LIGHTCURVE ANALYSIS FOR TWELVE MAIN-BELT AND ONE PHA ASTEROIDS

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(Received: 2023 September 11)

Photometric observations of twelve main-belt asteroids and one PHA were obtained between 2023/1/11 - 2023/7/17. We derived the following rotational synodic periods: 489 Comacina, 9.0250 ± 0.0012 h; 600 Musa, 5.88647 ± 0.00064 h; 716 Berkeley, 15.580657 ± 0.00048 h; 907 Rhoda, 22.4700 ± 0.0008 h; 1354 Botha, 8.3776 ± 0.0007 h; 3210 Lupishko, 14.247 ± 0.002 h; 3286 Anatoliya, 5.8103 ± 0.0009 h; 3379 Oishi, 19.2199 ± 0.019 h; 11736 Viktorfischl, 9.78407 ± 0.0012 h; 13653 Priscus, 6.7498 ± 0.0022 h; (23552) 1994 NB, 3.63175 ± 0.00052; (37638) 1993 VB, 3.529 ± 0.001 h; (76644) 2000 HY24, 9.6625 ± 0.012 h. And the following sidereal periods: 716 Berkeley, 15.57505 ± 0.00007 h; 11736 Victorfischl, 9.78218 ± 0.00003 h; (23552) 1994 NB, 3.628683 ± 0.000004; (76644) 2000 HY24, 9.702441± 0.00005 h

We report on the photometric analysis results for twelve main-belt asteroids and one PHA by Asociación Valenciana de Astronomía (AVA). The data were obtained during the first 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	106 mm Refr	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.

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 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 and Torppa (2001). This software uses the code written by J. Durech based on the original FORTRAN code written by Kaasalainen (2001): “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 no 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 ± ΔP are at the same epochs after Δt time.

As we can read in 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”.

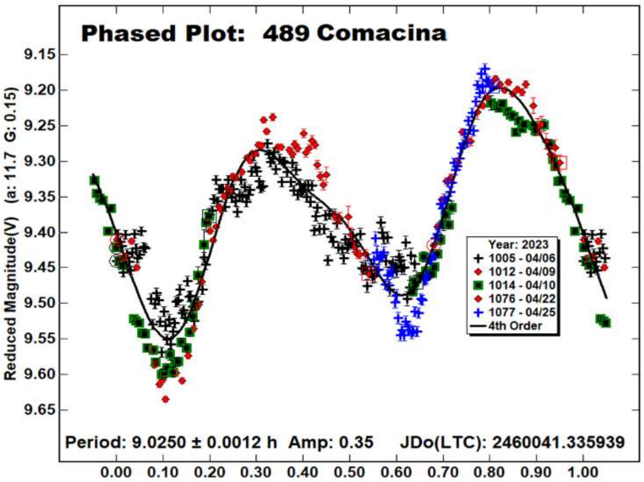
Durech (2006) proposes an estimate of error to be:

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

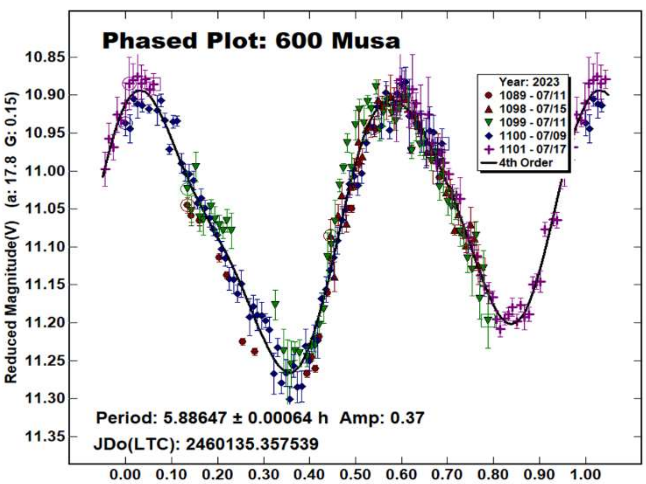
The factor 1/10 means that the period accuracy is 1/10 of the difference between local minima in the periodogram.

Results

<u>489 Comacina</u>. This outer main-belt asteroid was discovered on 1902 September 2 by L. Camera at Heidelberg in Germany. We made observations on 2023 April 6 to 25. We derived a rotation period of 9.0250 ± 0.0012 h and an amplitude of 0.39 mag. This is consistent with the previous result of 9 h from Weidenschilling et al. (1990) and Hawkins and Ditteon (2008), and 9.02 h from Stephens et al. (2001). Durech (2006) and Hanus et al. (2016) found a sideral period of 9.0232 h with the inversion method.

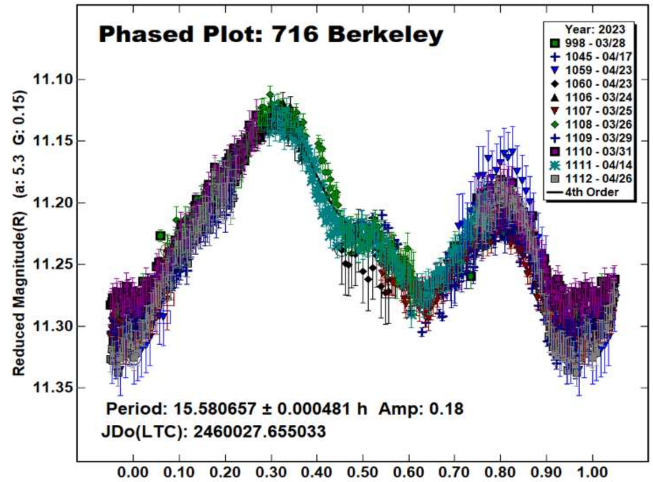


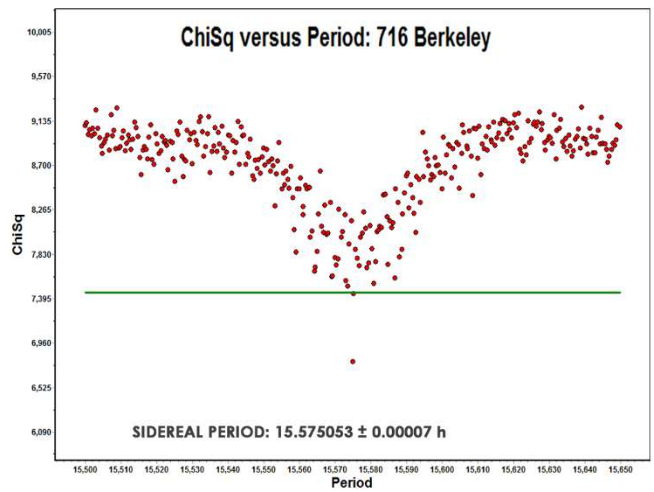
600 Musa. This middle main-belt asteroid was discovered on 1906 Jun 14 by J.H. Metcalf at Tauton. We made observations from 2023 Jul 11-17. From our data we derive a rotation period of 5.88647 ± 0.00064 h and an amplitude of 0.37 mag. Garcerán (2014web – no longer active) got 5.892 h, Behrend (2005web) got 5.8856 h and Binzel (1987) got 5.92 h. Hanus et al. (2013) found a sideral period of 5.88638 h with the inversion method.



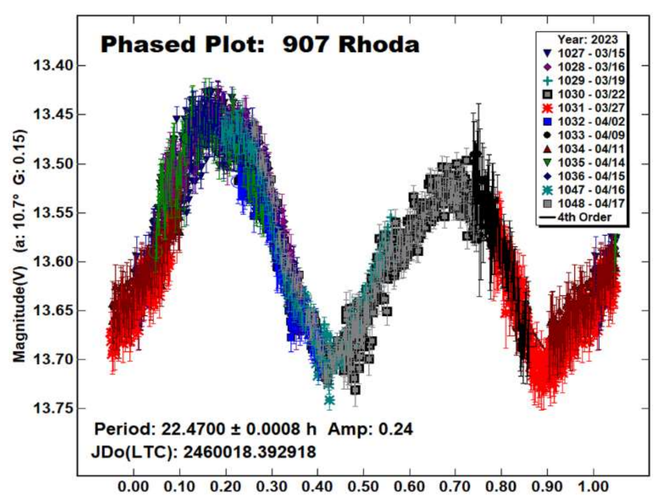
716 Berkeley. This middle main-belt asteroid was discovered on 1911 Jul 30 by J. Palisa at Vienna. We made observations on 2023 March 28 to April 23. In ALCDEF we found data from F. Pilcher on 2023 March 25 to April 26 with a very good quality. We have studied the rotation period of Berkeley using both sets of data. The period calculation is 15.580657 ± 0.00048 h and an amplitude of 0.18 mag. This is consistent with the previous result from Garlitz (2011web) with 15.55 h and Polakis (2021) with 15.46 h. Behrend (2018web) found 34.3 h, and Lagerkvist (1978) got 17 h. We can't agree with them.

In ALCDEF we found good quality data from Garlitz (2011web), Polakis (2021), Benisheck (LCDB) and Pilcher (LCDB). We use this data in conjunction with our own dense data and sparse data from Catalina (414 points, 2003/11/15 - 2023/4/2), Palomar (146 points, 2018/2/16 - 2022/4/9) and USNO (146 points, 1998/11/27 - 2007/12/6). With the inversion method we calculate a sidereal rotation period of 15.575053 ± 0.00007 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.

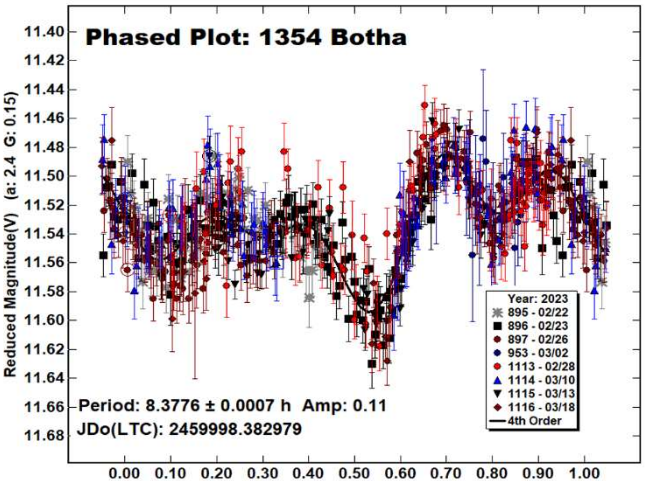




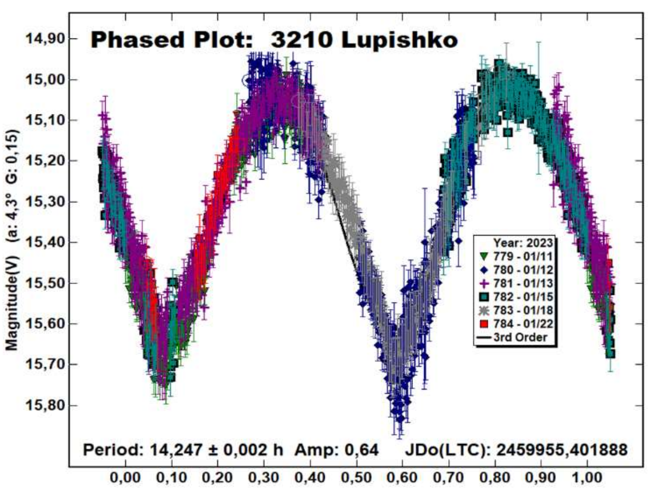
907 Rhoda. This middle main-belt asteroid was discovered on 1918 Nov 12 by M. Wolf at Heidelberg We made observations on 2023 from March 15 to April 17. From our data, we derive a rotation period of 22.4700 ± 0.0008 h and an amplitude of 0.24 mag. This is consistent with Marciniak (ALCDEF) who got 22.46 h and Behrend (2018web) with 22.4 h. Warner (2004) got 22.44 h. We can't agree with Pal et al. (2020) with 42.6307 h.



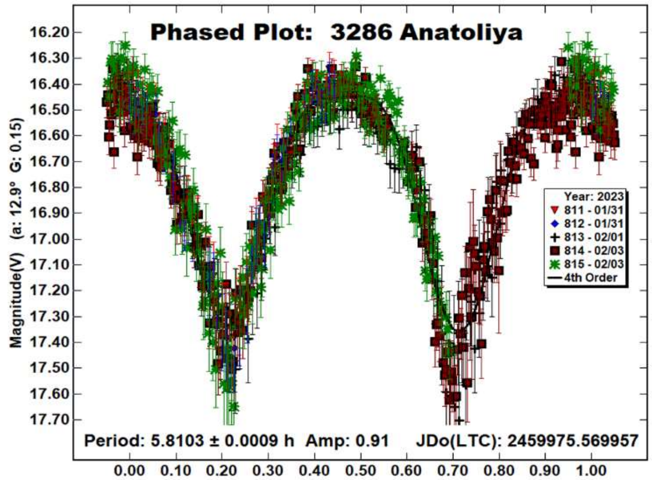
1354 Botha. This outer main-belt asteroid was discovered on 1935 April 3 by C. Jackson at Johannesburg. We made observations on 2023 Feb 22 to March 2. In ALCDF we found observations from Wiles (2023) for the same months in 2023 and we joined them to ours to improve the result. We derive a rotation period of 8.3776 ± 0.0007 h and an amplitude of 0.11 mag. In the LCDB we just find a previous calculation. Behrend (2003web) found 4 h.



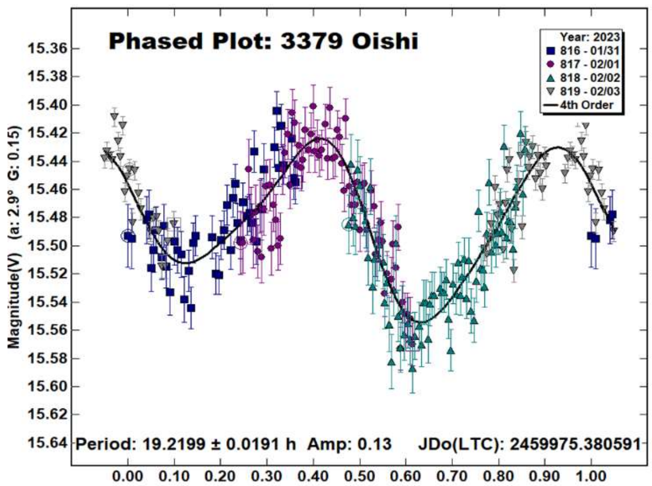
3210 Lupishko. This outer main-belt asteroid was discovered on 1983 Nov 29 by E. Bowell at Anderson Mesa. We made observations on 2023 Jan 11-22. From our data we derive a rotation period of 14.247 ± 0.002 h and an amplitude of 0.64 mag. There are several results in LCDB consistent with us: Waszczak et al. (2015) got 14.241 h and Montminy et al. (2018) found 14.255 h. Using the inversion method, Durech and Hanus (2018) found 14.2490 h, and Durech et al. (2020) got 14.24917 h.



3286 Anatoliya. This middle main-belt asteroid was discovered on 1980 Jan 23 by L.G. Karachkina at the Nauchnij observatory in Crimea. We made observations on 2023 Jan 31 to Feb 3. Data analysis found a rotation period of 5.8103 ± 0.0009 h and an amplitude of 0.91 mag. Durech et al. (2016) got a sidereal period of 5.81029 h with the inversion method.

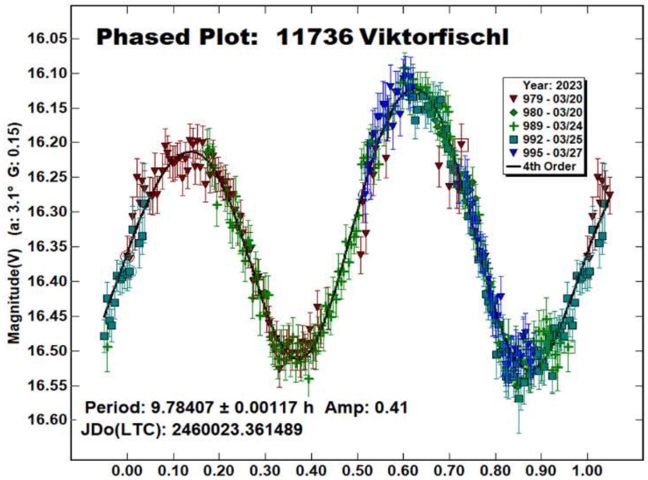


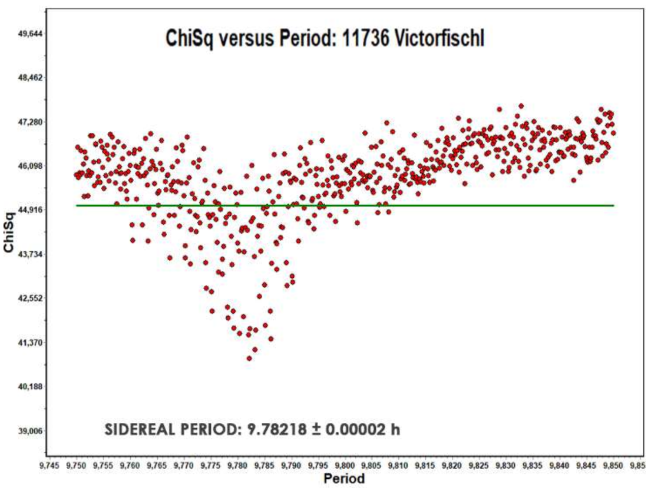
3379 Oishi. This inner main-belt asteroid was discovered on 1931 Oct 6 by K. Reinmuth at Heidelberg. We made observations on 2023 Jan 31 to Feb 3. From our data we derive a rotation period of 19.2199 ± 0.0191 h and an amplitude of 0.13 mag. We have not found previous information about its rotation period.



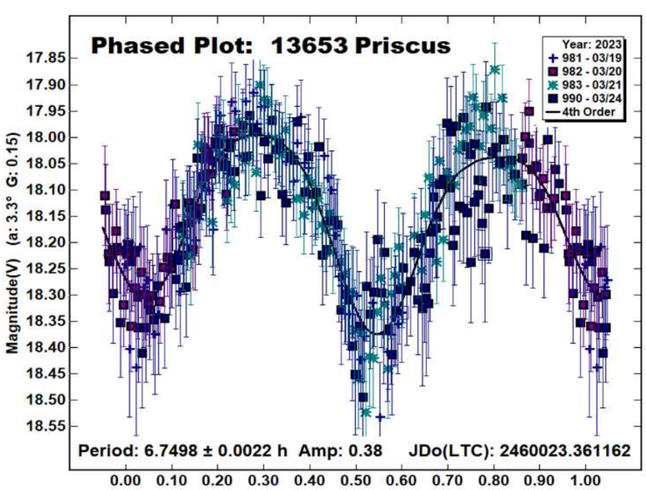
11736 Viktorfischl. This inner main-belt asteroid of the Nysa - Polana complex was discovered on 1998 Aug 18 at Ondřejov Observatory by L. Kotková. We made observations on 2023 March 20-27. From our data we derive a rotation period of 9.78407 ± 0.00117 h and an amplitude of 0.41 mag. Erasmus et al. (2020) found a period of 9.783 h which is consistent with us.

We use our dense data this data in conjunction with sparse data from Catalina (458 points, 2003/10/29 - 2023/6/21), Palomar (64 points, 2017/12/17 - 2022/4/6) and ATLAS (611 points, 2017/7/29 - 2023/3/25). With the inversion method we get a sidereal rotation period of 9.78218± 0.00002 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.



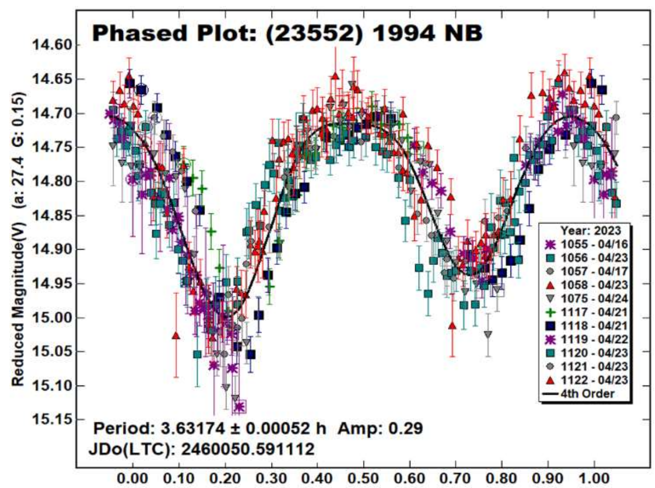


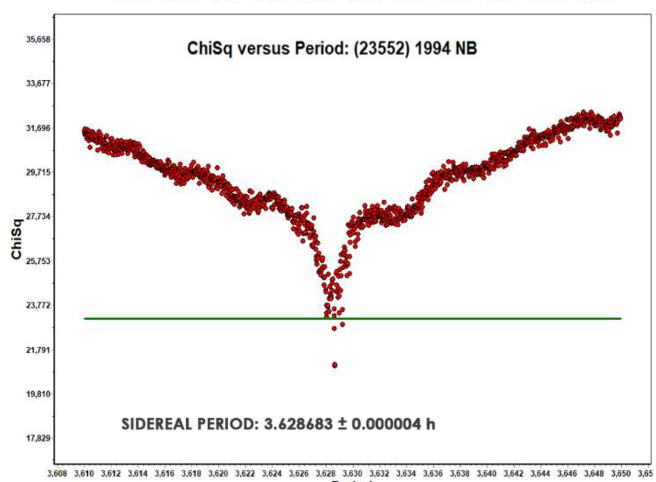
13653 Priscus. This inner main-belt asteroid was discovered on 1997 Feb 2 by V.S. Casulli at Coleverde observatory. We made observations 2023 March 19-24. From our data we derive a rotation period of 6.7498 ± 0.0022 h and an amplitude of 0.38 mag. We have not found previous information about its rotation period.



(23552) 1994 NB. This inner main-belt asteroid of the Phocacea family was discovered on 1994 Jul 3 by E.F. Helin at Palomar. We made observations on 2023 March 22-24. In ALCDEF we found data from Bucek (LCDB) on 2023 March 21-24 with a very good quality. We have studied the rotation period using both sets of data. Our period is 3.63175 ± 0.00052 h and an amplitude of 0.29 mag. Consistent with our results are those Waszczak et al. (2015) with 3.629 h and Skiff et al. (2023) with 3.630h. Pal et al. (2020) found a sidereal period of 3.62757 h with the inversion method.

In ALCDEF we found good quality data from Waszczak et al. (2015), Skiff et al. (2023), Pal et al. (2020), and Bucek (LCDB). We use these data in conjunction with our own dense data and sparse data from Catalina (454 points, 2003/12/5 - 2023/7/1), Palomar (42 points, 2018/12/13 - 2022/12/21) and ATLAS (671 points, 2015/9/17 - 2023/6/30). With the inversion method we get a sidereal rotation period of 3.628683± 0.000004 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.





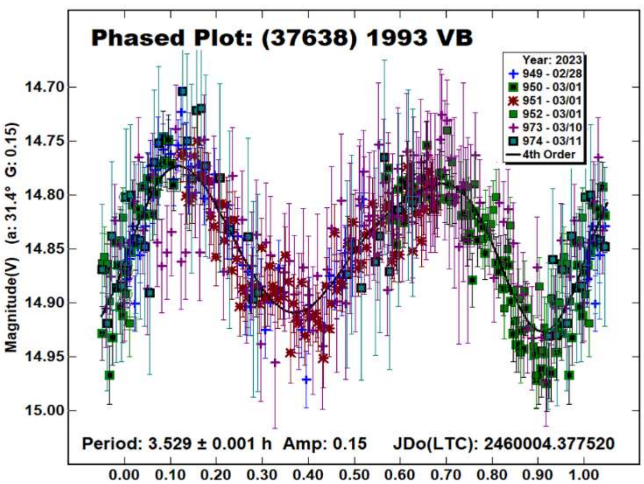
(37638) 1993 VB. This PHA was discovered on 1993 Nov 6 by R.H. McNaught at Siding Spring observatory. We made observations on 2023 Feb 28 to March 11. From our data we derive a rotation period of 3.529 ± 0.001 h and an amplitude of 0.158 mag. Pravec et al. (2022web) found 3.5301 h which is consistent with our data.

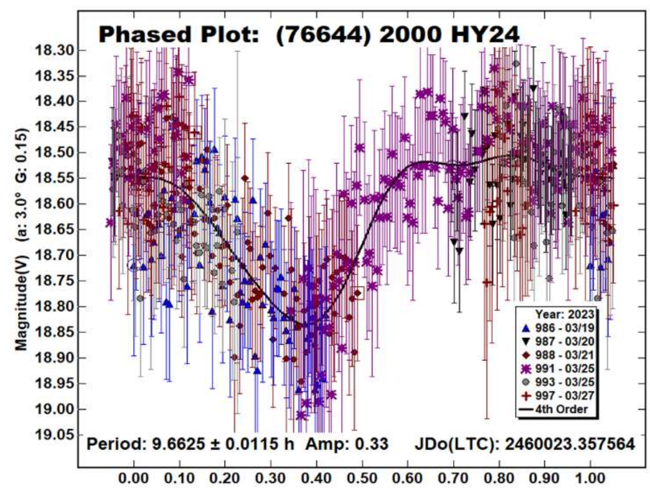
Number	Name	mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
489	Comacina	2023/4/6-25	11.4, 16.1	165.4	1.5	9.0250	0.0012	0.39	0.05	MB-O
600	Musa	2023/7/11-17	17.5, 19	250.4	10.9	5.88647	0.00064	0.37	0.05	MB-M
716	Berkeley	2023/3/28-4/23	5.3, 23	201.5	8.3	15.580657	0.00048	0.18	0.03	MB-M
	(from Pilcher)	2023/3/25-4/26								
907	Rhoda	2023/3/15-4/17	10.3, 10.6	188.1	15.8	22.4700	0.0008	0.24	0.02	MB-M
1354	Botha	2023/2/22-3/2	2.3, 4.4	149.1	6.1	8.3776	0.0007	0.11	0.02	MB-O
3210	Lupishko	2023/1/11-12	4.3, 3.9	120.8	-2.7	14.247	0.002	0.64	0.05	MB-M
3286	Anatoliya	2023/1/31-3/2	15.6, 7.7	162.1	13.8	5.8103	0.0009	0.91	0.05	MB-M
3379	Oishi	2023/1/31-3/2	2.8, 1.1	135.2	-.9	19.2199	0.0191	0.13	0.02	MB-I
11736	Viktorfischl	2023/3/20-27	3.2, 6.1	177.1	4.765	9.78407	0.00117	0.41	0.02	MB-I
13653	Priscus	2023/3/19-24	.1, 4.8	176.4	5.0	6.7498	0.0022	0.38	0.05	MB-I
23552	1994 NB	2023/3/22-24	23.6, 23.7	191.2	32.3	3.63175	0.00052	0.29	0.05	MB-I
37638	1993 VB	2023/2/28-3/11	34.1, 20.6	152.2	9.1	3.529	0.001	0.15	0.03	PHA
76644	2000 HY24	2023/3/19-27	2.4, 4.6	176.6	5.3	9.6625	0.012	0.18	0.05	MB-I

Table I. Sinodic 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; PHA: Potentially Hazardous *Asteroid*).

Number	Name	mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Grp
716	Berkeley	2023/3/28-4/23	5.3, 23	201.5	8.3	15.57505	0.00007	MB-M
	(From Pilcher)	2023/3/25-4/26						
11736	Viktorfischl	2023/3/20-27	3.2, 6.1	177.1	4.7	9.78218	0.00003	MB-I
23552	1994 NB	2023/3/22-24	23.6, 23.7	191.2	32.3	3.628683	0.000004	MB-I
76644	2000 HY24	2023/3/19-27	2.4, 4.6	176.6	5.3	9.70244	0.00005	MB-I

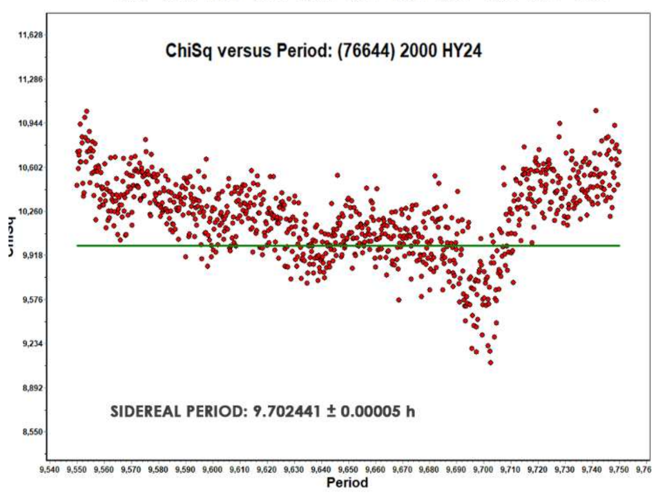
Table II. Sidereal Periods. Observing circumstances and results. The phase angle values are for the first and last date. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude and latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009). MB-I/O: Main-belt inner/outer.





<u>(76644) 2000 HY24</u>. This middle main-belt asteroid was discovered on 2000 April 24 by LONEOS at Anderson Mesa. We made observations on 2023 March 19-27. From our data we derive a rotation period of 9.6625 ± 0.0115 h and an amplitude of 0.33 mag. We have not previous information about its rotation period.

We use our dense data this data in conjunction with sparse data from Catalina (184 points, 2004/3/26 - 2023/10), Palomar (48 points, 2018/2/7 - 2022/12/19) and ATLAS (204 points, 2017/12/30 - 2023/3/25). With the inversion method we get a sidereal rotation period of 9.702441 ± 0.00005 h. For the error estimation we have used the interval 2004-2023. 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.



Acknowledgements

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

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