MAINBELT ASTEROIDS LIGHTCURVE ANALYSIS FROM *TAR* TELESCOPE NETWORK: 2018 OCTOBER - 2019 MAY

Amadeo Aznar Macías
APT Observatories Group, SPAIN
aptog@aptog.com

Javier Licandro
Instituto de Astrofísica de Canarias & Departamento de Astrofísica, Universidad de La Laguna
Tenerife, Spain

Miquel Serra-Ricart
Instituto de Astrofísica de Canarias Tenerife, Spain

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Lightcurves of twelve main-belt asteroids (MBA) obtained with the Telescopio Robótico Abierto network (TAR) and the Isaac Aznar Observatory from 2018 October to 2019 May are presented and analyzed to derive the rotation period, lightcurve amplitude, and axis size relationship.

CCD photometric observations of twelve main-belt asteroids (MBA) were obtained using the Telescopio Abierto Robótico (TAR) network between 2018 October and 2019 May. This work is included in the Mars-crossing survey we started with these telescopes in late 2018 (Licandro et al., in preparation). Due to the large field-of-view of the images obtained during the survey, we also obtained the lightcurve of every main-belt asteroid serendipitously identified in the images. Thus, it is necessary to remark that there is no previous asteroid selection process in this work, except for the three targets observed from the Isaac Aznar Observatory (IAO) in 2019 May.

Six of the observed asteroids do not have previously published lightcurves: 3830, 7673, 14105, 15925, 33729 and 62836. The others have been observed during previous apparitions and their rotation period is already determined. Even in those cases, the data presented in this paper are still useful to improve the rotation period determination and, combined with previous and future observations, to determine their spin orientation (pole position) and shape, e.g. using lightcurve inversion techniques (see e.g. Ďurech et al., 2010).

Our observations were made using the TAR network of robotic telescopes and the IAO 0.35m telescope. TAR telescope network consists of three telescopes located at Teide Observatory (Tenerife, Canary Islands, Spain, at 2390 meters above sea level). Two (TAR1 and TAR2) are 0.46-meter *f*/2.8 telescopes; TAR 3 is a 0.40-meter *f*/10 telescope. TAR1 and TAR2 use an SBIG ST11000 CCD camera with 4008x2672 pixels. The plate scale is 1.5 arcsec/pix. TAR 3 is equipped with an FLI MicroLine fitted with an E2V CCD47-10, 1024x1024 pixels. Combined with a focal reducer, the system has a plate scale of 1.5 arcsec/pixels.

Isaac Aznar Observatory (IAO) is located in Alcublas, Valencia, Spain, at an altitude of 870 meters and under dark skies (21.7 mag/arcsec^2 on average). It has a 0.35-meter telescope with an SBIG STL 1001+AO camera. The CCD is 1024x1024 pixels with a plate scale of 1.45 arsec/pixel.

A series of images, typically of 60s exposure time, were obtained in 1x1 binning mode and without any filter on different nights. Images were bias, dark, and flat field corrected using bias, dark, and twilight sky flat-fields obtained during the same night using the corrections routines included in *MaximDL*.

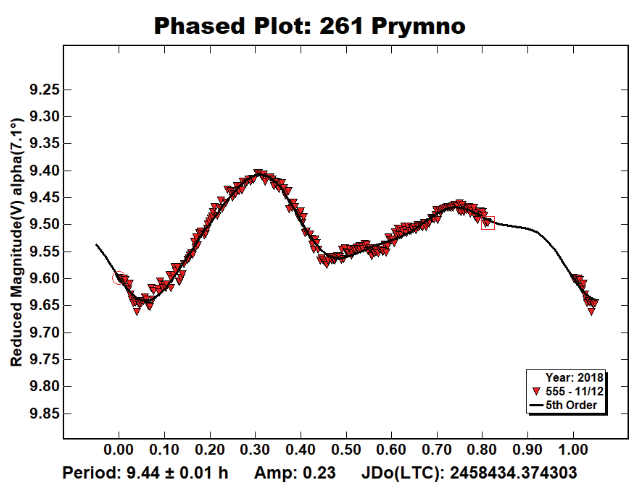
Aperture photometry was done using *MPO Canopus*. The Comp Star Selector utility in *MPO Canopus* found up to five comparison stars of near solar-color allowing to obtain accurate differential and calibrated photometry. The comp star magnitudes were taken from the APASS (Henden et al., 2009) and MPOSC3 catalogs, depending on the availability of comparison stars. The nightly zero points for both catalogs have been found to be generally consistent to about ± 0.05 mag or better, but on occasion reach 0.1 mag and more.

The StarBGone star subtraction algorithm in *MPO Canopus* was used when needed in order to remove the effect of stars located in the asteroid's path. This is most effective when the star's SNR is equal to or lower than asteroid's SNR (Aznar, 2013). The rotation period analysis was doing using the FALC period analysis algorithm developed by Harris (Harris et al., 1989) also included in *MPO Canopus*.

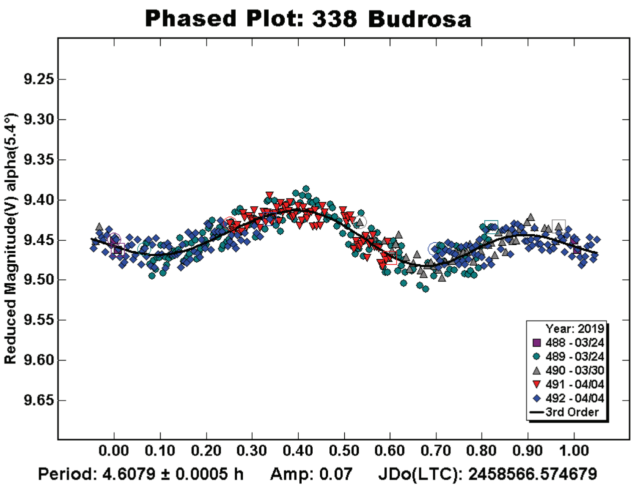
In Table I, we list the date of the observations, the derived rotation period, amplitude of the lightcurve, the axis ratio for an assumed triaxial ellipsoid *a/b*, and the telescope used. The ellipsoid is assumed to be *a* > *b* and the rotation is about the *c*-axis (Harris and Lupishko, 1989). These were derived after reducing the lightcurve amplitude to zero phase angle (Zappala et al., 1980).

We note that for the axis size relationship, we have assumed an equator-on viewing geometry. In this case, the *a/b* ratio is a lower limit since it depends in the observing geometry. More observations made in future are necessary to determine the proper shape of the asteroid.

<u>261 Prymno</u>. This asteroid was discovered in 1886. During the last years of the 20th century, this target was analyzed several times using photometric techniques. All recent measurements match with a rotation period of 9.44 h. We found a similar period (9.44 ± 0.01 h) based on 187 data points over one unique session. The main difference with respect to previous lightcurves is the amplitude. In our case the maximum amplitude reaches 0.23 mag, thus *a/b* = 1.20.

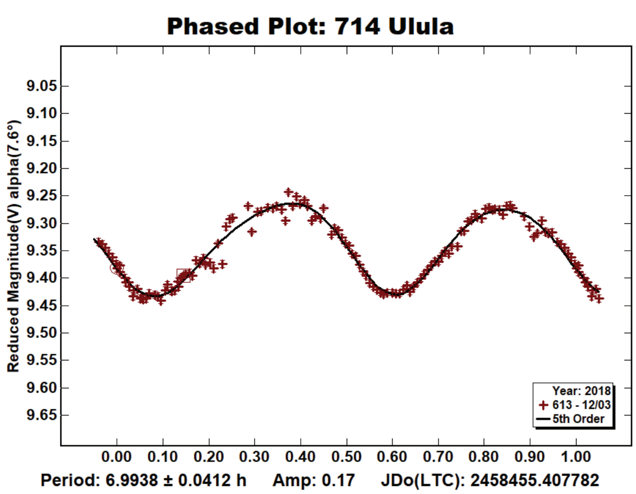


338 Budrosa. All previous analysis indicates a rotation period of about 4.608 h, e.g., Behrend (2016) and Hamanowa and Hamanowa (2011). We report a period of 4.6079 ± 0.0005 h based on a lightcurve with 420 data points. Previous results found a maximum amplitude of 0.46 mag; we found a maximum amplitude of 0.07 mag. L_{PAB} = 171°. The *a/b* axis relationship is 1.06.



714 Ulula. The rotation period of 6.9938 ± 0.0412 h reported here matches the period reported in Lightcurve Database (LCDB; Warner et al., 2009). This period was based on data from one night. Since 1990 this asteroid has been analyzed ten times with different maximum lightcurve amplitudes, from 0.02 in 2008 to 0.65 mag in 2005 (Marciniak, 2011).

Ulula has a pole and shape determination based on lightcurve inversion techniques in the DAMIT database (*http://astro.troja.mff.cuni.cz/projects/damit* by Ďurech et al., 2010). Our lightcurve has a shape and amplitude, 0.17 mag, that is similar to that expected using the DAMIT shape model and pole (Fig. 1). L_{PAB} = 83°, *a/b* = 1.14.



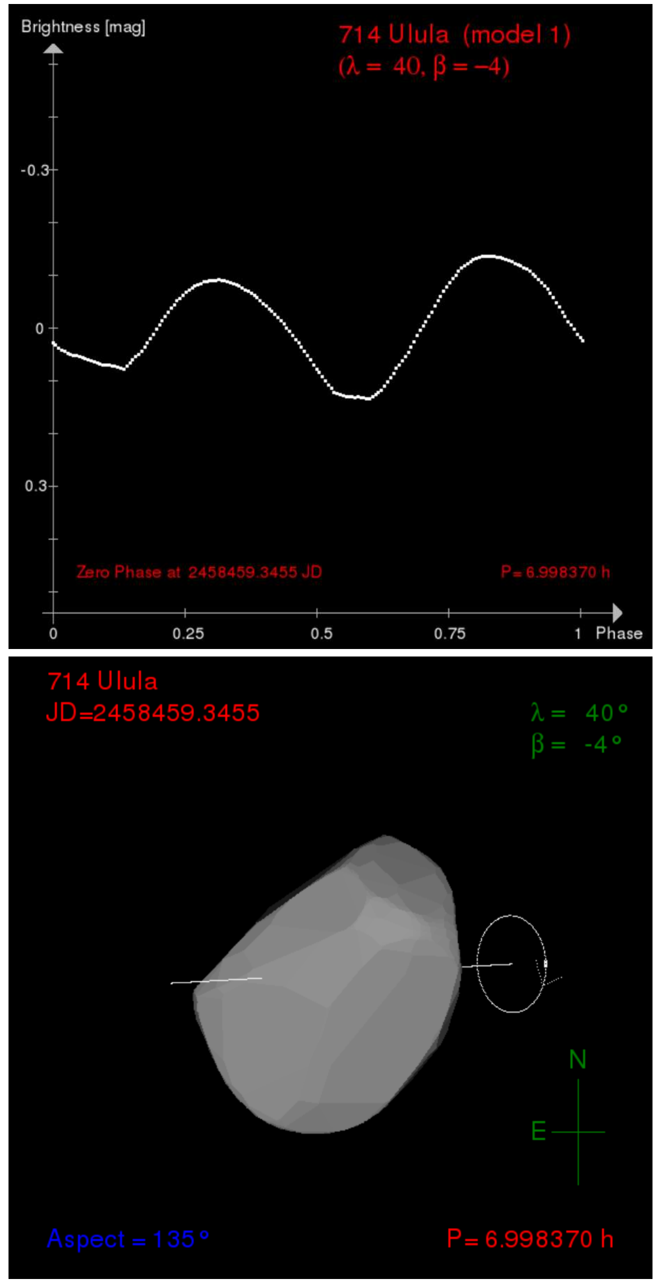
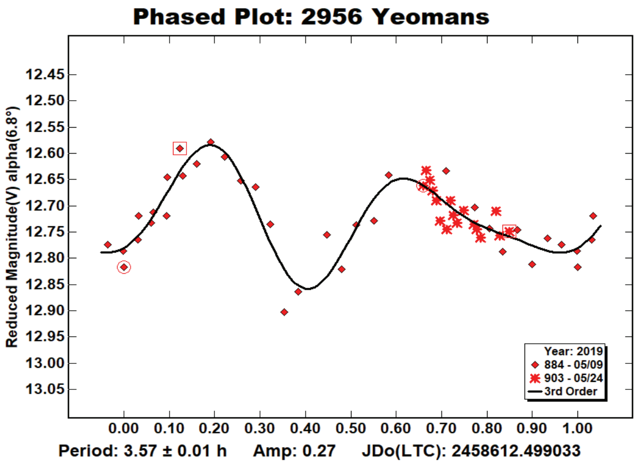


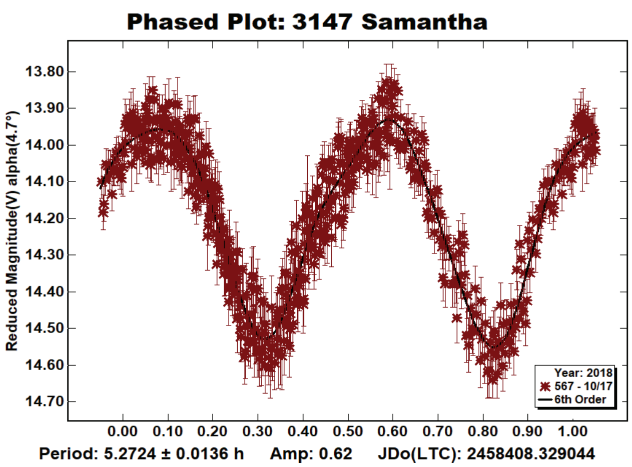
Figure 1. Expected lightcurve of 714 Ulula for the date of our observations (upper figure) produced with the shape model in the DAMIT database (lower figure). The images are produced using the Interactive Service for Asteroid Models (*http://isam.astro.amu.edu.pl/*).

2956 Yeomans. There are three entries in LCDB regarding this main-belt asteroid. It was first analyzed in 2015 (Aznar, 2015) with a rotation period of 3.40 h. A few years later, it was analyzed again (Waszczak et al., 2015; Oey, 2018), both authors suggested different rotation period values.

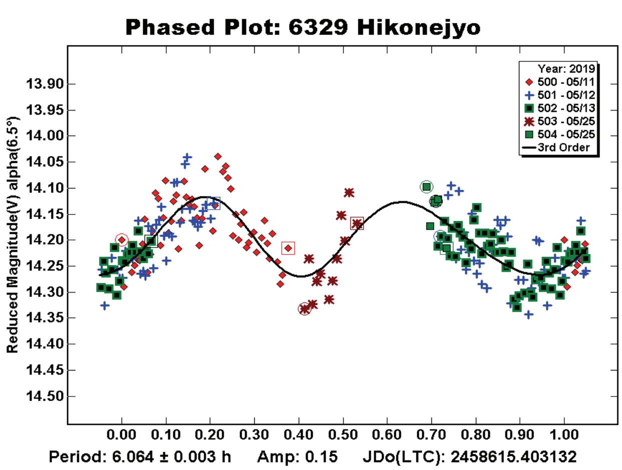
Our photometric work during 2019 derived a rotation period of 3.57 ± 0.01 h and a maximum lightcurve amplitude of 0.27 mag. L_{PAB} = 241°. The *a/b* axis relationship is 1.10.



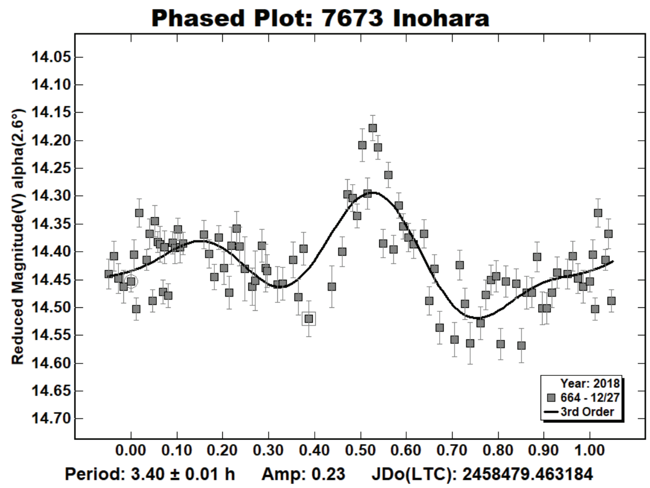
3147 Samantha. There is no entry in the most recent release of the lightcurve database (LCDB; Warner et al., 2009) for this main-belt asteroid. We report a rotation period of 5.2724 ± 0.0136 h from one observing session. The lightcurve shows a maximum amplitude of 0.62 mag, which suggests a very elongated shape (*a/b* = 1.68) for this asteroid.



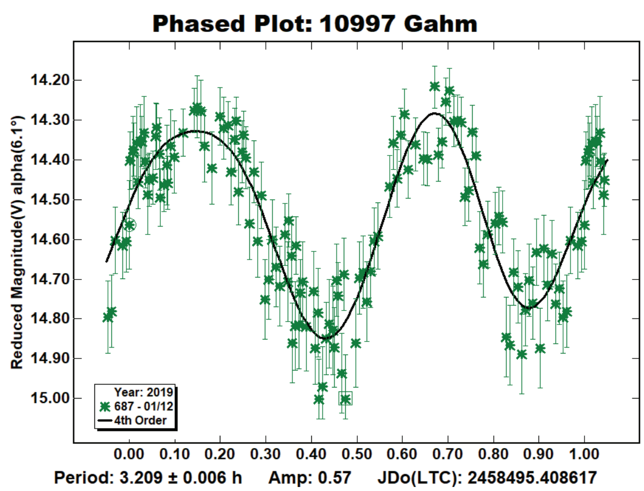
6329 Hikonejyo. The LCDB reports two different rotation periods for this object: 6.064 h (Behrend, 2012) and 8.066 h (Klinglesmith, 2012). Analysis of data obtained from 2019 May 11-25 provides a rotation period of 6.064 ± 0.003 h. The lightcurve shows a maximum amplitude of 0.15 mag. L_{PAB} = 225°. The *a/b* axis relationship is 1.13.



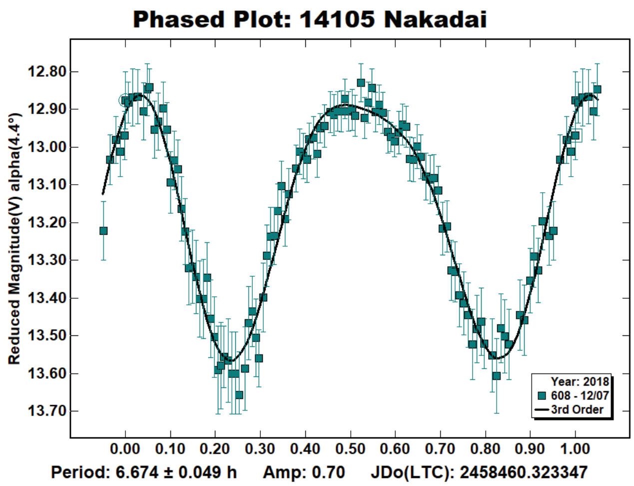
7673 Inohara. This the rotation period for this main-belt asteroid did not appear to be known prior to our work. We obtained a rotation period of 3.4 ± 0.01 h. This period should be considered as provisional. More data are necessary during future apparitions in order to confirm it. The lightcurve shows a maximum amplitude of 0.23 mag. L_{PAB} = 91°. The *a/b* axis relationship is 1.22.



10997 Gahm. There are three entries in the LCDB for this asteroid. All of them match with a rotation period of about 3.2 h. We have calculated a rotation period of 3.209 ± 0.006 h and amplitude of 0.57 mag. The lightcurve shows a typical bimodal shape and its amplitude maximum suggests a very elongated shape for this asteroid. The *a/b* axis relationship is 1.58.

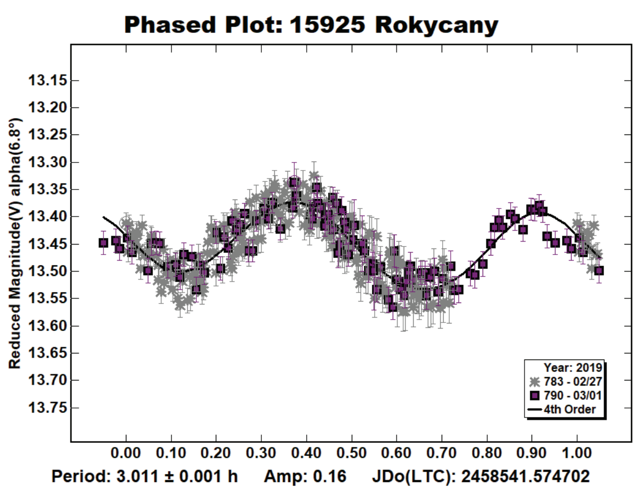


14105 Nakadai. There is no entry in the LCDB for this asteroid. We report a lightcurve composed of 211 points that has a period of 6.674 ± 0.049 h. The amplitude of 0.70 mag suggests a very elongated shape for this asteroid. L_{PAB} = 67°. The *a/b* axis relationship is 1.80



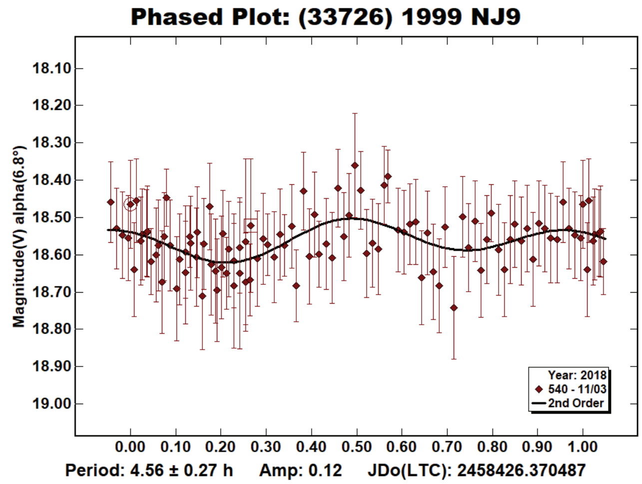
15925 Rokycany. This is a 6.4-km asteroid discovered in 1997 by L. Šarounová at Ondřejov observatory. No previous lightcurves of Rockycany are published, so this is the first photometric analysis of this asteroid.

We found a period of 3.01 ± 0.001 h based on 325 data points over one unique session. Its maximum amplitude suggests a moderate ellipsoidal shape when assuming an equatorial view of the asteroid. The *a/b* axis relationship is 1.14.



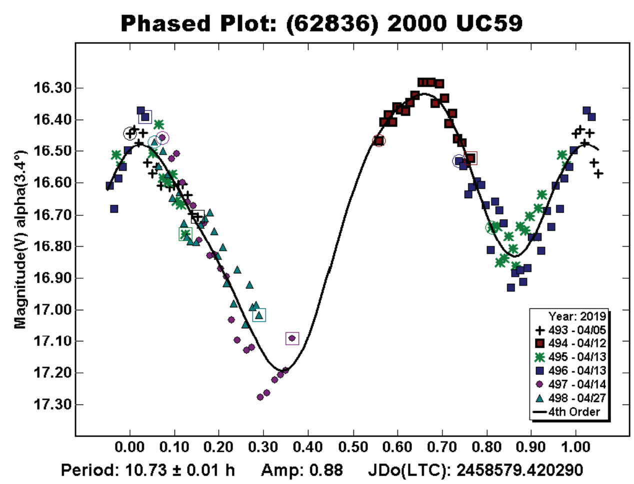
(33729) 1999 NJ21. This is a 12-km asteroid discovered in 1999 by LINEAR survey. There is no entry in the latest release of the LCDB.

We observed this target during one night only, 2018 Nov 3. The derived rotation period is 4.56 ± 0.27 h based on 178 points. The curve shows a typical bimodal shape with a maximum amplitude of 0.12 magnitudes at L_{PAB} = 27°. This suggests a very moderate ellipsoid asteroid shape. We recommend new observations in future apparitions for the purpose of supplementing this analysis. The *a/b* axis relationship is 1.01.



(62836) 2000 UC59. This is a main-belt asteroid with an estimated diameter of 3.4 km; it was discovered in 2000 by the LINEAR survey. There is no published photometric study of this asteroid. After six nights of observing, we concluded that the rotation period is around 10.73 ± 0.01 h. More data are needed in order to improve this determination.

The lightcurve obtained shows a maximum amplitude of 0.88 mag at L_{PAB} = 190°. This amplitude suggests a very elongated shape. The *a/b* axis relationship is 2.12.



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Number	Name	20xx mm/dd	Phase	L_{PAB}	B_{PAB}	Period (h)	P.E.	Amp	A.E.	a/b	Scope
261	Prymno	18/11/12-11/12	7.2	63	38	9.44	0.01	0.23	0.01	1.20	TAR 2
338	Budrosa	19/03/24-04/04	5.3,9.0	171	-7	4.6079	0.0005	0.07	0.01	1.06	OIA
714	Ulula	18/12/03-12/03	7.6	83	8	6.9938	0.0041	0.17	0.01	1.14	TAR 2
2956	Yeomans	19/05/09-05/24	6.8,1.5	241	3	3.57	0.01	0.27	0.03	1.10	TAR 2
3147	Samantha	18/10/17-10/17	4.6	14	2	5.2724	0.0136	0.62	0.02	1.68	TAR 2
6329	Hikonejyo	19/05/11-05/25	6.5,11.6	225	9	6.064	0.003	0.15	0.03	1.13	OIA
7673	Inohara	18/12/27-12/27	2.6	91	-9	3.40	0.01	0.23	0.03	1.22	TAR 3
10997	Gahm	19/01/12-01/12	6.1	125	2	3.209	0.006	0.57	0.09	1.58	TAR 3
14105	Nakadai	18/12/07-12/07	4.1	67	-7	6.674	0.049	0.70	0.05	1.80	TAR 3
15925	Rokycany	19/02/27-03/04	6.8	160	-13	3.011	0.001	0.16	0.03	1.14	TAR 1
33729	1999 NJ21	18/11/09-11/09	6.5	27	8	4.56	0.27	0.12	0.08	1.01	TAR 1
62836	2000 UC59	19/04/05-04/27	2.8,14.8	190	-2	10.73	0.01	0.88	0.06	2.12	OIA

Table I. Observing circumstances and results. Pts is the number of data points used in the analysis. The phase angle values are for the first. L_{PAB} and B_{PAB} are the average phase angle bisector longitude and latitude. Period is in hours. Amp is peak-to-peak amplitude in magnitudes. The last column gives the a/b ratio for an assumed triaxial ellipsoid viewed equatorially based on the amplitude.