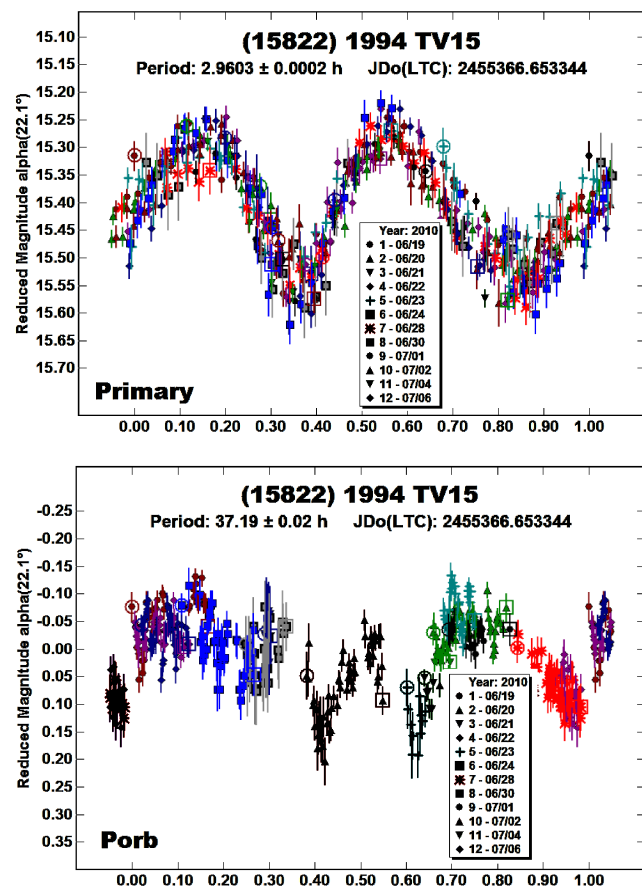


Carbuncle Hill Observatory was provided by a Gene Shoemaker NEO Grant from the Planetary Society.

References

Warner, B.D. (2007). “Asteroid Lightcurve Analysis at the Palmer Divide Observatory – March – May 2007”, *Minor Planet Bul.* **34**, 104-107.



LIGHTCURVES AND PERIODS OF EIGHTEEN NEAS AND MBAS

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Eighteen asteroids, NEAs and MBAs, were observed and lightcurves measured at OAVdA from 2009 January through 2010 September: 869 Mellena, 1643 Brown, 2983 Poltava, 3387 Greenberg, 3833 Calingasta, 3870 Mayre, 4223 Shikoku, 4391 Balodis, 4928 Vermeer, 11277 Ballard, 13009 Voloshchuk, (14691) 2000 AK119, 14815 Rutberg, (19261) 1995 MB, (68350) 2001 MK3, (162900) 2001 HG31, 2009 FD and 2009 NH.

This paper features the results of photometric observations on asteroids, both main-belt asteroids (MBAs) and near-Earth

asteroids (NEAs), made at the Astronomical Observatory of the Autonomous Region of the Aosta Valley (OAVdA) (Carbognani and Calcidesse, 2007), from 2009 January through to 2010 September. The data are helpful to increase the number of asteroid rotation periods to have a comprehensive statistical picture of the rotational evolution of these bodies (Carbognani, 2010a; 2010b).

The images were captured by means of a Ritchey-Cretien 0.81-m telescope operating at f/7.9. The CCD cameras used were a FLI P1001E (1024×1024 pixel, field of view of 13.2'×13.2' and an image scale of 1.5"/pixel) or a FLI PL 3041-1-BB (2048×2048 pixel, a field of view of 16.5'×16.5' and an image scale of 0.97"/pixel). Unless otherwise indicated, the CCD camera used for the observations is the latter.

We used MPO Canopus (Warner, 2009), version 9.5.0.14, for the differential photometry and the period analysis. In some cases, i.e. when the periods are long, the relative positions of the lightcurves, from the different sessions for the same asteroid, are determined by measuring the magnitude of the first point of the lightcurve in R band (the magnitudes are from the r' values of the CMC14 catalog, see Miles and Dymock, 2009) and by setting the DeltaComp values in Canopus so that the lightcurves shift is the same as the R magnitude shift. To calculate the magnitude of the asteroid, we used 5 comparison stars, manually selected. In the case of very different phase angles, the magnitude has been corrected by taking the H value from JPL Small-Body Database Browser (JPL, 2010), and putting $G = 0.15$, the mean value between C and S-type asteroids (Shevchenko and Lupishko, 1998). With this method (hereafter, called “R shift method”), the relative lightcurves location is accurate within few hundredths of magnitude.

The amplitude of the lightcurve is obtained as the difference between maximum and minimum of a polynomial interpolation of twelfth-twentieth degree (the degree varies depending on the lightcurve complexity). The amplitude uncertainty is the standard deviation of the observed magnitude points, taking as average the value provided by the polynomial interpolating the entire lightcurve calculated at the same phase, i.e.:

$$\sigma = \sqrt{\frac{\sum_i^N (m_i - p_i)^2}{N - 1}} \quad (1)$$

In Eq. (1) N is the number of points in the lightcurve, m_i is the magnitude of the i -th point and p_i is the magnitude of the i -th point given by the polynomial fit. Thus, we obtain a representative value of the uncertainty of the entire lightcurve. Table I shows the period and the amplitude results, both with their uncertainties.

The data for the known periods were drawn from Asteroid LightCurve Data Base (or ALCDB, version of 2010 May 21), care of Alan W. Harris and Brian D. Warner of Space Science Institute and Petr Pravec of the Astronomical Institute, Czech Republic (Warner et al., 2009)

869 Mellena is an MBA. A total of 210 images were taken on 4 nights in R and V band. The observations were made in the presence of a full Moon and a hazy sky but the lightcurve coverage is complete. From the data we extracted a rotation period of 6.515 ± 0.001 hours and an amplitude of 0.26 ± 0.03 mag. Following the same procedure as was used with 2009 NH, the V-R color index is 0.24 ± 0.03 (mean of 3 values), compatible with a C-type asteroid. For this object, no period was already known.

1643 Brown is an MBA. A total of 92 images were taken on 2 nights in R band. From the data we extracted a rotation period of 5.9310 ± 0.0005 hours and an amplitude of 0.50 ± 0.02 mag. The coverage is complete. No period was already known.

2983 Poltava is a MBA. A total of 61 images were taken on 2 nights in R band. From the data we estimated a rotation period of 8.865 ± 0.003 hours and an amplitude of 0.67 ± 0.02 mag. The relative positions of the lightcurves were determined with the R shift method with correction for the phase angle difference. The coverage is complete, no period was already known.

3387 Greenberg is an MBA. A total of 55 images were taken in 3 nights in R band. From the data we extracted a rotation period of 2.6940 ± 0.0005 hours, the shortest value in the entire survey, and an amplitude of 0.18 ± 0.02 mag. The lightcurve is complex and the coverage is complete. No period was already known.

3833 Calingasta is an MBA. A total of 204 images were taken on 4 nights in R band. In the first two sessions, the sky was cloudy with a full Moon and the lightcurves are noisy while, in the last two sessions, the sky was clear. From the data we extracted a possible rotation period of 38.61 ± 0.05 hours and an amplitude of 0.49 ± 0.01 mag but the coverage is far from complete. The relative positions of the lightcurves were established with the R shift method with correction for the phase angles difference. No period was already known.

3870 Mayre is an MBA. A total of 210 images were taken on 4 nights in R and V band. The conditions of observation were similar to those for Mellena and the lightcurve coverage is complete. From the data we extracted a rotation period of 3.9915 ± 0.0001 hours and an amplitude of 0.44 ± 0.03 mag. The V-R color index is 0.45 ± 0.04 (mean of 3 values), compatible with a M-type asteroid. As for the above objects, for this no period was already known.

4223 Shikoku is an MBA. A total of 139 images were taken on 5 nights in R band. For the sessions of September 9 and 10 the comparison stars are the same. A rotation period of 9.138 ± 0.001 hours and an amplitude of 0.18 ± 0.02 mag. were extracted from the data. The coverage is complete. The points scattered between the phase 0.8 and 0.9 can be attributed to non-optimal conditions. No period was already known.

4391 Balodis is an MBA. A total of 127 images were taken on 4 nights in R band. In the first two sessions, the sky was very cloudy and the lightcurves are noisy but the coverage is complete. The third session is the best, whereas the fourth is useless, because of poor vision. A rotation period of 3.448 ± 0.001 hours and an amplitude of 0.29 ± 0.03 mag. were extracted from the data of sessions 2 and 3. No period was already known.

4928 Vermeer is a MBA. A total of 57 images were taken on 2 nights in R band. From the data we extracted a rotation period of 3.687 ± 0.001 hours and an amplitude of 0.68 ± 0.02 mag. The coverage is complete. No period was already known. Due to its short rotation period and to the two long observation sessions (easily stackable manually), this asteroid was used as a test for the R shift method validity.

11277 Ballard is an MBA. A total of 49 images were taken on 2 nights in R band. From the data available we can assume that the rotation period is greater than 10 hours and that the amplitude is greater than 0.30 mag. The relative positions of the lightcurves were determined with the R shift method. No period was already known.

13009 Voloshchuk is an MBA. A total of 226 images were taken on 6 nights. A rotation period of 14.8212 ± 0.0008 hours and an amplitude of 0.67 ± 0.03 mag. were extracted from the data. For some sessions, the relative positions of some lightcurves were determined with the R shift method. No period was already known.

(14691) 2000 AK119 is an MBA. A total of 69 images were taken in 3 nights in R band and the coverage is complete. From the data we extracted a rotation period of 3.6524 ± 0.0002 hours and an amplitude of 0.73 ± 0.02 mag., the coverage is complete. The lightcurve appear to have a textbook shape, with two maximums and two minimums of equal intensity. For this object no period was already known.

14815 Rutberg is an MBA. A total of 69 images were taken on 2 nights in R band but the coverage is far from complete and the first session is very noisy due to hazy sky together with a full Moon. The rotation period appears greater than 10 hours with an amplitude greater than 0.50 mag. The relative positions of the lightcurves were determined with the R shift method with phase angle correction. For this asteroid no period was already known.

(19261) 1995 MB is an MBA. A total of 71 images were taken on 2 nights in R band. From the data we extracted a rotation period of 4.586 ± 0.004 hours and an amplitude of 0.54 ± 0.03 mag. The coverage is complete. As for 14691, the asteroid's shape appears quite symmetrical. No period was already known.

(68350) 2001 MK3 is an Amor object. A total of 163 images were taken on 2 nights (the second session, for technical reasons, is divided into two subsections) with a C filter and an FLI 1001E CCD camera. The coverage is complete. The first session is a bit noisy but relevant to determine the rotation period. From the data we extracted a rotation period of 3.273 ± 0.001 hours and an amplitude of 0.20 ± 0.02 mag. The period and amplitude in ALCDB for this object are 3.24 h and 0.20 with U=2. No lightcurve of this object had been published before.

(162900) 2001 HG31 is an Amor object. A total of 120 images were taken on 1 night in R band with an FLI 1001E CCD camera. Being the collected data limited, it was not possible to establish a rotation period but only a lower limit for the amplitude of about 0.60 mag. due to a sudden drop in brightness. The period and amplitude in ALCDB for this object are 60.61 h and 0.56 with U=3. This is a tumbling asteroid.

2009 FD is an Apollo asteroid. A total of 348 images with a C (clear) filter were taken on 2 consecutive nights with FLI 1001E CCD camera. The data are rather noisy due to the low magnitude of the target (about +16.7) and the lightcurve coverage is not complete. From the data we extracted a rotation period, rather approximate, of 5.87 ± 0.02 hours and an amplitude of 0.24 ± 0.04 mag., but the coverage is not complete. The period and amplitude in ALCDB for the object are 4.0 h and 0.35 with U=2, which is not too different from our values.

2009 NH is an Amor asteroid. A total of 533 images were taken on 2 nights, with C, V and R filters. The lightcurve coverage is complete. From the data we extracted a rotation period of 3.033 ± 0.002 hours and an amplitude of 0.13 ± 0.014 mag. The asteroid was observed in V and R band, which made it possible to us to estimate the mean V-R color index. To this purpose, we used CMC14 catalogue and Richard Miles and Roger Dymock's method (Miles and Dymock, 2009). The result is $V-R = 0.37 \pm 0.05$ (the mean of 3 values). The individual color indices are essentially independent of the rotational phase, because they were

corrected with the synodic period which was found. This V-R value is typical of a C-type asteroid (Shevchenko and Lupishko, 1998). For this object, no period was already known.

H_R , G and diameter estimate for 13009 Voloshchuk

In the case of asteroid 13009 Voloshchuk there are sufficient values of R magnitude (Miles and Dymock, 2009), taken at very different phase angles, for a fit in the H_R -G parameter space (see Table II). The fit gives the following results: $H_R = 12.90 \pm 0.09$ mag., $G = 0.03 \pm 0.09$ (see Fig. 19). This low G value is typical of a C-type asteroid or similar (Shevchenko and Lupishko, 1998).

If we consider that the mean V-R value for this asteroid type is 0.38 ± 0.05 mag., we can estimate the absolute magnitude in the visual band as $H_V = 13.3 \pm 0.1$. Assuming the typical p_V value for C-type (0.06 ± 0.02) we can finally estimate the actual diameter of 13009 Voloshchuk as $D = 12 \pm 2$ km.

Acknowledgments

Research on asteroids at OAVdA Observatory is supported by Director, Prof. Enzo Bertolini, and funded with a European Social Fund grant from the Regional Government of the Regione Autonoma della Valle d'Aosta (Italy). This research has made use of the SIMBAD and VIZIER databases with Aladin Sky Atlas that operate at CDS (Strasbourg, France) and of the NASA's Astrophysics Data System.

References

- Carbognani, A. (2010a). "Statistical analysis of C and S Main Belt Asteroids." *Icarus* **205**, 497-504.
- Carbognani, A. (2010b). "A possible YORP effect on C and S Main Belt Asteroids." DOI: 10.1016/j.icarus.2010.09.007.
- Carbognani, A. and Calcidesse, P. (2007). "Lightcurve and rotational period of asteroids 1456 Saldanha, 2294 Andronikov and 2006 NM." *Minor Planet Bulletin*, **34**, 18-19.
- Dymock, R. and Miles, R. (2009). "A method for determining the V magnitude of asteroids from CCD images". *J. Br. Astron. Assoc.* **119**, 149-156.
- Shevchenko V. G. and Lupishko D. F. (1998). "Optical properties of Asteroids from Photometric Data." *Solar System Research*, **32**, 220-232.
- JPL, 2010. <http://ssd.jpl.nasa.gov/sbdb.cgi>
- Warner, B.D., Harris, A.W, and Pravec, P. (2009). "The asteroid lightcurve database." *Icarus*, **202**, 134-146.
- Warner, B.D. (2009). MPO Software, Canopus. Bdw Publishing, <http://minorplanetobserver.com/>.

Number	Dates yyyy mm dd	Phase [deg]	Period [h]	Amp [mag]
869	2010 06 24/25 2010 07 05/06	11.0– 15.6	$6.515 \pm$	$0.26 \pm$

Number	Dates yyyy mm dd	Phase [deg]	Period [h]	Amp [mag]
			0.001	0.03
1643	2010 09 21/28	6.1– 3.6	$5.9310 \pm$ 0.0005	$0.50 \pm$ 0.02
2983	2010 09 19/28	3.0– 6.1	$8.865 \pm$ 0.003	$0.67 \pm$ 0.02
3387	2010 09 12/13/19	13.3– 15.5	$2.6940 \pm$ 0.0005	$0.18 \pm$ 0.02
3833	2010 08 24/27 2010 09 02/03	19.1– 22.4	$38.61 \pm$ 0.05	$0.49 \pm$ 0.01
3870	2010 06 24/25 2010 07 05/06	13.1– 17.2	$3.9915 \pm$ 0.0001	$0.44 \pm$ 0.03
4223	2010 09 09/10/13/19/22	7.7– 11.9	$9.138 \pm$ 0.001	$0.18 \pm$ 0.02
4391	2010 07 09/10/15 2010 08 24	6.1– 7.1 23.9	$3.448 \pm$ 0.001	$0.29 \pm$ 0.03
4928	2010 09 09/10	11.9– 12.5	$3.687 \pm$ 0.001	$0.68 \pm$ 0.02
11277	2010 07 15/19	17.4– 17.8	≥ 10	≥ 0.30
13009	2010 08 01/20 2010 09 09/10/13/22	10.6– 17.1	$14.8212 \pm$ 0.0008	$0.67 \pm$ 0.03
14691	2010 07 19/21/24	6.6– 5.7	$3.6524 \pm$ 0.0002	$0.73 \pm$ 0.02
14815	2010 07 24/30	7.7– 4.9	≥ 10	≥ 0.50
19261	2010 07 09/10	5.1– 5.2	$4.586 \pm$ 0.004	$0.54 \pm$ 0.03
68350	2009 01 22/29	32.4– 28.7	$3.273 \pm$ 0.001	$0.20 \pm$ 0.02
162900	2009 01 22	41.0	---	≥ 0.6
2009 FD	2009 03 21/22	17.9– 18.3	$5.87 \pm$ 0.02	$0.24 \pm$ 0.04
2009 NH	2009 08 21/22	8.7– 8.9	$3.033 \pm$ 0.002	$0.13 \pm$ 0.014

Table I. The list of observed asteroids with the observation dates, minimum and maximum solar phase angles, derived synodic rotation periods and lightcurve amplitudes, both with their uncertainties.

Month/Day	UT	R	α (°)
08 20	21:04	14.84	0.61
09 09	20:16	15.61	10.97
09 10	19:39	15.37	11.47
09 22	20:00	15.91	17.09

Table II. The R magnitude values, corrected for the rotational phase with the 14.8212 h period, used for the H_R -G estimate of the asteroid (13009) Voloshchuk. The last column shows the corresponding phase angle.

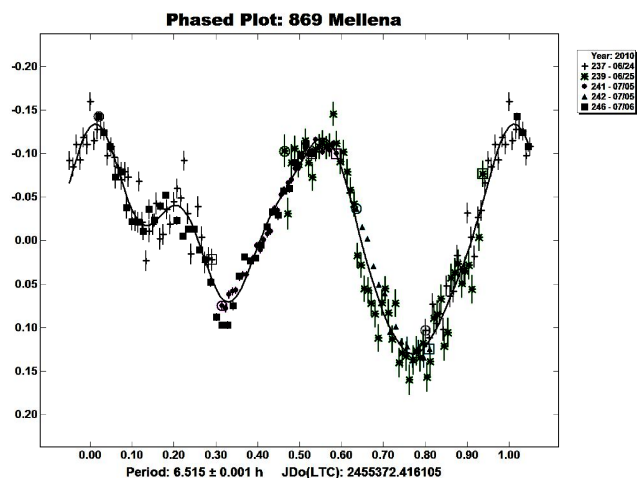


Figure 1. Full lightcurve of 869 Mellena.

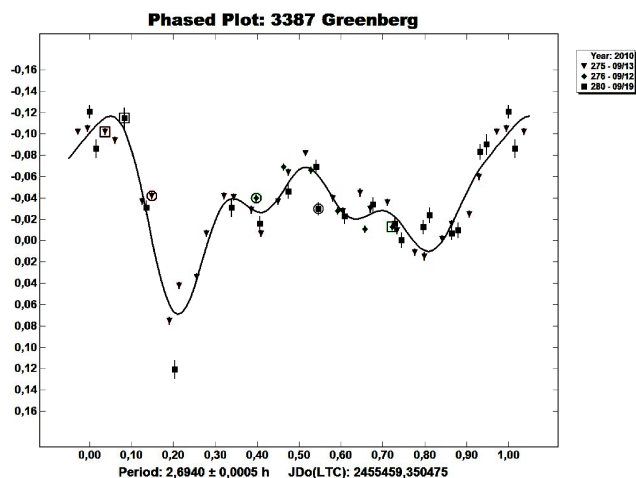


Figure 4. Full lightcurve of 3387 Greenberg.

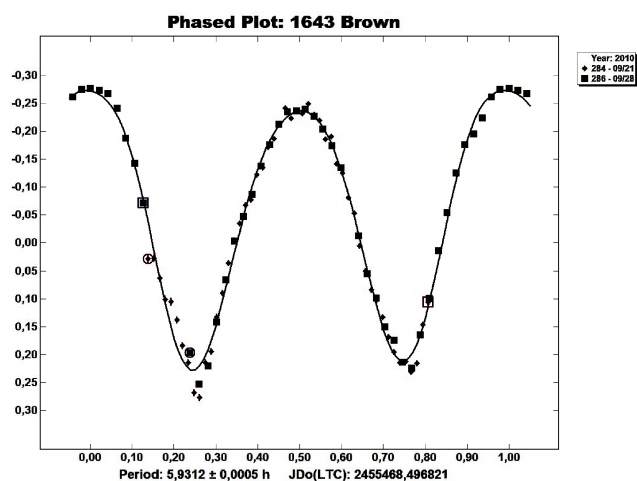


Figure 2. Full lightcurve of 1643 Brown.

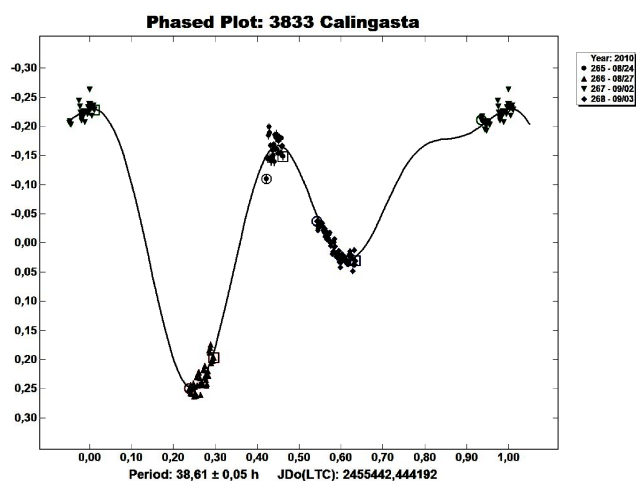


Figure 5. The partial lightcurve of 3833 Calingasta.

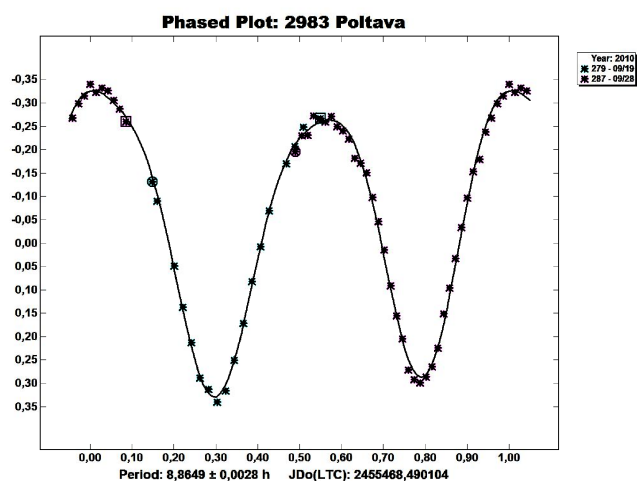


Figure 3. Full lightcurve of 2983 Poltava.

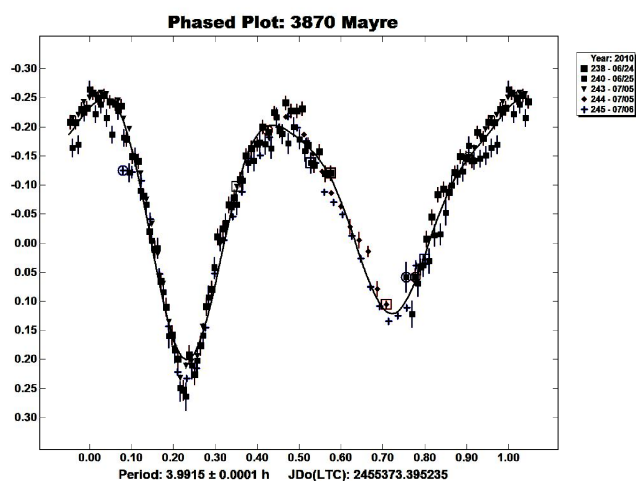


Figure 6. The full lightcurve of 3870 Mayre.

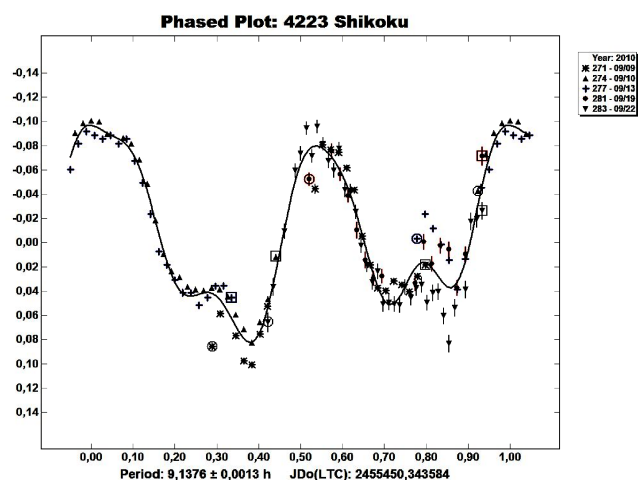


Figure 7. The full lightcurve of 4223 Shikoku.

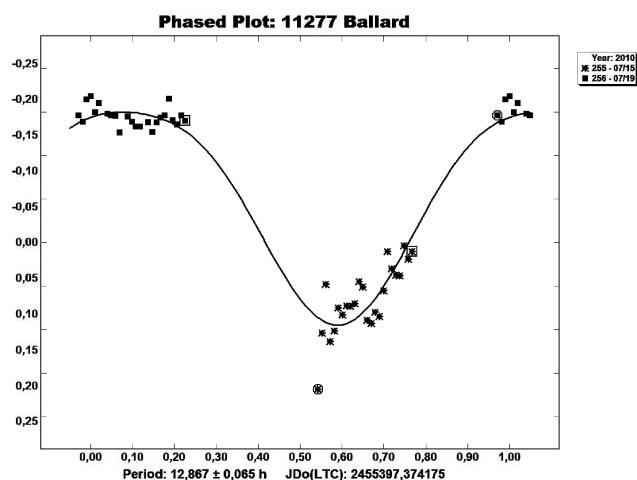


Figure 10. The partial lightcurve of 11277 Ballard.

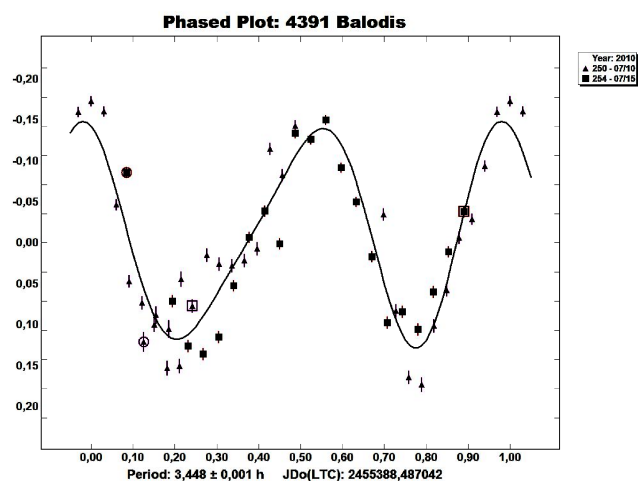


Figure 8. The full lightcurve of 4391 Balodis.

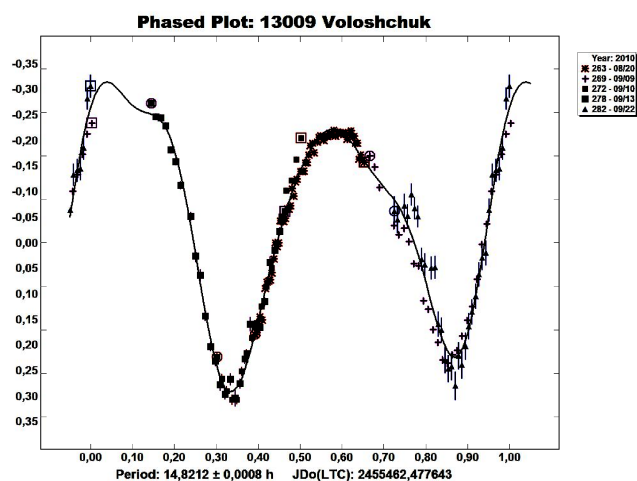


Figure 11. The full lightcurve of 13009 Voloshchuk.

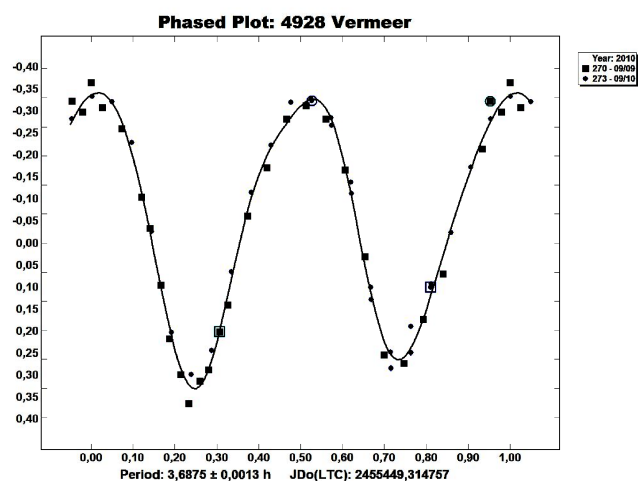


Figure 9. The full lightcurve of 4928 Vermeer.

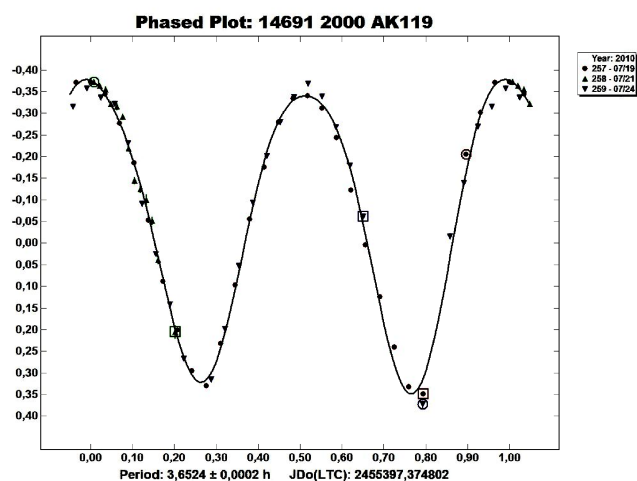


Figure 12. The full lightcurve of (14691) 2000 AK 119.

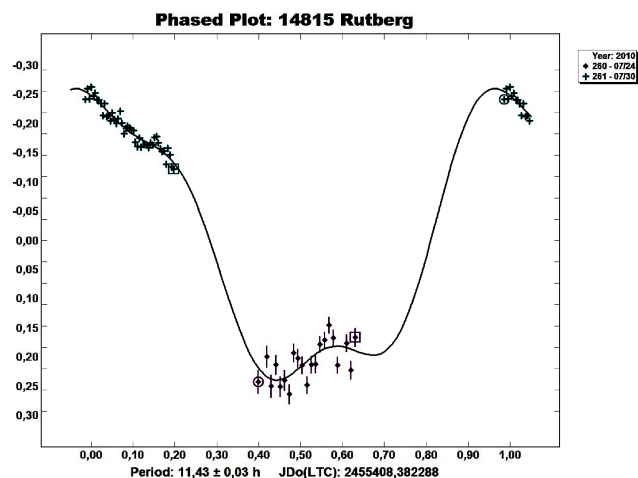


Figure 13. The partial lightcurve of 14815 Rutberg.

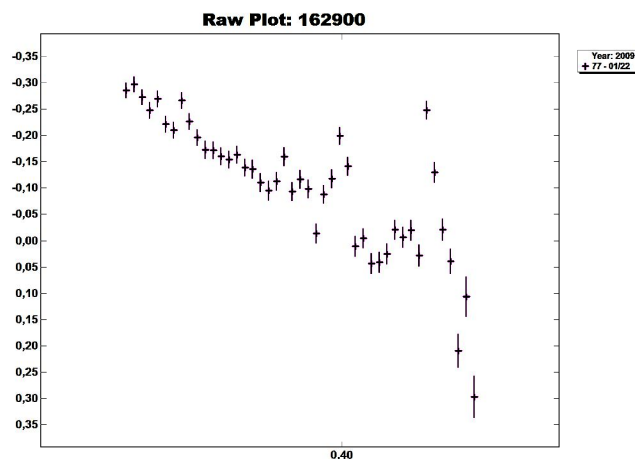


Figure 16. The partial lightcurve of (162900) 2001 HG31.

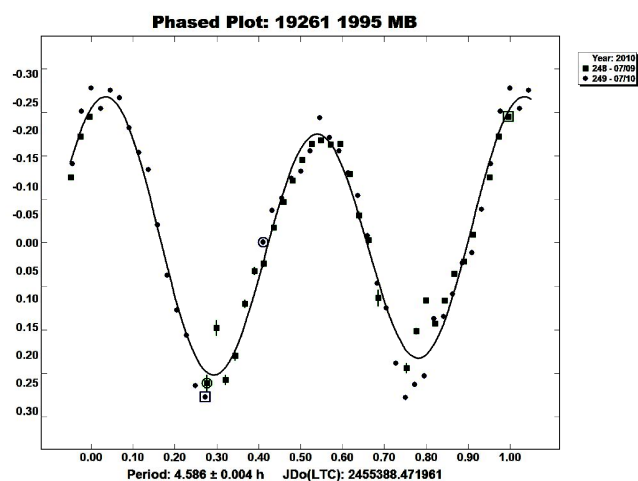


Figure 14. The full lightcurve of (19261) 1995 MB.

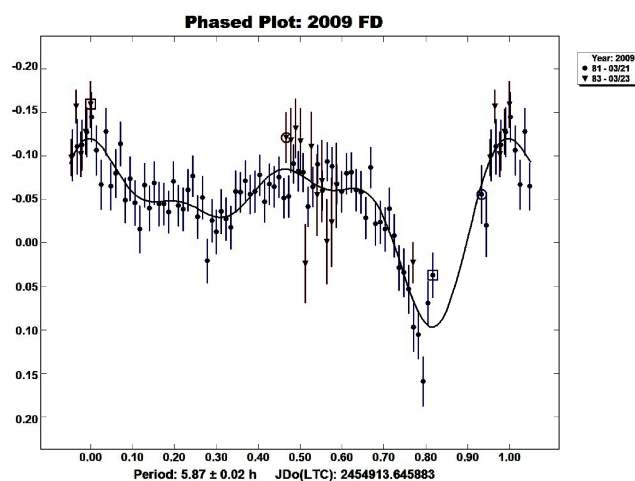


Figure 17. Partial lightcurve of 2009 FD.

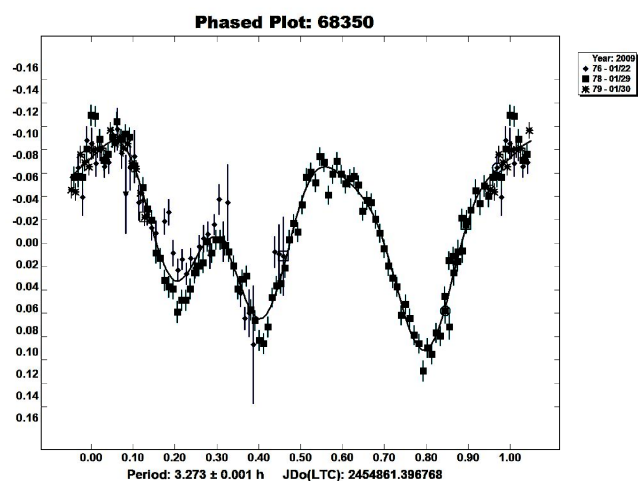


Figure 15. The full lightcurve of (68350) 2001 MK3.

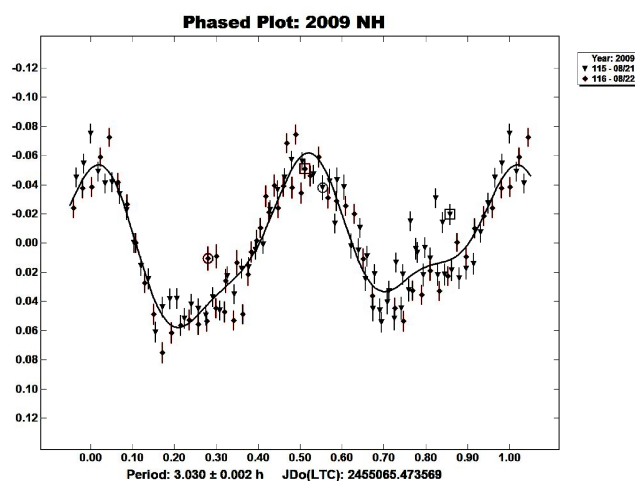


Figure 18. Full lightcurve of 2009 NH.

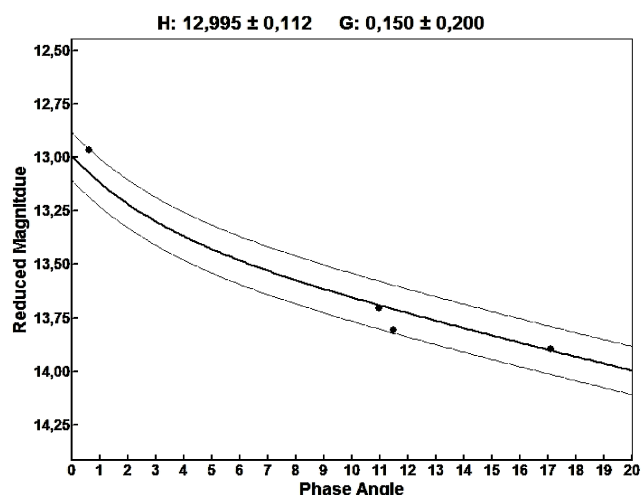


Figure 19. The H_R -G plot for 13009 Voloshchuk.

UPON FURTHER REVIEW: V. AN EXAMINATION OF PREVIOUS LIGHTCURVE ANALYSIS FROM THE PALMER DIVIDE OBSERVATORY

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Updated results are given for nine asteroids previously reported from the Palmer Divide Observatory (PDO). The original images were re-measured to obtain new data sets using the latest version of MPO Canopus photometry software, analysis tools, and revised techniques for linking multiple observing runs covering several days to several weeks. Results that were previously not reported or were moderately different were found for 1659 Punkajarju, 1719 Jens, 1987 Kaplan, 2105 Gudy, 2961 Katsurahama, 3285 Ruth Wolfe, 3447 Burckhalter, 7816 Hanoi, and (34817) 200^{SE116}. This is one in a series of papers that will examine results obtained during the initial years of the asteroid lightcurve program at PDO.

The availability of improved analysis tools and techniques along with the experience gained over more than a decade of asteroid lightcurve photometry have lead to a program to re-examine the early work and results at the Palmer Divide Observatory (ca 1999-2006). In most cases, any changes in the period and/or amplitude as a result of the new analysis were statistically insignificant. Some, however, fit into a gray area between significant and not but are still worth noting. This paper is one in a series that reports updated results from the initial stage of new analysis, in this case giving updates on six asteroids that fit into that gray area. Subsequent stages will likely produce additional revisions.

For background on the justification and methodology of this project, see the first paper in the series (Warner, 2010).

Presentation of the New Analysis

A brief analysis of the new data set and lightcurve based on that new data set are given below, even if there is no significant difference in the period. The “improvement” may be a revised amplitude or “simply better data” to be used for modeling in the future (e.g., the U code may have a higher rating; see Warner et al., 2009, for information about the U code rating system). The exact observing details will not be given. Instead, a table lists the original and new results along with a reference to the original paper. The original reference gives data on the equipment used and references to results from other authors and so those will not be repeated here.

The plots show the *R-band* reduced magnitude of the asteroid. This means that the data for each night were corrected to “unity distance” using $-5 \log(rR)$ where r was the Earth-asteroid distance and R was the Sun-asteroid distance, both in AU. The data were also corrected to the phase angle of the earliest session using $G = 0.15$ (unless otherwise stated).

1659 Punkaharju. The only change with the new analysis was a slightly larger amplitude for the 2000 apparition.

1719 Jens. The revised amplitude is slightly larger and the precision for the period has been reduced from the previous results, bringing the latter more into line with the period and span of the data set.

1987 Kaplan. The revised period is slightly shorter (0.03 h).

2105 Gudy. The period and amplitude have been revised a small amount. The U code assignment was improved.

2961 Katsurahama. The period is essentially unchanged but the amplitude increased by about 0.1 mag as a result of the new analysis.

3285 Ruth Wolfe. The original data were reanalyzed (Warner, 2005) and a new period found. The new data set allowed refining the precision of the corrected period and improved the U code assignment.

3447 Burckhalter. A new look at the original images from 2001 finds a period of 51 ± 1 h, contradicting the original analysis of 22.8 h. This latest result does not fit with the finding of Warner and Bembick (2005), who found $P = 60$ h. The data used in that latter work cannot be forced to a reasonable fit with the 51 h period. This asteroid needs a dedicated campaign involving observers at widely-separated longitudes with all data linked to a common magnitude system.

7816 Hanoi. The new analysis resulted in very slight changes to the period and amplitude and an improved U code assignment.

(34817) 2001 SE116. The amplitude increased by 0.12 mag and the precision of the period decreased to reflect the period and span of the data set.

Acknowledgements

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