A LIGHTCURVE ANALYSIS FOR NINE MAIN-BELT AND ONE MARS-CROSSING ASTEROIDS

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Photometric observations of nine main-belt and one Mars-crossing asteroids were obtained from 2024 February 4 to October 10. We derived synodic rotational periods for 728 Leonisis, 1698 Christophe, 1802 Zhang Heng, 2741 Valdivia, 3583 Burdett, 3895 Earhart, (12543) 1998 QM5, (20490) 1999 OW2, (31545) 1999 DN6, and (32575) 2001 QY78. Sidereal rotation periods were found 728 Leonisis, 1802 Zhang Heng, 2741 Valdivia, and 3895 Earhart.

We report on the photometric analysis result for nine main-belt and one Mars-crossing asteroids. This work was done from Observatorio Polop MPC Z93 (Alicante) operated by members of the Valencian Astronomy Association (AVA). This database (*http://www.astroava.org*) shows lightcurves, each phased to a given period.

We managed to obtain several accurate and complete lightcurves. Five of them had no previously reported period.

We concentrated on asteroids with no reported period and those where the reported period was poorly established and needed confirmation. We also prioritized asteroids for which we had dense data collected by our team in previous years with the aim of finding sidereal periods using *LCInvert* (Bdw Publishing). All of the targets were selected from the Collaborative Asteroid Lightcurve (CALL) website (*http://www.minorplanet.info/call.html*) and Minor Planet Center (*http://www.minorplanet.net*). The Asteroid Lightcurve Database (LCDB; Warner et al., 2009) was consulted to locate previously published results.

The observations were made with a 0.20-m Schmidt-Cassegrain and ASI 2600 MM camera. Images were calibrated in *MaximDL* and measured using *MPO Canopus* (Bdw Publishing) with a differential photometry technique. The comparison stars were restricted to near solar-color to avoid introducing color dependencies, especially at larger air masses. The lightcurves give 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 there were sufficient data in the Asteroid Lightcurve Data Exchange Format database (ALCDEF; *https://alcdef.org*) in addition to our own, we tried to find a sidereal rotation period using *LCInvert* (Bdw Publishing). This program uses the inversion method described by Kaasalainen and Torppa (2001) and is based on the C code written by Joseph Ďurech that was derived from the original FORTRAN code written by Kaasalainen. The advantage of this method is that it allows the use of *dense* data such those we obtained in our observations, the previous *dense* data kept in ALCDEF, and *sparse* data such as those available in databases from Catalina, USNO, ATLAS, Palomar, etc.

LCInvert uses an iterative method that, based on an initial estimate of the synodic period given by the lightcurve, finds the local minimum of χ^2 and gives the corresponding solution for the sidereal period. 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. There is not always a clear solution. We report on only those asteroids with an unambiguous result.

When using *LCInvert,* we assigned weighting coefficients to consider different density and quality of the data. For *dense* data a weight value of 1 was used; *sparse* data, a value of 0.3 was assigned.

Error estimates for the inversion method are not obvious. The smallest separation (ΔP) of local minima (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 $P \pm \Delta P$ are at the same epochs after Δt time.

As stated by Kaasalainen et al. (2001), *"The period error is mostly governed by the epochs of the lightcurves. If the best local χ^2 minimum 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."*

Ďurech proposes an error estimate using

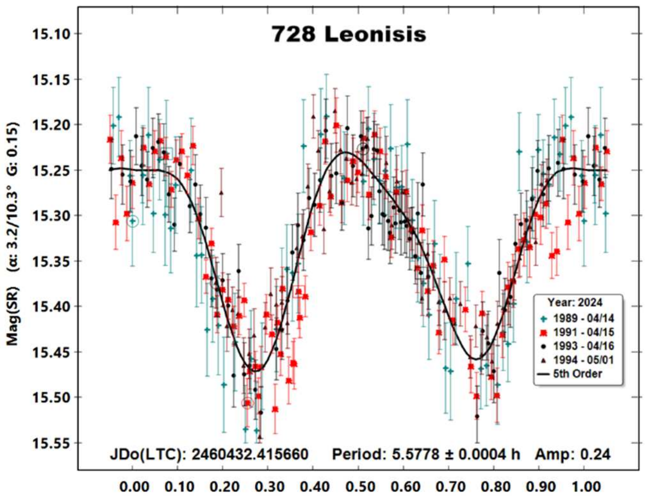
$$\Delta P \approx (1/10 * 0.5) * P^2/\Delta t$$

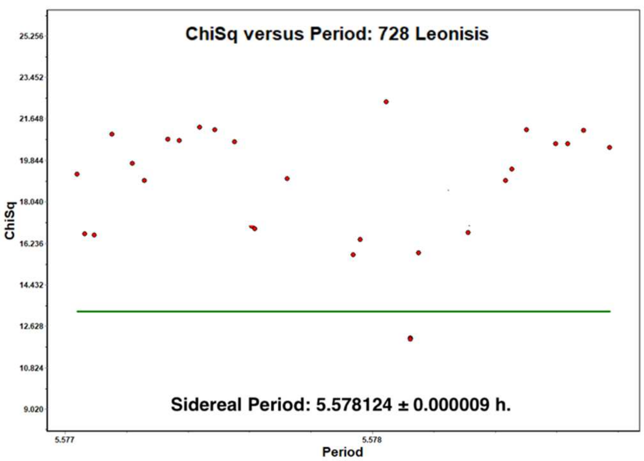
The factor 1/10 means that the period accuracy is 1/10 of the difference between local minima in the periodogram. When using *LCInvert*, we used Durech's formula as error estimate.

<u>728 Leonisis</u> is an asteroid of the Flora family (inner main-belt), that was discovered by Johann Palisa on 1912 February 16 in Vienna. We made observations from 2024 April 14 to May 1. Our analysis derived a synodic rotation period of 5.5778 ± 0.0004 h. Previous results include Behrend (2007web; 5.586 h), Galad (2010; 5.5789 h), Pilcher (2010; 5.5783 h), Waszczak et al. (2015; 5.710 h), and Mas et al. (2018; 5.58 h).

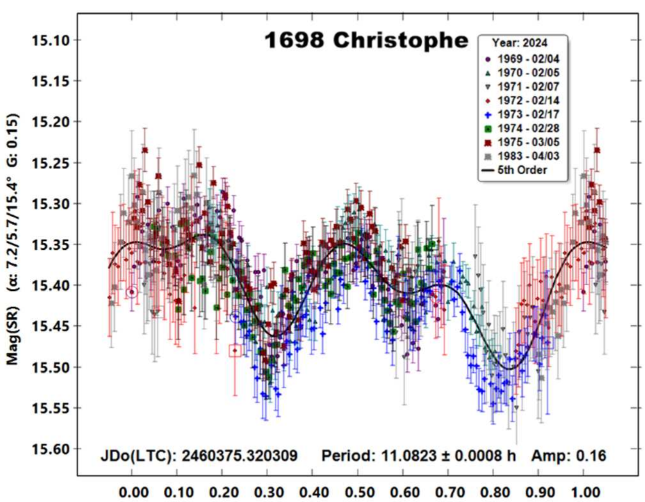
For this asteroid, we had additional dense data from our AVA Team from 2017. On the ALCDEF site, we found data from Pilcher (2010), Waszczak et al. (2015), and Mas et al. (2018). We also used sparse data from Catalina (442 points 2005-2023), Palomar (42 points 2019-2021), USNO (63 points 1998-2004), ATLAS (880 points 2017-2024).

The use of *LCInvert* with both new and old data led to a sidereal rotation period of 5.578124 ± 0.000009 h. That is consistent with Ďurech et al. (2020) who found a sidereal period of 5.57811 h.

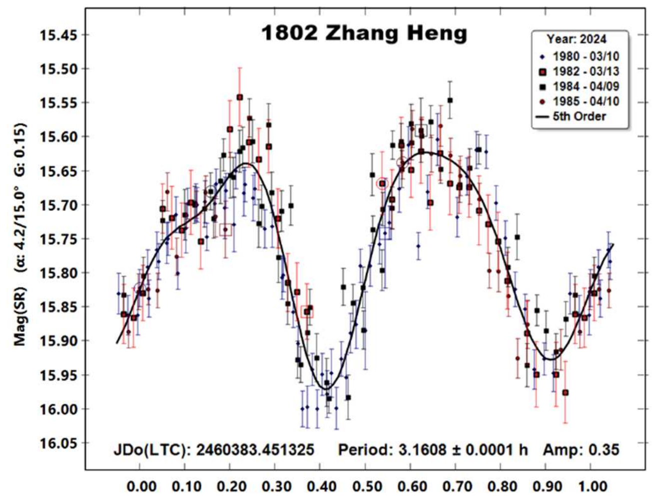




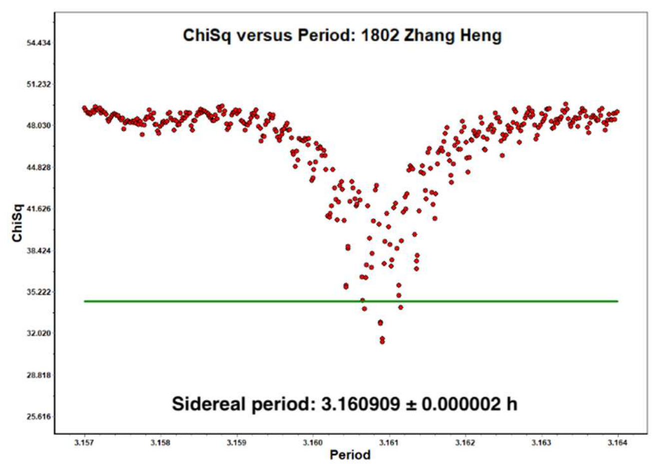
1698 Christophe was discovered by Eugène Joseph Delporte on 1934 February 10 at the Royal Observatory of Belgium, Uccle. We made observations from 2024 February 4 to April 3. We derived a synodic rotation period of 11.0823 ± 0.0008 h. There were no previously reported periods.



1802 Zhang Heng was discovered by the team at the Purple Mountain Observatory in Nanjing, China, on 1964 October 9. It was initially designated as 1964 TW1 and later named in honor of the Chinese astronomer Zhang Heng. We made observations from 2024 March 3 to April 3. We derived a synodic rotation period of 3.1608 ± 0.0001 h. This result is consistent with the previous results from Simpson et al. (2013; 3.162 h), Waszczak et al. (2015; 3.160 h), Mannucci and Montigiani (2019; 3.1554 h), Erasmus et al. (2020; 3.161 h), and Carreño et al. (2020; 3.161 h)

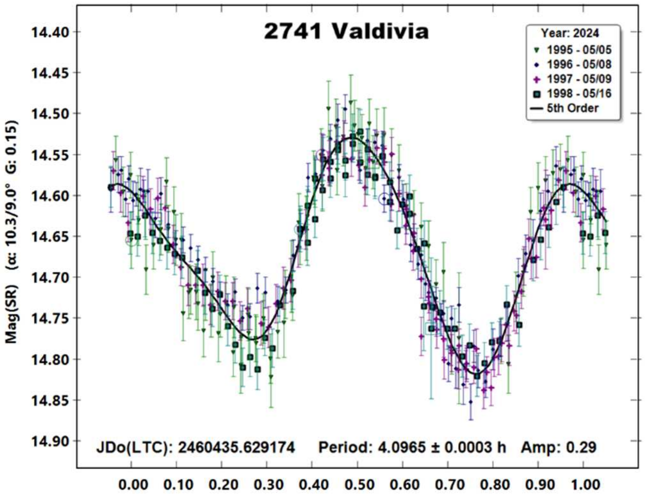


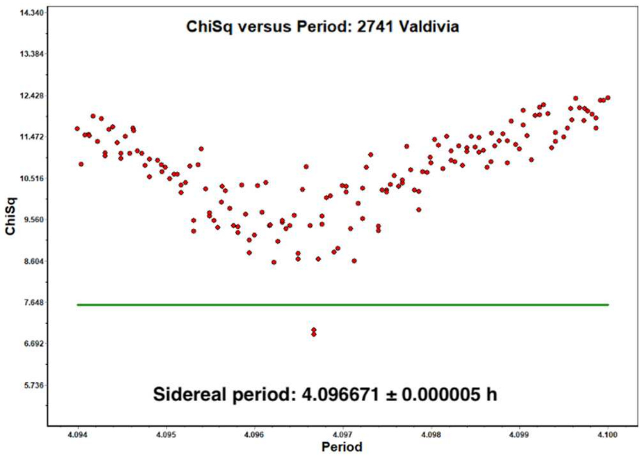
For this asteroid we also had the dense data from our AVA Team and ALCDEF (Carreño et al., 2020). We also used sparse data from Catalina (381 points 2005-2023), Palomar (42 points 2019-2021), LONEOS (34 points 1999-2007), USNO (92 points 1999-2007), and ATLAS (1476 points 2017-2024).



LCInvert led us to a sidereal rotation period of 3.160909 ± 0.000002 h. There was no previously reported sidereal period.

2741 Valdivia has a diameter of approximately 11 km. It was discovered on 1975 December 1 by Chilean astronomers Carlos Torres and Sergio Barros at the Cerro El Roble Station northwest of Santiago de Chile. The asteroid was named after Spanish conquistador Pedro de Valdivia. We made observations from 2024 May 5 to 15. We derived a synodic rotation period of 4.0965 ± 0.0003 h. This result is consistent with earlier results of Behrend (2003web; 8.1922 h and 8.191 h), Pray (2004; 4.096 h), Waszczak et al. (2015; 4.096 h), Brines et al. (2017; 4.098 h), and Pal et al. (2020; 4.09644 h).

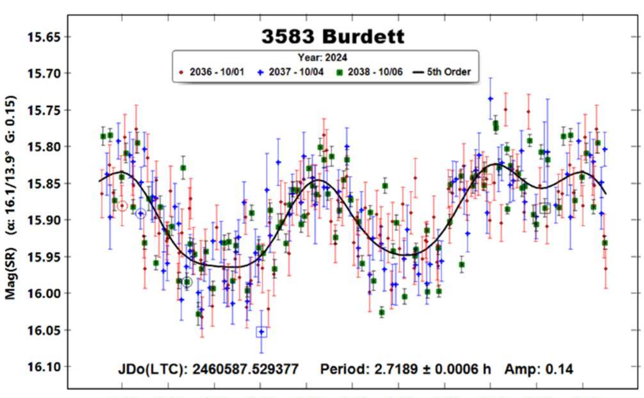




For this asteroid, we also had the dense data from our AVA Team, Brines et al. (2017). On ALCDEF we also found data from Pray (2004) and Hopkins (2024). We also used sparse data from Catalina (419 points 2006-2024), Palomar (127 points 2013-2022) and Atlas (1153 points 2017-2024).

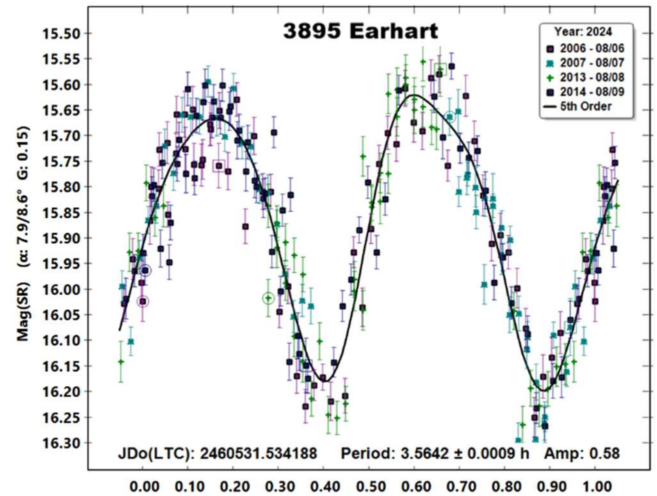
LCInvert led us to a sidereal rotation period of 4.096671 ± 0.000005 h. This is consistent with previous Hanus (2016), who found a sidereal period of 4.09668 h.

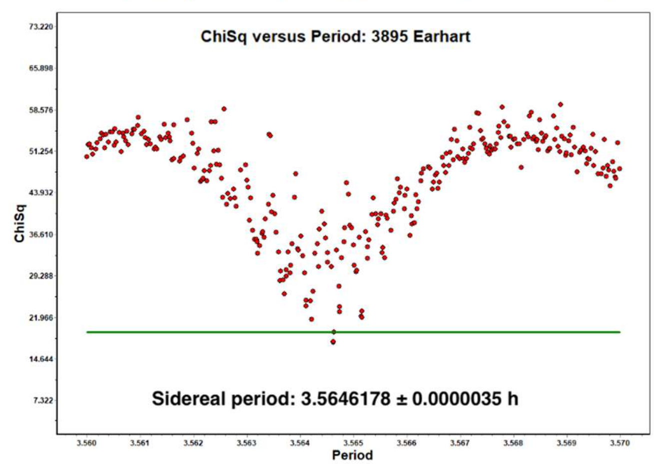
3583 Burdett was discovered on 1929 October 5 by Clyde Tombaugh from the Lowell Observatory in Flagstaff, Arizona. It was named in honor of the American town of Burdett, where the discoverer lived during his youth.



We made observations from 2024 October 1-6 and derived a synodic period of 2.7189 ± 0.0006 h. There was no previously reported period.

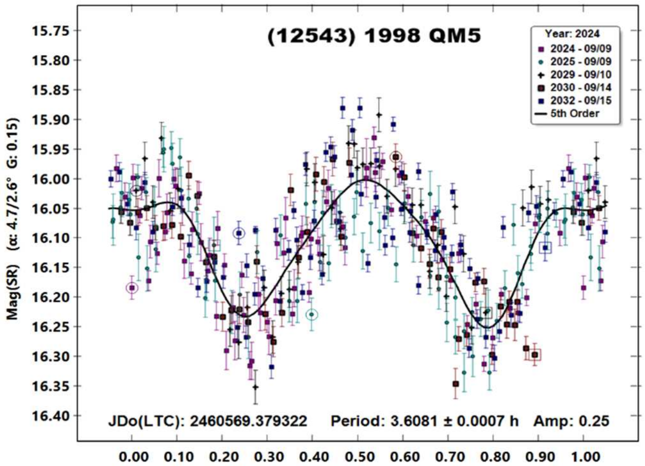
3895 Earhart was discovered on 1987 February 23 by Carolyn Shoemaker from the Palomar Observatory. It was named in honor of the American aviator Amelia Earhart. We made observations from 2024 August 6-9. We found a synodic period of 3.5642 ± 0.0009 h. This value is fully in line with several previously determined periods listed in LCDB: Behrend (2009web; 3.56451 h), Behrend (2016web; 3.5645 h), Behrend (2020web; 3.56501 h), Skiff (2016web; 3.5645 h), Warner (2009; 3.564 h), Aznar et al. (2016; 3.556 h), Stephens and Warner (2021; 3.567 h), and Benishek (2021; 3.57 h and 3.5646 h).



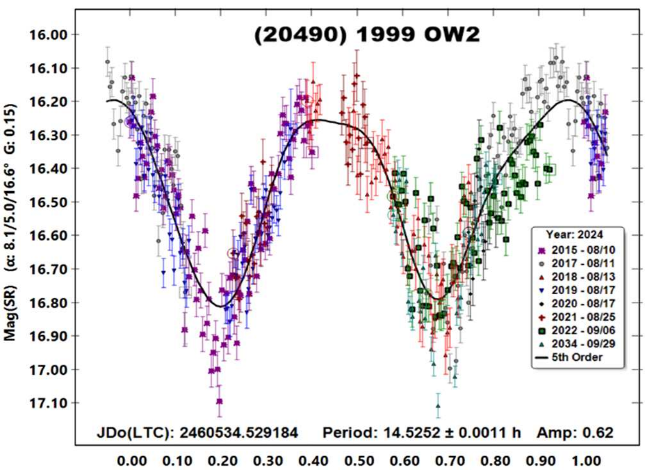


For this asteroid we also had the dense data from our AVA Team, Aznar et al. (2016) and Fornas (2023). On ALCDEF we also found data from Warner (2009) and Stephens and Warner (2021). We also used sparse data from Catalina (485 points 2003-2023), Palomar (68 points 2018-2022), and ATLAS (1323 points 2017-2024). Using these data in *LCInvert* led us to a sidereal rotation period of 3.5646178 ± 0.0000035 h. Ďurech et al. (2020) found a sidereal period of 3.564614 h.

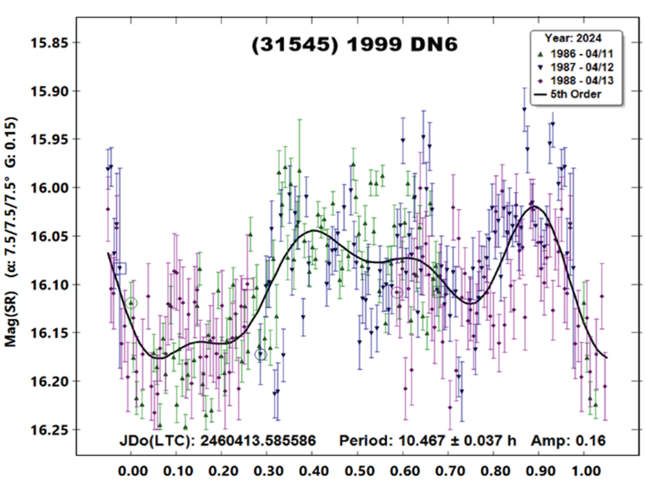
(12543) 1998 QM5 was discovered on 1998 August 23 by Australian amateur Frank B. Zoltowski at Woomera, Australia. We made observations from 2024 September 9-15. Data analysis found a synodic period of 3.6081 ± 0.0003 h. There was no previously reported period for this asteroid.



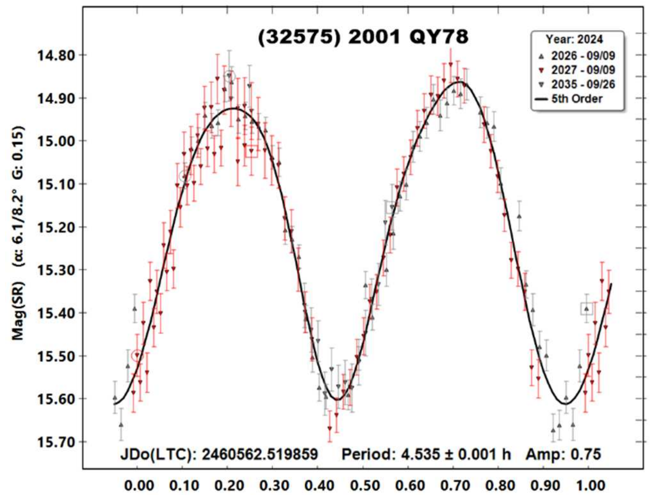
(20490) 1999 OW2 has an estimated diameter of 7.779 km. It was discovered on 1990 July 22 at the Magdalena Ridge Observatory by the Lincoln Near-Earth Asteroid Research (LINEAR) project. We observed from 2024 August 10 to September 29, finding a synodic period of 14.5252 ± 0.0011 h. We found no previous period.



(31545) 1999 DN6 was discovered in 1999 February 20 at the Magdalena Ridge Observatory by the Lincoln Near-Earth Asteroid Research (LINEAR) project. We made observations from 2024 April 11-13 and found a synodic period of 10.467 ± 0.037 h. We found no previously published period.



(32575) 2001 QY78 is a Mars-crossing asteroid discovered on 2001 August 16 at the Magdalena Ridge Observatory by the Lincoln Near-Earth Asteroid Research (LINEAR) project. We found a synodic period of 4.535 ± 0.001 h. This is consistent with previous results from Behrend (2014web), who found a period of 4.5344 h. Ďurech et al. (2016) reported a sidereal period of 4.535495 h.



Acknowledgements

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Number	Name	yyyy mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
728	Leonisis	2024 04/14-05/01	3.1,10.2	204	5	5.5778	0.0004	0.24	0.02	MB-I
1698	Christophe	2024 02/04-04/03	7.2,15.5	153	2	11.0823	0.0008	0.16	0.02	MB-O
1802	Zhang Heng	2024 03/03-04/03	0.9,12.4	161	1	3.1608	0.0001	0.35	0.03	MB-M
2741	Valdivia	2024 05/05-05/15	10.2,8.9	234	15	4.0965	0.0003	0.29	0.03	MB-M
3583	Burdett	2024 10/01-10/06	16.1,11.3	36	0	2.7189	0.0006	0.14	0.02	MB-M
3895	Earhart	2024 08/06-08/09	7.7,8.1	304	8	3.5642	0.0009	0.58	0.05	MB-I
12543	1998 QM5	2024 09/09-09/15	4.7,2.6	352	4	3.6081	0.0007	0.25	0.02	MB-I
20490	1999 OW2	2024 08/10-09/29	*8.4,16.3	333	11	14.5252	0.0011	0.62	0.05	MB-M
31545	1999 DN6	2024 04/11-04/13	7.5,7.5	203	12	10.467	0.037	0.16	0.02	MB-M
32575	2001 QY78	2024 09/09-09/26	*6.6,7.8	354	4	4.535	0.001	0.75	0.05	M-C

Table I. **Synodic periods**. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema during the period. LPAB and BPAB are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009).

Number	Name	yyyy mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.
728	Leonisis	2024 04/14-05/01	3.1,10.2	204	5	5.578124	0.000009
1802	Zhang Heng	2024 03/03-04/03	0.9,12.4	161	1	3.160909	0.000002
2741	Valdivia	2024 05/05-05/15	10.2,8.9	234	15	4.096671	0.000005
3895	Earhart	2024 08/06-08/09	7.7,8.1	304	8	3.5646178	0.0000035

Table II. **Sidereal periods.** Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extrema during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984).

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