NEW PHOTOMETRY OF 1473 OUNAS

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(Received: 4 January Revised: 16 March)

Semi-calibrated lightcurves were obtained of 1473 Ounas in 2012 August – October which indicate a long synodic rotation period of 139.1 ± 0.1 hours, amplitude 0.6 ± 0.1 magnitudes. Some sessions provide data which do not fit for any derived period and are an indicator of tumbling. But errors of calibration are sufficiently large to hamper finding the tumbling period.

The Asteroid Lightcurve Data Base (Warner et al. 2012) shows no previous observations of 1473 Ounas. Vladimir Benishek, Andrea Ferrero, and Daniel Klinglesmith III began observing 1473 Ounas independently. When they learned of each other's work through the CALL website they agreed to share their data. Later Frederick Pilcher contributed additional observations. Also Rene Roy had posted his results on R. Behrend's web site (2012) and accepted the invitation to share data and join the collaboration.

A total of 55 sessions were obtained by the five observers in the interval 2012 Aug. 2 – Oct. 23. Almost all are by direct comparison to catalog magnitudes of stars in the CCD field. As a consequence of their having started observations independently, different filters R, V, and Clear were used by the different observers and in different sessions. Details of the separate sessions are provided in a table below.

Data Analysis. *MPO Canopus* software was used by all observers except Roy to measure the images photometrically. R. Behrend used CoubRot software (Behrend, 2001) to measure the images by Roy. Only stars with near solar colors were used, and in each of the several different sessions 2 to 5 comparison stars were used. The Comparison Star Selector (CSS) procedure in *MPO Canopus* computes and displays a separate value for the magnitude of the asteroid as compared with the catalog magnitude of each comparison star. Errors of calibration arise from errors in the catalog magnitudes, intrinsic color differences V-R between star and asteroid, and instrumental effects arising from the filters. For each session the range in asteroid magnitudes as compared with each comparison star was often in the range 0.05 – 0.10 magnitudes, but occasionally as high as 0.25 magnitudes. This provides an order of magnitude of the calibration errors. The asteroid magnitude used for a single session in the subsequent steps of analysis is the mean obtained from these 2 to 5 catalog based magnitudes. When several sessions are combined into a single lightcurve *MPO Canopus* software adjusts the measured magnitudes on the different nights for changes caused by variations in geocentric and heliocentric distances and phase angle with a default G = 0.15. A further calibration error systematic with phase angle arises if G is considerably different from 0.15. Figure 1 is a raw plot of all observations adjusted as described above. A scatter considerably beyond rotational variations, for some sessions as high as 0.3 to 0.4 magnitudes, is likely due to both errors in calibration and the effects of tumbling of a slowly rotating target. Minor planet 1473 Ounas has diameter near 15 km and this investigation finds a rotation period near 6 days, as is described below. Tumbling behavior is common among objects of this size and rotation period. However there is no overall trend with phase angle which implies the real value of G for 1473 Ounas is not greatly different from 0.15.

MPO Canopus contains the FALC algorithm (Harris et al. 1989) which searches the data for many possible periods and plots a lightcurve for the period with the best (lowest rms residual) fit. A period near 140 hours is found and shown in Figure 2. Symbols on this figure are shown for successive cycle numbers of the approximately 140 hour period. Next the magnitudes of the separate sessions are adjusted, one at a time, up and down through several hundred separate steps until a best fit is obtained. This is shown in Figure 3, in which symbols are again shown for successive cycle numbers. In principle this removes errors of calibration, but it also removes variations caused by tumbling which have periods longer than a single session. The lightcurve in Figure 3 is unrealistically smooth. At a given phase slope variations, especially those in which rising sessions overlap falling sessions, are still readable, but all night magnitude differences caused by tumbling have been removed. The first order period due to principal axis rotation of 139.22 hours should however be reliable. Inspection of a lightcurve with this period shows that some sessions at nearly the same phase in different rotational cycles have inconsistent slopes. We illustrate in Figures 4 and 5 two spectacular cases in which rising segments overlap falling segments. These are small parts of the complete lightcurve produced by Pilcher with *MPO Canopus* software in which the magnitudes (mean for entire lightcurve = 0) and phase have been carefully preserved. In Figure 4 the misfit session with blue + sign symbols near phase 0.03 is for the interval Aug. 2 21:30 UT – Aug. 3 02:34 UT. In Figure 5 the misfit session with black triangle symbols near phase 0.23 is for the interval Oct. 1 2:57 – 6:59 UT. A careful inspection of Fig. 3 finds several much smaller but probably significant slope misfits. This behavior we can only explain by tumbling behavior in the target. Unfortunately the errors of calibration are sufficiently large to hamper determination of a second period.

The lightcurve presented here (Figure 3) with period 139.22 ± 0.01 hours was prepared with a single period search with *EXELIS IDL* (Interactive Data Language, www.exelisvis.com) software by author Klinglesmith. Other authors have independently prepared lightcurves which we do not present here. The periods they find are: Raoul Behrend 139.01 ± 0.07 hours with *CourbRot* software (Behrend, 2001); Andrea Ferrero 139.12 ± 0.02 hours with *MPO Canopus*; Frederick Pilcher 139.14 ± 0.02 hours also with *MPO Canopus*. These quoted errors are all one sigma errors which are likely unrealistically small. If we assign equal weight to the four periods stated above, a least squares solution provides a period 139.12 ± 0.06 hours. With some caution we should claim an error not smaller than ± 0.1 hours.

It is significant that all four independent period determinations all converged to a value very near 139.1 hours. The period spectrum between 130 and 150 hours (Figure 6) also shows that there is no viable period other than one near 139.1 hours. The removal of magnitude ordinate variations by the procedure of adjusting all sessions to best fit does not invalidate the period of 139.1 hours thus obtained, but does make the amplitude of principal variation somewhat uncertain. The amplitude we find here, about 0.6 magnitudes, is sufficiently large that despite a likely considerable error the only possible period is the one which produces our bimodal lightcurve. We claim that the reliability of this period is secure.

We conclude that this study indicates that 1473 Ounas has a rotation period of 139.1± 0.1 hours with amplitude 0.6 ± 0.1 magnitudes and a very strong suggestion of tumbling.

Future studies. The next favorable opposition of 1473 Ounas occurs in 2016 July near +4 degrees declination and brightest magnitude 14.4. This is comparably observable from both northern and southern hemispheres. We recommend that a consortium of observers from a wide range of terrestrial longitudes be assembled. Prior to the beginning of observation, probably 2016 May, procedures for improving the calibration magnitudes should be refined and adopted uniformly by all participating observers.

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Acknowledgements

The authors thank reviewers Alan Harris and Brian Warner for many helpful comments which greatly improved this paper.

Observer equipment: VB, Vladimir Benishek; AF, Andrea Ferrero; DK, Daniel Klinglesmith III; FP, Frederick Pilcher; RR, Rene Roy.

VB	40 cm S-C	SBIG ST-10 XME
AF	30 cm R-C	SBIG ST9XE
DK	35 cm S-C	SBIG ST10
FP	35 cm S-C	SBIG STL-1001E
RR	40 cm f/5.1	1603ME Binnig Platinum 2x2 Audine

Session Data: Cy, cycle number; Obs, observer; Date 2012 of session; UT of first and final data points of session; Filter, C clear, R red, V visual; RA and Dec in J2000 coordinates of mid time of session; Phase angle in degrees.

Cy	Obs	Date 2012	UT	Filter	RA	Dec	Phase
01	VB	Aug 02-03	21:30-02:34	C	21 36.6	+12 42	15.6
01	VB	Aug 04-05	21:22-02:37	C	21 35.4	+12 40	15.0
01	VB	Aug 06-07	20:51-02:28	C	21 34.1	+12 37	14.5
01	VB	Aug 07-08	20:55-02:24	C	21 33.4	+12 35	14.3
02	VB	Aug 08-09	20:46-02:07	C	21 32.8	+12 32	14.2
02	VB	Aug 09	20:59-23:35	C	21 32.1	+12 30	14.1
04	VB	Aug 21-22	20:06-01:19	V	21 23.8	+11 23	12.6
04	VB	Aug 24-25	20:31-01:05	C	21 21.8	+10 58	12.7
05	AF	Aug 26-27	19:42-02:27	R	21 20.6	+10 40	12.9
05	AF	Aug 27-28	20:09-02:25	R	21 20.0	+10 30	13.0
05	DK	Aug 28	03:20-04:11	C	21 19.8	+10 28	13.0
05	DK	Aug 28	04:14-05:59	C	21 19.8	+10 28	13.0
05	DK	Aug 28	06:11-09:27	C	21 19.7	+10 27	13.0
05	AF	Aug 28-29	19:13-02:26	R	21 19.4	+10 20	13.1
05	DK	Aug 29	03:50-08:36	C	21 19.2	+10 18	13.1
05	DK	Aug 30	03:39-09:30	C	21 18.7	+10 08	13.3
05	DK	Aug 31	03:02-09:48	C	21 18.2	+09 58	13.5
06	DK	Sep 01	02:33-03:53	C	21 17.7	+09 48	13.7
06	DK	Sep 02	04:26-09:33	C	21 17.2	+09 36	13.9
06	DK	Sep 03	03:01-05:32	C	21 16.7	+09 26	14.1
07	AF	Sep 06-07	19:16-01:41	R	21 15.2	+08 42	15.1
07	AF	Sep 09-10	18:40-01:29	R	21 14.2	+08 06	15.9
07	AF	Sep 11	18:47-22:14	R	21 13.7	+07 43	16.5
08	AF	Sep 12-13	21:27-00:53	R	21 13.5	+07 30	16.8
08	AF	Sep 13-14	18:46-01:10	R	21 13.4	+07 18	17.1
08	AF	Sep 14	18:49-20:39	R	21 13.2	+07 05	17.5
08	DK	Sep 15	02:37-05:33	C	21 13.2	+07 02	17.5
08	AF	Sep 15-16	18:39-00:48	R	21 13.1	+06 53	17.8
08	DK	Sep 16	02:15-04:38	C	21 13.1	+06 50	17.8
08	AF	Sep 16-17	18:26-01:03	R	21 13.1	+06 40	18.1
08	AF	Sep 17-18	21:54-00:52	R	21 13.0	+06 27	18.4
09	AF	Sep 19-20	18:57-00:42	R	21 13.0	+06 02	19.0
09	DK	Sep 20	02:00-06:13	C	21 13.0	+06 00	19.1
09	AF	Sep 20	18:40-23:20	R	21 13.1	+05 50	19.3
10	AF	Sep 24	18:14-20:44	R	21 13.7	+05 02	20.6
10	VB	Sep 25	18:59-23:01	R	21 13.7	+04 50	20.9
11	FP	Sep 30	01:36-07:37	C	21 15.2	+03 59	22.0
11	FP	Oct 01	02:57-06:59	C	21 15.7	+03 47	22.3
11	AF	Oct 01	19:34-23:28	R	21 16.0	+03 39	22.6
11	RR	Oct 01-02	18:35-00:57	C	21 16.0	+03 39	22.6
11	FP	Oct 02	01:40-06:39	C	21 16.2	+03 36	22.7
11	AF	Oct 02	18:13-23:12	R	21 16.5	+03 28	22.9
11	DK	Oct 03	02:17-05:39	C	21 16.6	+03 24	23.0
11	DK	Oct 04	02:15-06:11	C	21 17.1	+03 13	23.2
11	FP	Oct 05	01:31-07:37	C	21 17.7	+03 02	23.4
12	FP	Oct 08	01:31-07:23	C	21 19.5	+02 31	24.2
12	FP	Oct 09	01:31-07:18	C	21 20.1	+02 21	24.4
12	FP	Oct 11	01:44-05:51	C	21 21.5	+02 01	24.9
13	AF	Oct 12	18:07-22:59	R	21 22.8	+01 45	25.3
13	FP	Oct 14	01:19-06:12	C	21 23.9	+01 32	25.6
13	AF	Oct 16	17:48-22:47	R	21 26.2	+01 09	26.2
14	FP	Oct 18	01:32-06:32	C	21 27.4	+00 58	26.4
14	FP	Oct 19	01:22-05:09	C	21 28.3	+00 50	26.6
14	FP	Oct 20	01:12-05:05	C	21 29.3	+00 42	26.7
14	FP	Oct 23	01:18-04:51	C	21 32.4	+00 20	27.2

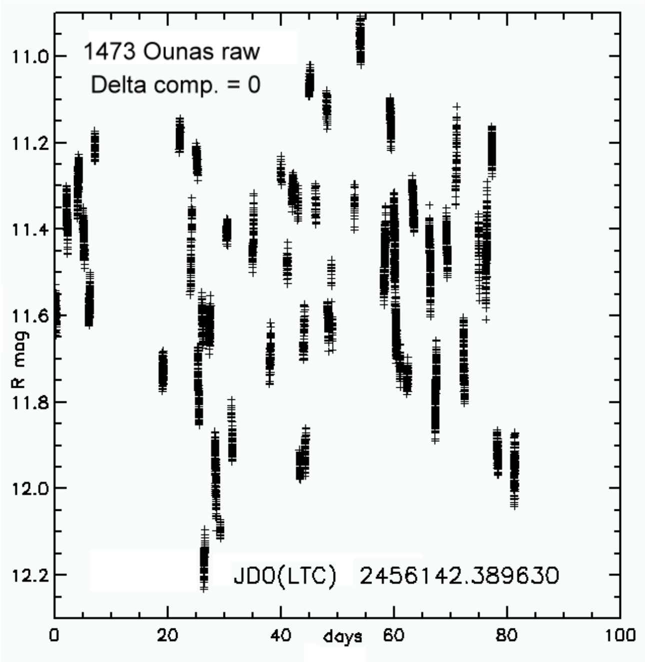

Figure 1. Raw plot of all CSS observations of 1473 Ounas adjusted for changes in Sun and Earth distances and assumed G = 0.15.

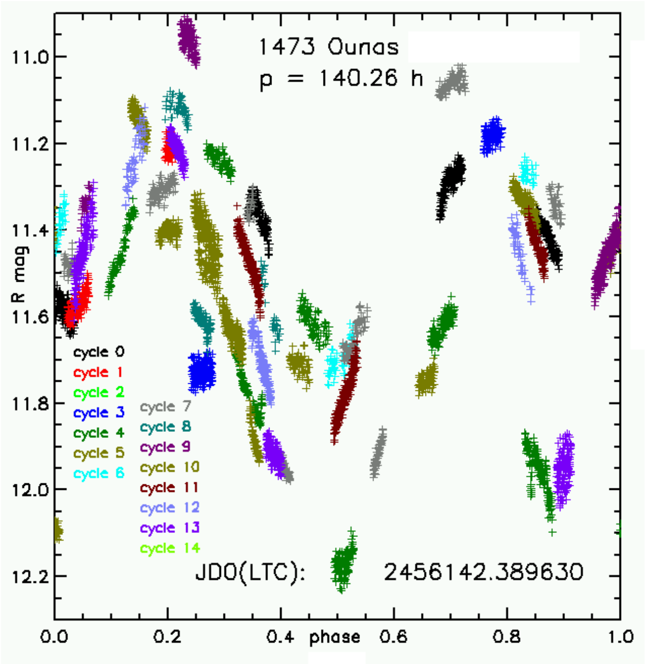

Figure 2. Phased plot of all CSS observations of 1473 Ounas coded by cycle number and adjusted for changes in Sun and Earth distances and assumed G = 0.15.

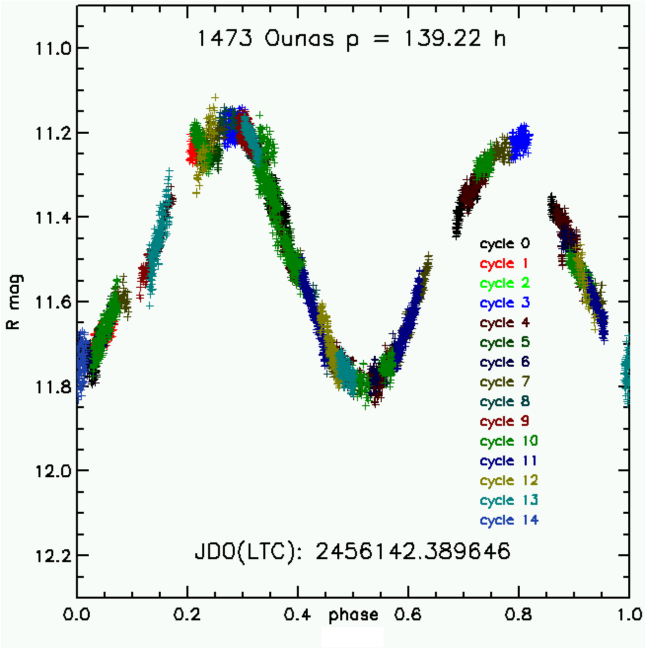

Figure 3. Phased plot of all observations of 1473 Ounas coded by cycle number with magnitudes of separate sessions adjusted for best fit.

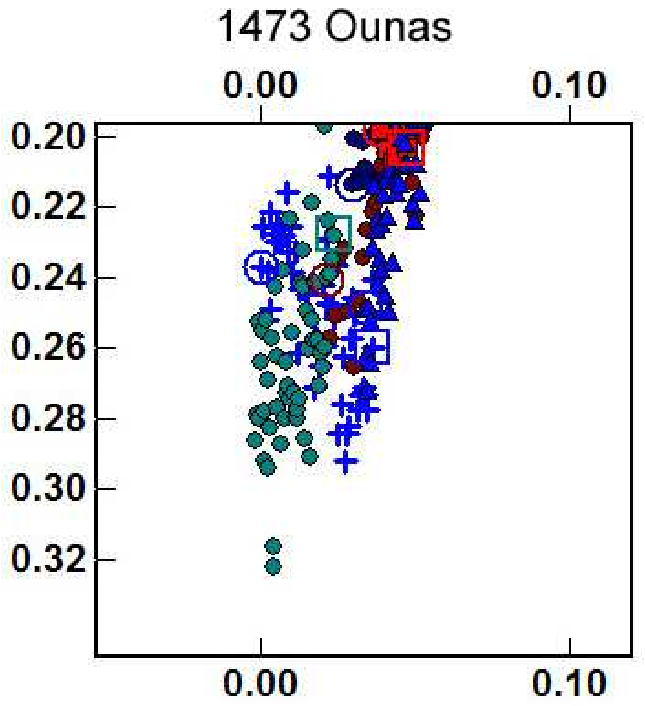

Figure 4. Enlargement of a small section of the lightcurve showing the session of Aug. 2 21:30 UT - Aug. 3 02:34 UT (blue + signs) with a slope misfit.

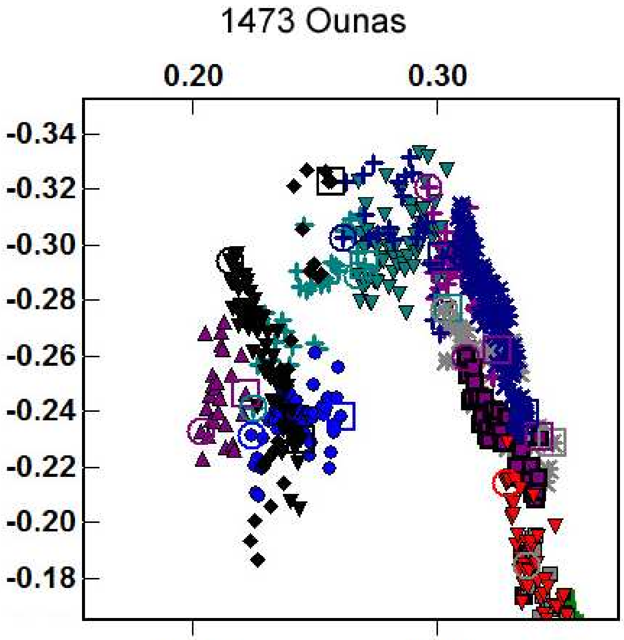

Figure 5. Enlargement of a small section of the lightcurve showing the session of Oct. 1 02:57 UT - 06:59 UT (black triangles) with a slope misfit.

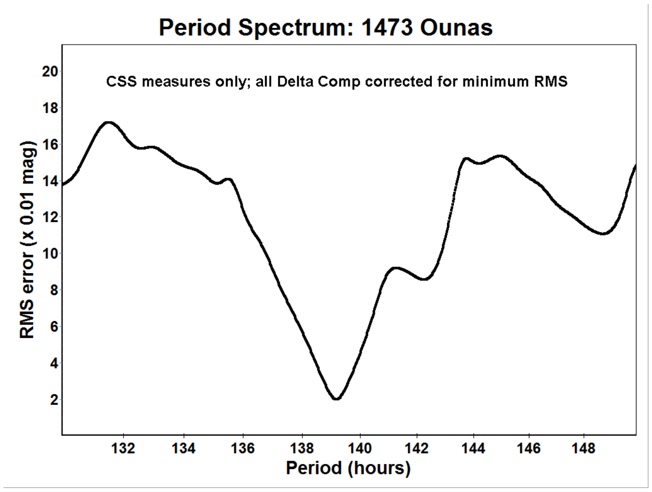

Figure 6. Period spectrum of 1473 Ounas between 130 and 150 hours with magnitudes adjusted as in Fig. 3.

1727 METTE: A NEW HUNGARIA BINARY

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(Received: 10 March)

Analysis of CCD photometric observations of the Hungaria asteroid 1727 Mette made in 2013 January shows that the asteroid is a binary system. A bimodal lightcurve for the primary has a period 2.98109 ± 0.00007 h with an amplitude of 0.33 ± 0.01 mag. This makes the primary one of the more elongated objects in the small binary population. The orbital period of the satellite is 20.99 ± 0.02 h. Based on the depth of the mutual events, the satellite-primary diameter ratio is estimated to be $D_s/D_P = 0.21 \pm 0.02$.

The rotation period of the (now known to be) primary of the Hungaria asteroid 1727 Mette had been determined on several previous occasions, e.g., Wisiniewski (1987, 2.63 h), Behrend *et al.* (2003, 2.981 h), Gandolfi (2009), and Warner (2011, 2.981 h). Other observers have reported periods of 2.4-2.6 h over the years. See the references in the asteroid lightcurve database (LCDB; Warner *et al.*, 2009). None of the previous results seemed to indicate signs of the asteroid having a satellite.

As part of the regular observations of the Hungaria asteroids conducted at the Palmer Divide Observatory since 2005, CCD photometric observations of 1727 Mette were started in 2013 January. In this case, the intent was to provide additional dense lightcurves for modeling the asteroid's spin axis and shape. Initial observations showed what appeared to be deviations from a 2.98 hour lightcurve (Figure 1). This prompted additional observations so that the primary curve could be well-determined and then subtracted from the overall data set to determine the period of the satellite events (occultations and/or eclipses), i.e., the orbital period.

The observations at the Palmer Divide Observatory (PDO) were made using a 0.30-m Schmidt-Cassegrain and SBIG ST-9XE CCD camera. Exposures were 120 seconds and unfiltered. Observations at the Center for Solar System Studies (CS3) were made with a 0.35-m Schmidt-Cassegrain and SBIG STL-1001E. Exposures were also unfiltered and 120 seconds. All images were measured in *MPO Canopus*. The dual-period feature in that program, based on the FALC algorithm developed by Harris (Harris *et al.*, 1989) was used to subtract one of the periods from the data set in an iterative process until both periods remained stable. Night-to-night calibration of the data was done using the Comp Star Selector feature in *MPO Canopus*. Catalog magnitudes for the comparison stars were derived from J-K to BVRI formulae developed by Warner (2007) using stars from the 2MASS catalog (Skrutskie *et al.*, 2006). A description of this method was described by Stephens (2008).

The results of the analysis are shown Figures 1-3. Figure 1 shows the full data set before subtracting the effects of the occultation and/or eclipses caused by the satellite. This shows the nature of the deviations that prompted the additional analysis. Figure 1 also demonstrates the usual nature of these events in *unprocessed* lightcurves: they are not sharp, short-lived, and deep. Instead they