ASTEROIDS LIGHTCURVES AT OAVDA: 2013 DECEMBER – 2014 JUNE

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Twelve asteroids, main-belt (MBA) and near-Earth (NEA), were observed at OAVdA from 2013 December through 2014 June: 1678 Hveen, 2834 Christy Carol, 3744 Horn-d'Arturo, 7436 Kuroiwa, (21374) 1997 WS22, (53435) 1999 VM40, (143649) 2003 QQ47, (242708) 2005 UK1, (243566) 1995 SA, (251346) 2007 SJ, 2013 XY8, and 2014 CU13.

This paper features the results of photometric observations on asteroids, both main-belt (MBA) and near-Earth (NEA), made at OAVdA Observatory (Carbognani and Calcidese, 2007), from 2013 December through to 2014 June, and as outlined in Carbognani (2011). It was not possible to determine the amplitude and the rotation period for all the observed asteroids, but the data collected are nevertheless provided for all objects (see Table 1). At the end of June, 2014 MF6, an Apollo-PHA object, was also observed in collaboration with others; the results for that NEA will be presented in a separate paper.

The images, unless otherwise noted, were captured by means of a modified Ritchey-Chrétien 0.81-m *f*/7.9 telescope using an FLI 1001E CCD with an array of 1024×1024 pixels. The field-of-view was 13.1×13.1 arcmin and the plate scale was 0.77 arcsec per pixel in 1×1 binning mode.

We used *MPO Canopus* (Warner, 2009) version 10.4.1.0 for differential photometry and period analysis. When possible, the sessions were calibrated with the *MPO Canopus* "Comp Star Selector" (CSS), which chooses comparison stars that are similar in color to the target (in general solar-type stars), and the "DerivedMags" approach. The amplitude of the lightcurve was also obtained directly from *MPO Canopus* and not with a polynomial fit as in Carbognani (2011).

Known rotation periods were all drawn from the asteroid lightcurve database (LCDB; Warner *et al.*, 2009; 2014 February 28 update).

1678 Hveen is an MBA. A total of 290 images in V band were taken on three nights, for about 12 hours of observations: the first on 2013 December 10, the second on 2013 December 11 (with bad seeing), and the last on 2014 January 27. All sessions were calibrated with the CSS. A period value of 5.987 ± 0.002 h is the most probable for all the sessions, with an amplitude of about 0.07 mag (Figure 1). No period was known for this object before.

2834 Christy Carol is an MBA. A total of 269 images in V and R band was taken over 2 nights (2013 December 3-12), for a total of 11 hours of observation. Unlike all the other asteroids, Christy Carol was been observed with a Ritchey-Chrétien 0.40-m *f*/8 telescope using a Moravian G2-3200 CCD with an array of 2184×1472 pixels in 1×1 binning mode. The bimodal lightcurve appears almost completely covered (Figure 2). The best rotation period is 9.450 ± 0.004 h with amplitude of 0.50 mag. Other values close to this period are possible. No period was known for this object before.

3744 Horn-d'Arturo is an MBA. A total of 449 images in V band were taken over 5 nights, from 2013 December 3 to December 12, before the opposition date. All sessions were calibrated with CSS. Between the first two and the last three sessions, the lightcurve showed significant changes due to variation in lighting conditions. The period is 7.18 ± 0.01 h with amplitude of 0.45 mag for the first two sessions (Figure 3), and 7.09 ± 0.01 h with amplitude of 0.28 mag for the last three (Figure 4). The results appear coherent and the mean period is 7.13 ± 0.01. No period was known for this object before.

7436 Kuroiwa is an MBA. A total of 170 images using a clear filter during 8 hours of observation were taken in three sessions in the second half of 2014 March. The object was faint and the lightcurve in Figure 5 is a bit noisy; moreover, the amplitude is low. Despite these issues, the lightcurve shows a period of 5.61 ± 0.01 h with amplitude of 0.07 mag. This result is not compatible with the LCDB value of 1.8192 h with U = 1. Note how this first value was below the spin barrier of about 2.2 h despite the estimated size of about 3 km for Kuroiwa. The new value appears to be more reasonable for this asteroid.

(21374) 1997 WS22 is an Amor object and a Mars-crosser. A total of 100 images using a C filter was taken in 8 hours spread over two nights on 2014 April 5/6, long before Earth flyby occurred on May 21 at 0.12 AU. The object was about 17.5 mag so the lightcurve, also with a 240 s exposure, is noisy. The best rotation period is 2.292 ± 0.004 h with an amplitude of 0.17 mag (Figure 6). The rotation period is just above the spin barrier, reasonable for an asteroid of about 1-2 km in diameter. No period was known for this object before, and for a check of this value it must be kept in mind that this asteroid will make its next closest approach in 2027, November 08.

(53435) 1999 VM40 is an Amor object. A total of 177 images in V band were taken over 5.8 hours in a single nights (2014 January 27). Despite the single session, the lightcurve appears fully covered and the best period is 5.09 ± 0.02 h with an amplitude of 0.25 mag (Figure 7). The period value is in good agreement with that of the LCDB (5.189 h, with U = 3).

(143649) 2003 QQ47 is an Apollo-PHA object. A total of 174 images with a clear filter (to maximize the signal-to-noise ratio), were taken over 8 hours distributed on two nights on 2014 March 8/9 (the minimum distance from Earth of 0.129 UA was reached on March 26). The differential photometry of this object was made difficult by the rather dense stellar fields through which it is passed. The images in which the asteroid was close too close to brighter stars were deleted. Because of the resulting poor data set, the rotation period is very difficult to determine. We can guess a value of about 4.1 ± 0.1 h with an amplitude of about 0.53 mag (Figure 8). No period was known before.

(242708) 2005 UK1 is an Apollo-PHA object. A total of 556 images using clear filter were taken in 10 hours on four sessions between 2014 May 24 and June 7 (the flyby with Earth was on May 21 at 0.094 UA). The lightcurve was very noisy (Figure 9), the most probable period is about 4.3 ± 0.1 h, with an amplitude of 0.13 mag. No period was known before.

(243566) 1995 SA is an Apollo-PHA asteroid which made its Earth flyby on 2014 April 2 at 0.188 AU. A total of 214 images with no filter were taken in 7 hours over 3 nights in 2014 January 28 and March 6/8. Photometry was made difficult by the low signal-to-noise of the asteroid, its angular velocity, and by the crowded star field. As before, images where the asteroid passed close to bright stars were deleted from data analysis. The better session is that in January with a resulting period of 2.23 ± 0.08 h and an amplitude of 1.12 mag, indicative of a very elongated object (Figure 10). The other sessions are more noisy, and so of little use, even if the resulting period is about the same but with an amplitude of the lightcurve of 0.14 mag. No period was known before.

(251346) 2007 SJ is an Apollo-PHA that made an Earth flyby on 2014 January 21 at 0.049 AU. A total of 138 images in R band were taken during 5 hours session in a single clear night (2013 December 12). The phased lightcurve and the comparison stars (solar type only) seemed normal but the peak of the maximum of the curve changed by 0.04 mag during the session (Figure 11 and 11a). The minimum changed as well. If this was due to background noise, one would expect greater scattering of the lightcurve. A search for possible background stars that may have altered the lightcurve was negative. These variations may be due to an asynchronously binary system without mutual phenomena. The result for a double period search with *MPO Canopus* is shown in the Figures 11b, 11c, and 11d. A monolithic satellite with about 1.65 h rotation period and amplitude of 0.08 mag would be able to justify the difference observed, but the data are not sufficient to be sure. The rotation period value for the primary is 2.78 ± 0.02 h with amplitude of 0.17 mag, in good agreement with that of the LCDB (2.718 h, with U = 3).

2013 XY8 is an Apollo object, with an estimated diameter of about 50 meters. This asteroid was observed for both photometry and astrometry in the night of 2013 December 9 following a request by the Goldstone radar team published on the minor planet Mailing List (MPML). The first photometric observations indicated a rotation period of 0.0605 h with a substantially symmetrically rather noisy bimodal lightcurve with an amplitude of 0.18 mag. Given the cloudy sky at times, a post was made on MPML so that other observers could help confirm the short rotation period. At OAVdA, a total of 737 images with a clear filter was taken on a session 4.5 hours long. The result are shown in the Figures 12, 13 and 14 (period spectrum). The period spectrum with a fourth order Fourier fit shows four possible periods: about 0.03 h (P/2, monomodal solution), 0.06 h (P, bimodal solution), 0.09 h (3P/2, trimodal solution) and 0.12 h (2P, quadramodal solution). The RMS value for these four solutions is almost identical, with a value slightly smaller for 0.09 h. The lightcurve is too noisy to decide among these different values. Considering that asteroids usually have an elongated shape, the value of 0.06056 h with amplitude 0.18 is the more physically plausible. This period value is in good agreement with that reported on the LCDB (0.06055 h, with U = 3-).

2014 CU13 is an Apollo-PHA. A total of 60 images with no filter was collected in a single night on 2014 March 3, while the flyby with Earth was on March 13 at 0.0048 AU. The session lasted for only 1 hour and the data are insufficient to derive a rotation period. From the raw lightcurve trend (Figure 15), and assuming that the curve is bimodal, it is reasonable to assume a period of 4-5 hours with a minimum amplitude of 0.3 mag. No period was known before.

Acknowledgements

This research has made use of the NASA's Astrophysics Data System and JPL Small-Body Database Browser. Thanks to Jon Giorgini (NASA/JPL) for the appreciation about the astrometric observations of 2013 XY8 (private communication). Thanks to the Planetary Society for the award of the 2013 Shoemaker NEO Grant to OAVdA which made it possible to upgrade the telescope used to observe the NEAs.

References

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Carbognani, A., Calcidese, P. (2007). "Lightcurve and rotational period of asteroids 1456 Saldanha, 2294 Andronikov and 2006 NM." *Minor Planet Bulletin* **34**, 18-19.

Warner, B.D., Harris, A.W, Pravec, P. (2009). "The asteroid lightcurve database." *Icarus*, **202**, 134-146.

Warner, B.D. (2009). MPO Software, *MPO Canopus*. Bdw Publishing. *http://minorplanetobserver.com/*

Number	Dates yyyy mm dd	Phase [deg]	Period [h]	Amp [mag]
1678	2013 12 10 2013 12 11 2014 01 27	8.3- 13.1	5.987 ±0.002	0.07
2834	2013 12 03 2013 12 12	8.1- 4.7	9.450 ±0.004	0.50
3744	2013 12 03 2013 12 04 2013 12 05 2013 12 11 2013 12 12	8.2- 3.2	7.18±0.01 7.09±0.01	0.45 0.28
7436	2014 03 18 2014 03 20 2014 03 24	13.7- 16.6	5.61±0.01	0.07
21374	2014 04 05 2014 04 06	54.8- 54.8	2.292 ± 0.004	0.17
53435	2014 01 27	20.4	5.09 ± 0.02	0.25
143649	2014 03 08 2014 03 09	88.0- 88.6	4.1±0.1 (?)	0.53
242708	2014 05 24 2014 06 05 2014 06 06 2014 06 07	61.6- 29.3	4.3±0.1 (?)	0.13
243566	2014 01 28 2014 03 06 2014 03 08	22.4- 46.2	2.23 ± 0.08	1.12
251346	2013 12 12	59.8	2.78 ± 0.02 (binary?)	0.17
2013 XY8	2013 12 09	17.9	0.06056 ± 0.00002	0.18
2014 CU13	2014 03 06	23.1	4-5 (?)	≥ 0.30

Table 1. The number/provisional designation, date of observations, range of phase angles, rotation period and amplitude for the observed asteroids.

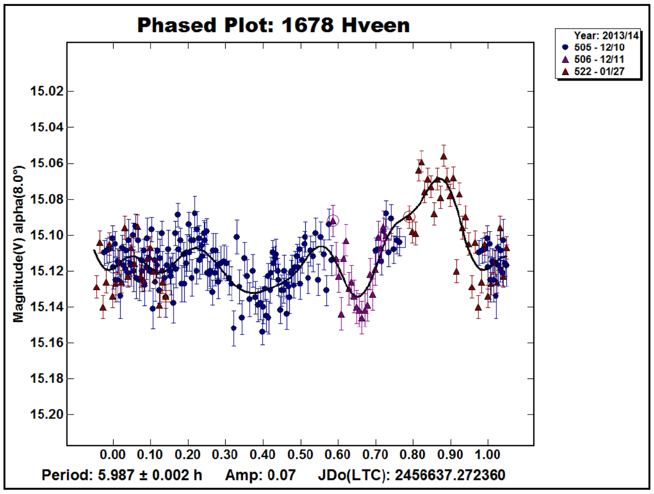

Figure 1. The phased lightcurve for 1678 Hveen with a period of about 6 h and low amplitude.

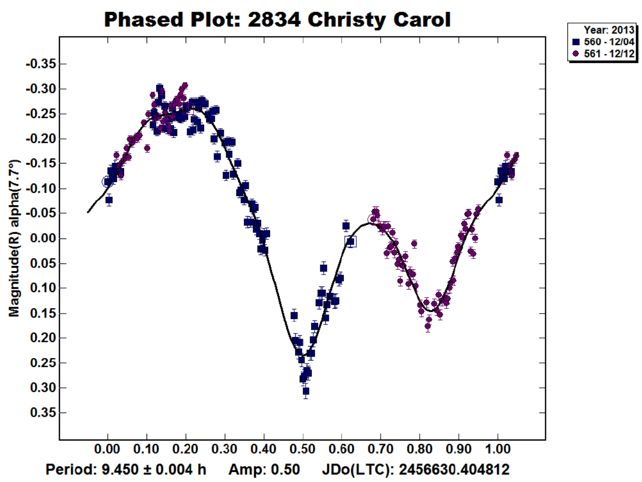

Figure 2. The phased lightcurve for 2834 Christy Carol.

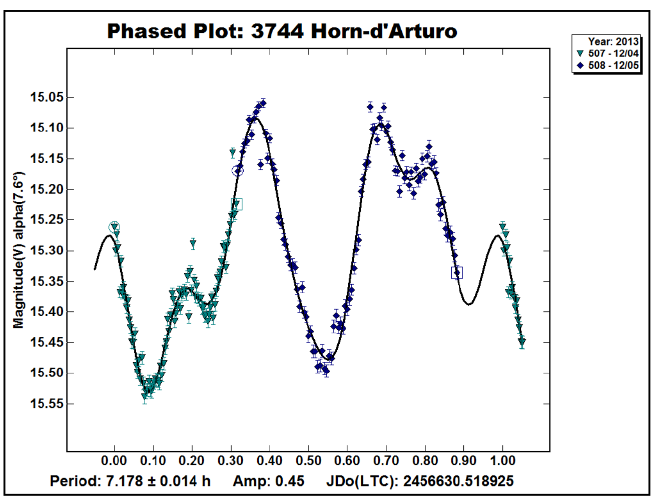

Figure 3. The lightcurve for the first two sessions of 3744 Horn-d'Arturo.

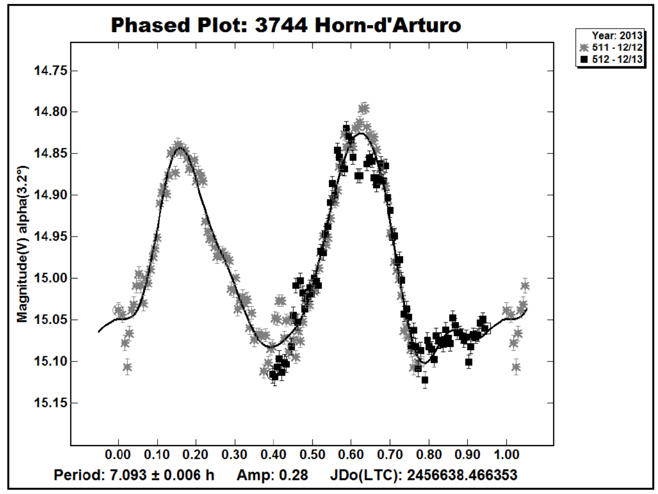

Figure 4. The lightcurve for the last three sessions of 3744 Horn-d'Arturo. The difference with the previous figure is evident.

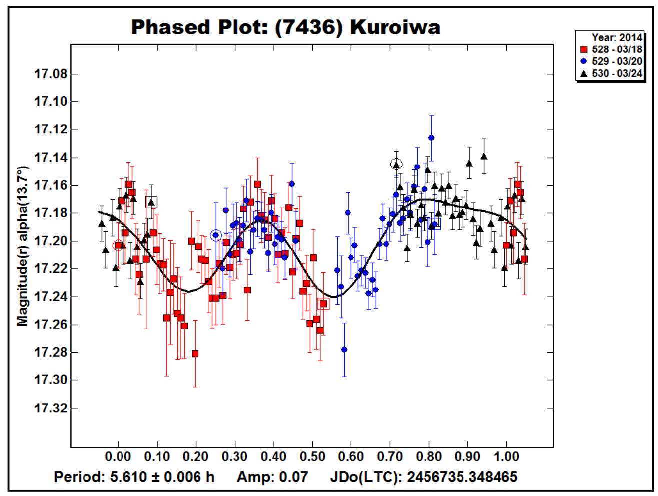

Figure 5. The full lightcurve of 7436 Kuroiwa with a period of about 5.6 h.

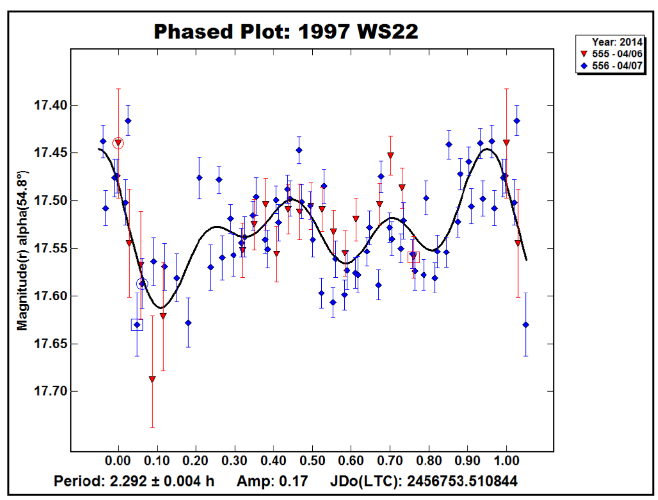

Figure 6. The lightcurve of (21374) 1997 WS22.

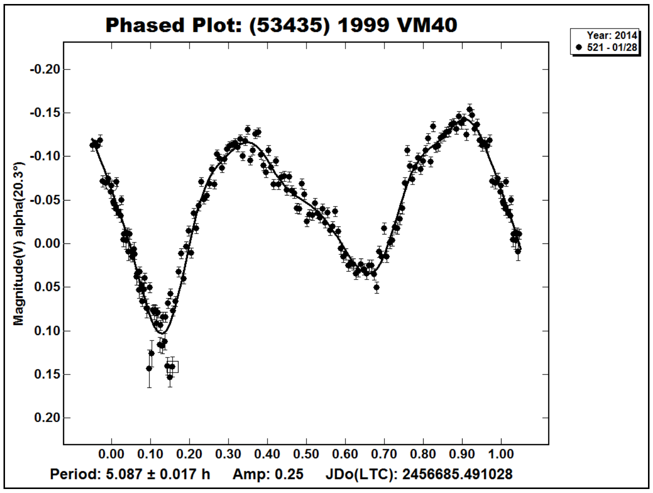

Figure 7. The lightcurve of (53435) 1999 VM40 from a single session.

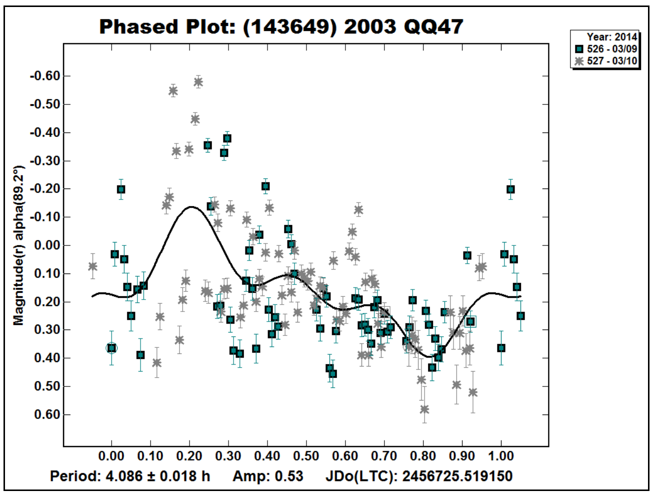

Figure 8. The noisy lightcurve of the Apollo-PHA object (143649) 2003 QQ47.

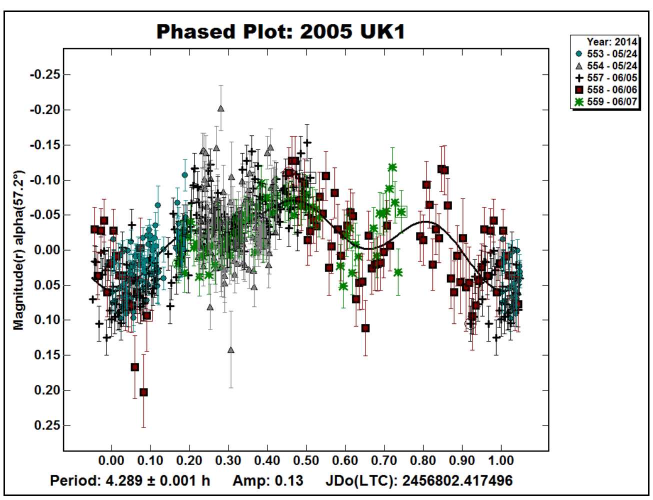

Figure 9. The lightcurve of the Apollo-PHA (242708) 2005 UK1.

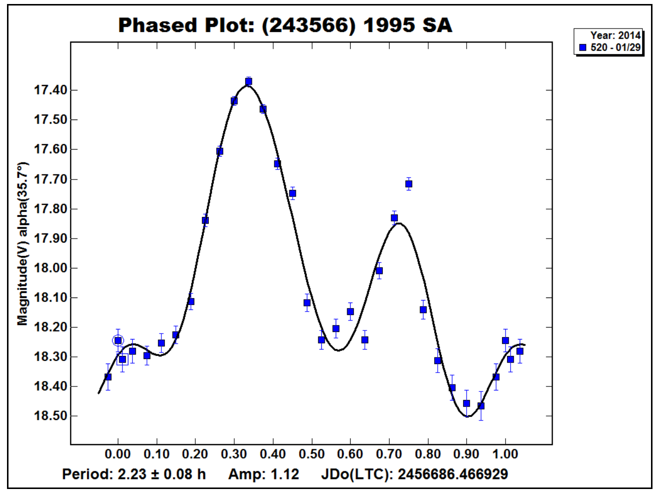

Figure 10. The good lightcurve of the Apollo object (243566) 1995 SA.

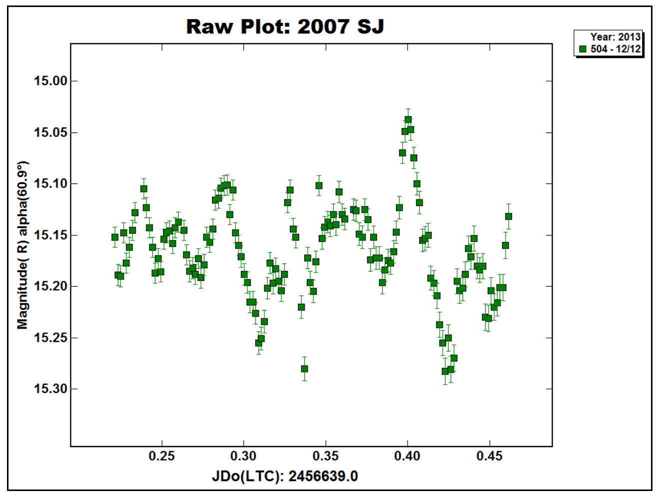

Figure 11. The raw lightcurve of (251346) 2007 SJ. The height of the main peak of the curve (in 0.29 and 0.40) is changed during the same session. Also the minimum (in 0.31 and 0.42) is changed.

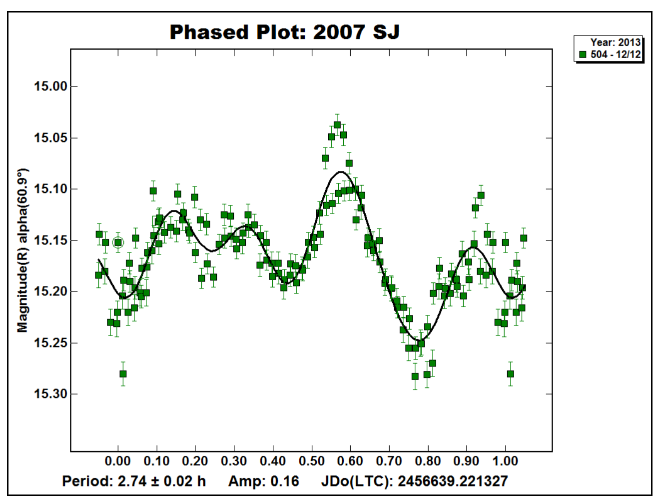

Figure 11a. The full lightcurve of (251346) 2007 SJ.

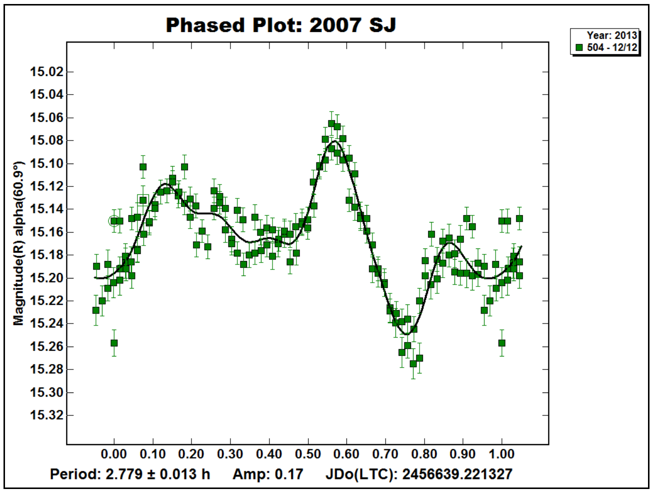

Figure 11b. The phased lightcurve for the primary period only of (251346) 2007 SJ.

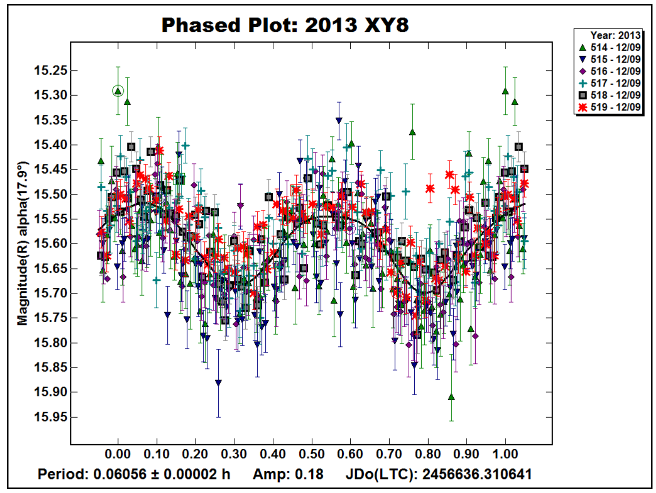

Figure 12. The bimodal lightcurve of the Apollo object 2013 XY8.

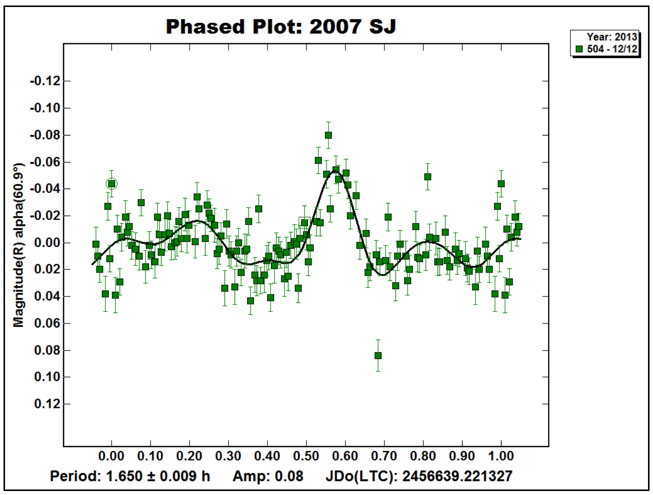

Figure 11c. The lightcurve for the secondary rotation period of (251346) 2007 SJ.

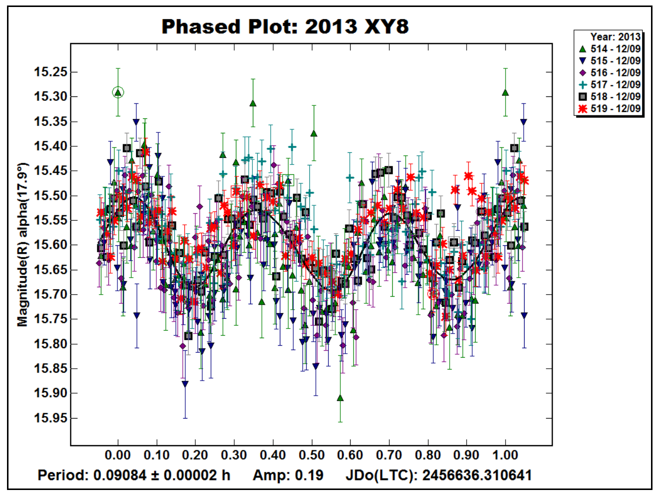

Figure 13. The trimodal lightcurve for 2013 XY8.

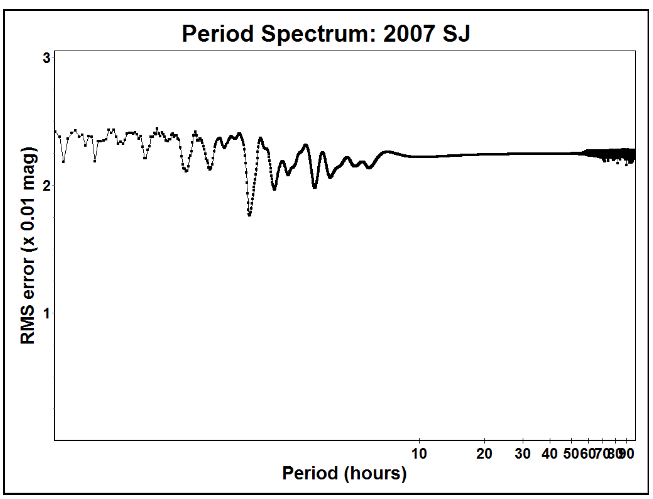

Figure 11d. The period spectrum for the secondary rotation period of (251346) 2007 SJ.

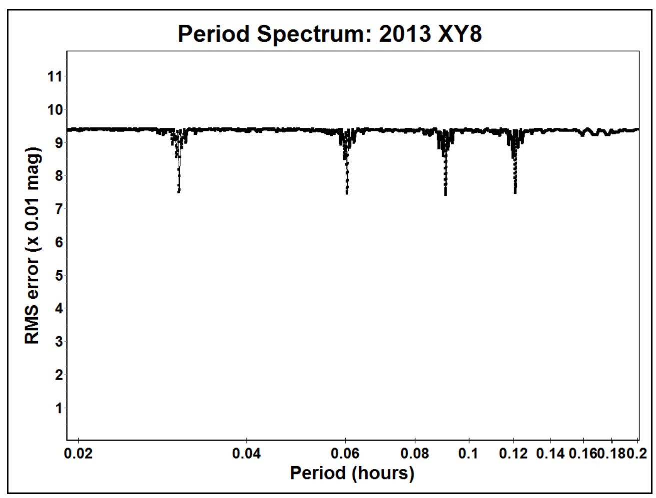

Figure 14. The period spectrum for 2013 XY8. From left to right: P/2, P, 3P/2, 2P peaks.

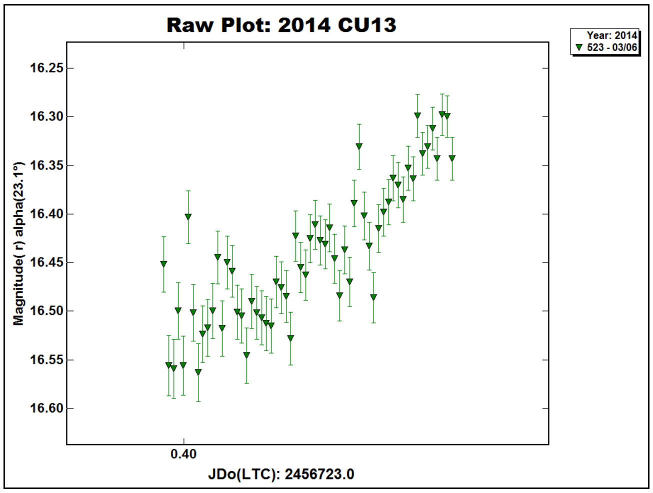

Figure 15. The raw lightcurve of the Apollo-PHA object 2014 CU13. The data are insufficient to constrain a rotational period.

TARGET ASTEROIDS! OBSERVING TARGETS FOR OCTOBER THROUGH DECEMBER 2014

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Asteroids to be observed by the *Target Asteroids!* program during the period of October to December 2014 are presented. In addition to asteroids on the original *Target Asteroids!* list of easily accessible spacecraft targets, an effort has been made to identify other asteroids that are 1) brighter and easier to observe for small telescope users and 2) analogous to (101955) Bennu, the target asteroid of the OSIRIS-REx sample return mission.

Introduction

The *Target Asteroids!* program strives to engage telescope users of all skill levels and telescope apertures to observe asteroids that are viable targets for robotic sample return. The program also focuses on the study of asteroids that are analogous to (101955) Bennu, the target asteroid of the NASA OSIRIS-REx sample return mission. Most target asteroids are near-Earth asteroids (NEA) though observations of relevant Main Belt asteroids may also be requested.

Even though many of the observable objects in this program are faint, acquiring a large number of low S/N observations allows many important parameters to be determined. For example, an asteroid's phase function can be measured by obtaining photometry taken over a wide range of phase angles. The albedo can be constrained from the phase angle observations, as there is a direct correlation between phase function and albedo (Belskaya and Shevchenko (2010). The absolute magnitude can be estimated by extrapolating the phase function to a phase angle of 0°. By combining the albedo and absolute magnitude, the size of the object can be estimated.

An overview of the *Target Asteroids!* program can be found at Hergenrother and Hill (2013).

Quarterly Targets

Target Asteroids! objects brighter than V = 20.0 are presented in detail. A short summary of our knowledge of each asteroid and 10-day (shorter intervals for objects that warrant it) ephemerides are presented. The ephemerides include rough RA and Dec positions, distance from the Sun in AU (r), distance from Earth in AU (Δ), V magnitude, phase angle in degrees (PH) and elongation from the Sun in degrees (Elong).

We ask observers with access to large telescopes to attempt observations of asteroids that are between V magnitude ~20.0 and ~22.0 during the quarter (contained in the table below).