	Chkalov	07/12-07/28	6.3, 5.2	300	11	6.5914	0.0019	0.13	0.02	MB-O
3895	Earhart	07/09-08/11	11.0, 8.8	304	15	3.564716	0.00004	0.54	0.05	MB-I
23512	1992 PC3	08/09-09/09	8.5, 9.4	331	13	2.8966	0.0001	0.12	0.02	MB-O
23880	Tongil	08/03-09/04	9.4,10.6	324	11	3.35217	0.00017	0.21	0.02	MB-M
25330	1999 KV4	04/12-05/11	35.7,17.4	213	17	4.89998	0.00003	0.06	0.01	NEA
31545	1999 DN6	04/13-05/08	7.4,14.7	210	13	5.2241	0.0005	0.10	0.01	MB-M
32459	2000 SK87	04/10-05/04	8.5,17.2	196	11	8.3562	0.0008	0.15	0.02	MB-M
39489	1981 EU6	08/01-08/09	19.2,15.9	328	13	2.41151	0.00028	0.08	0.01	NEA
42449	3496 T-3	09/14-09/29	4.1, 6.9	355	4	6.7450	0.0012	0.24	0.05	MB-M
84833	2003 AF9	08/07-09/28	9.5,26.9	325	16	11.9055	0.0005	0.62	0.05	MB-I
96720	1999 LP	05/09-05/15	27.2,26.3	239	35	6.011	0.001	0.88	0.05	MB-I
352143	2007 LR32	09/09-10/01	32.0,28.2	356	22	2.4175	0.0001	0.11	0.02	NEA

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; MC: Mars-Crosser.

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