PHOTOMETRIC OBSERVATIONS OF NEAR EARTH ASTEROID 2012 TC4

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Abstract. We present three hours of photometry for minor planet 2012 TC4, during the close approach in October 12th, 2017. Our observations and data analysis show a fast spinning asteroid with a period of 0.204 ± 0.001 hours, a non-principal axis rotator with a ratio of about 1.7 between axis in the assumption of an ellipsoidal shape. This synodical period is compatible with a monolithic structure of the object.

Key words: Near-Earth Asteroid – photometry – lightcurve.

1. INTRODUCTION

Some Near-Earth Asteroids (NEA), which can approach the Earth closer to 1 lunar distance (1 LD), are subject of research concerning the natural risks (Chapman and Morrison, 1994). They also represent a unique opportunity to examine small-sized objects within our immediate neighbourhood. Thus, it is crucial that during such an opportunity window, the spectrum and brightness variation of this type asteroid, as well as radar echoes and thermal infra-red data to be recorded. From a complete data-set of observations, the mineralogical composition, the rotational period, the shape and size of the object can be determined. For very small asteroids (smaller than 10 m) all the characteristics described above can only be determined during a very close approach.

The asteroid 2012 TC4 was discovered on 4th Oct 2012, by the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) at Haleakala Observatory on the Hawaiian Island of Maui, in the United States. In 2017, 2012 TC4 had a close approach with the Earth on October 12th, being at only 50,151 km from our planet (`https://ssd.jpl.nasa.gov/sbdb.cgi?sstr=2012\%20TC4;old=0;orb=0;cov=0;log=0;cad=1\#cad`). The object was recovered in August 2017 using FORS2 instrument on ESO's Very Large Telescope (`http://www.eso.org/public/images/ann17052a/`). The asteroid was spotted when its apparent magnitude was 27, by far the faintest NEA ever measured.

Although it was not observable from our longitude at minimum distance (2017-Oct-12 05:42 UT), we observed the asteroid on two prior nights. According to JPL Solar System Dynamics, this was the closest approach of 2012 TC4 since the discovery (2012-Oct-12 05:30 UT) and until 2108 (the furthest time for which a good ephemeris can be computed).

During the previous approach (Odden *et al.*, 2013), (Warner, 2013) and (Polishook, 2013) found a synodic period of 0.204 hours, while (Carbognani, 2014) reported 0.2067 hours. (Carbognani, 2014) also estimates minimal $\frac{a}{b}$ axial ratios of 2.3 $\pm$ 0.2. Based on an absolute magnitude of 26.7, and albedo conservative values of 0.05 and 0.5, the effective diameter of the minor planet is between 9 and 30 meters (`https://minorplanetcenter.net/iau/lists/Sizes.html`). The astronomical community organized an international campaign to fully characterize the physical and mineralogical properties of 2012 TC4.

2. OBSERVATIONS

The observations were carried at the Astronomical Institute of the Romanian Academy (IAU MPC code 073). We used the 0.38 meter f/6 Ritchey-Chretien telescope (Gherase *et al.*, 2017) and a SBIG STL-11000M CCD camera, cooled down to $-20\,^{\circ}$C. The field-of-view is 44x29 arcmin and the pixel scale of 1.3 arcsec/pixel (a 2x2 binning was used during the run, in order to minimize image download time from sensor). The observations were carried in two nights, with a total observing time of 6.4 hours, while the distance from the Earth decreased by a factor of three. The apparent magnitude decreased and the asteroid sky motion attained a value of 117"/min.

Table 1

Observing circumstances with the beginning and the end of every observing run and the air mass of the object at the corresponding times. Delta is the Earth-asteroid distance in lunar distances, and V is the calculated visual magnitude of the asteroid.

Night	UT start - UT end [hh:mm]	Exposure time [s]	V [mag]	Airmass	Delta [LD]
10.10.2017	18:00 - 22:18	60s	16.7	1.7 - 2.0	2.2-1.99
11.10.2017	18:30 - 20:47	10-30s	15.0 - 14.7	1.8 - 2.0	0.74-0.58

3. DATA PROCESSING

The raw images were calibrated with bias, flats, and darks using the standard procedures of (MaxIm DL, 2016) software. The dataset was processed with MPO Canopus software (Warner, 2015). Differential photometric measurements were performed using the Comp Star Selector (CSS) procedure in MPO Canopus, which allows selecting up to five comparison stars with a near solar color. The magnitudes of the comparison stars were taken from the CMC-15 catalogue. While the asteroid has a large sky apparent motion, the reference stars changed approximately every 30 minutes of observations. On the calibrated images the asteroid is visible as an elliptical trail. Thus, for direct measurement of the asteroid and reference star brightness, a measuring aperture size of two times FWHM was used. Further, the period analysis was performed using MPO Canopus software (Warner, 2015), which includes uses the FALC (Fourier Analysis for Lightcurves) algorithm (Harris *et al.*, 1989).

4. RESULTS

Our data show a fast-rotating object with an important brightness variation. A particular case of a spinning minor planet is the 'tumbling state', when the rotation is not characterized by a single time period, but by two: the proper rotation period and the precession period. These are asteroids with 'non-principal axis rotation' when, for the observer, the axis of rotation position changes. The asteroid spins with a period around 12 minutes, in agreement with determinations from previous observations from 2012 when 2012 TC4 grazed the Earth. The amplitude of the lightcurve was estimated around 1.4 magnitudes. In the assumption of oblate spheroidal shape of 2012 TC4, we compute the ratio of 1.7 between its axis (Kwiatkowski *et al.*, 2010).

4.1. RAW LIGHTCURVES AND PERIODICITY

Our set-up provides a visual field of 44x30 arcmin and minor planet 2012 TC4 crossed it in about 20 minutes. We were limited in using the same comparison stars only for that period of time, but the short rotation period of the object allowed the coverage of a full spin. Every data set shows a fast-rotating object, with a period around 12 minutes (Figure 1).

The photometric data from the first observing run (10.10.2017) were not used for period determination. The exposure time used to acquire images was too long and, combined with the image download time from the sensor, gave us only a few data points per cycle. The lightcurve (Figure 2) shows the fast rotation and large brightness variation.

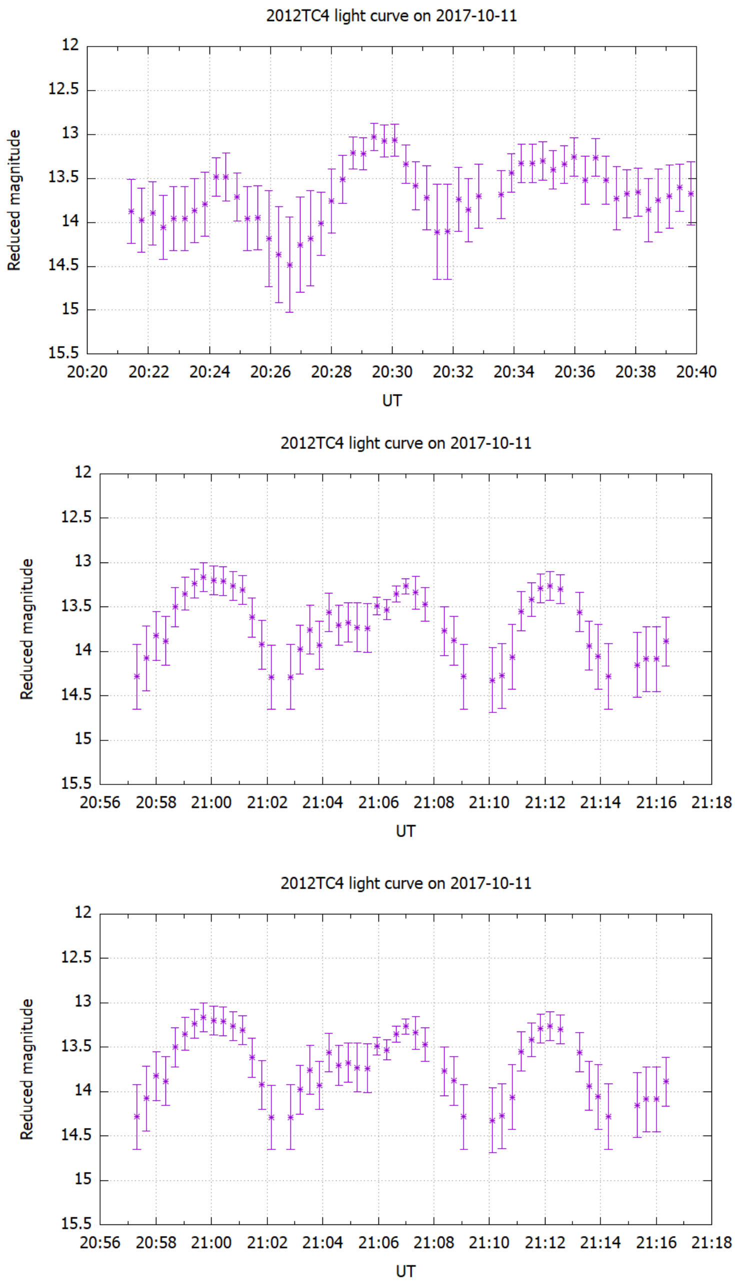

Fig. 1 – Three individual lightcurves obtained during the night of 11 October 2014. Each figure shows the reduced magnitude variation versus time. An estimation of error in magnitude is also represented.

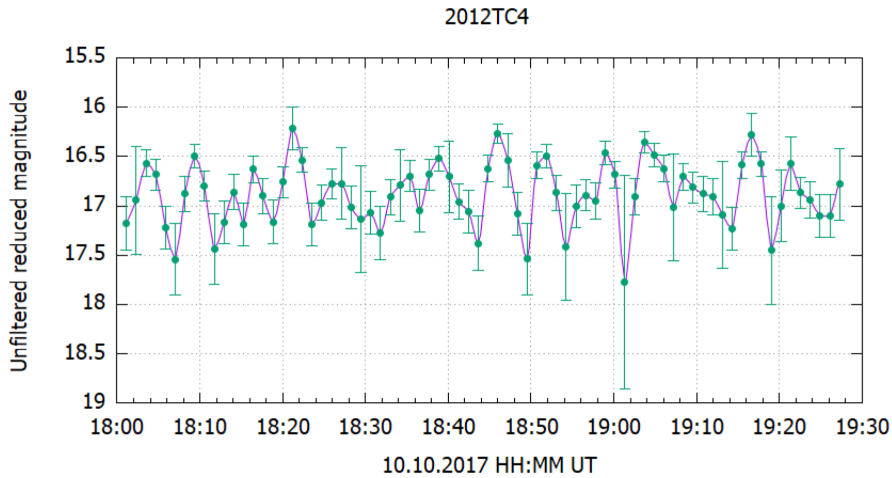

Fig. 2 – Brightness variation of 2012 TC4 during the night of 10.10.2017. The plot shows the magnitude errors and a spline fit through data points.

Table 2

Data about the runs used to determine the synodic period. The duration of each observing run is given as well as the number of photometric points obtained. Last column presents the computed synodical period for each sequence.

Date [UT]	Duration [min]	Number of individual images	Synodical period[h]
11.10.2017 18:38-18:52	14	41	0.214 ± 0.003
11.10.2017 19:32-19:48	16	38	0.206 ± 0.005
11.10.2017 20:21-20:40	19	53	0.200 ± 0.005
11.10.2017 20:57-21:16	19	49	0.205 ± 0.001

4.2. NON-PRINCIPAL AXIS ROTATION AND SYNODIC ROTATION

We analysed the rotation period in every case and we found that the value varied and the shape of the lightcurve is complex. This usually indicates a ”tumbling” state of rotation, with a complex lightcurve that is not a simple periodic function. In our case this phenomenon (non-principal axis rotation) was found by applying the FLAC algorithm (Harris, 1989), using MPO Canopus software (Warner, 2015), for every session of observations, which showed multiple rotation periods (Table 4.2, Figure 3).

In order to determine the synodical period of 2012 TC4, we used MPO Canopus FLAC algorithm, with six harmonic orders in the Fourier analysis, starting with 0.1 hours initial period and a 0.0001 hours step, for 2300 steps. We found three most probable periods, of 0.102, 0.203 and 0.306 hours respectively, as presented in the

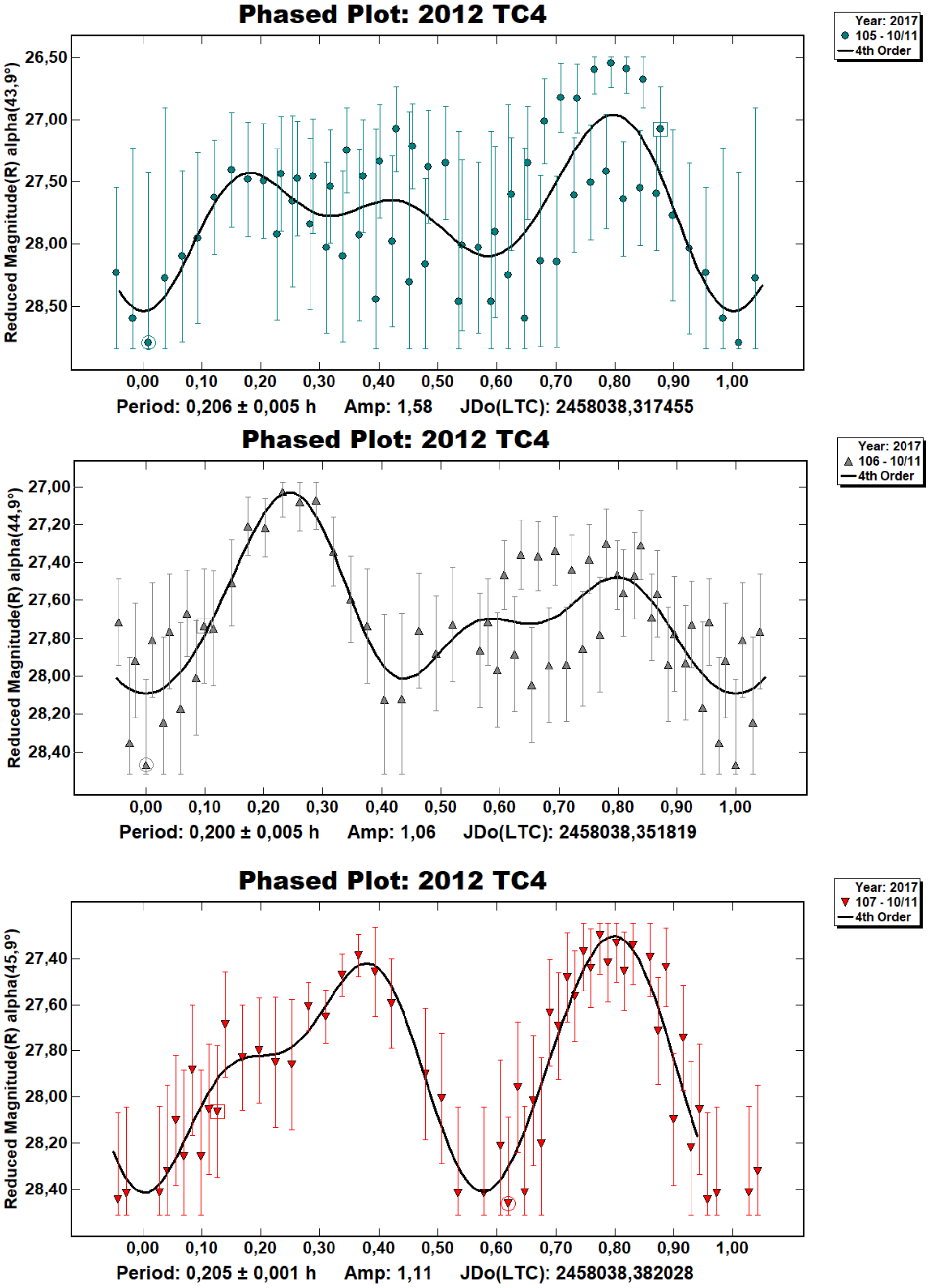

Fig. 3 – Plots showing photometric data folded to the synodic period determined from our data. On each figure, the period, the amplitude and the time of first observation plotted are indicated.

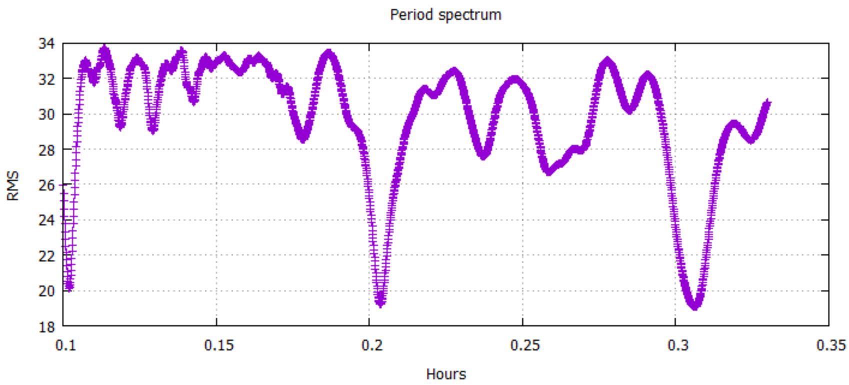

Fig. 4 – Periodogram of 2012 TC4 observations. The most probable periods have the lowest RMS. We identified three periods.

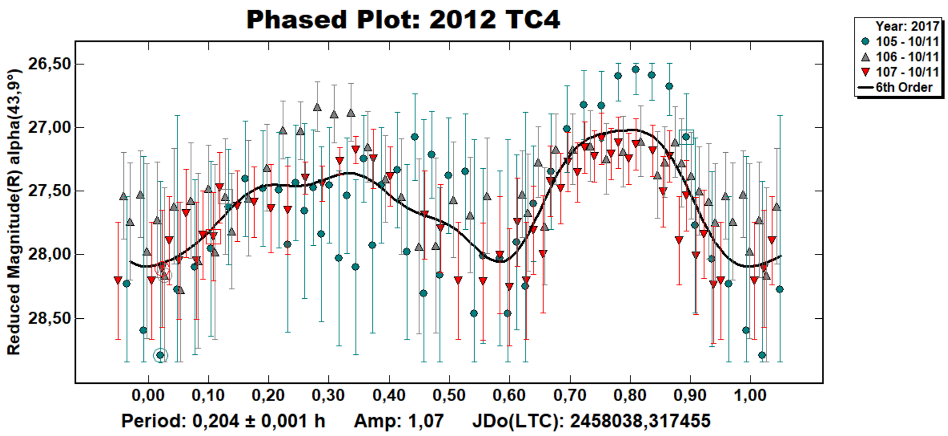

Fig. 5 – Composite lightcurve of asteroid 2012 TC4.

periodogram (Figure 4).

We dropped the solutions for periods of 0.102 and 0.306 hours. Indeed, they show unusual variations with only one or multiple minima per rotation. The period which fitted the data was 0.204 $\pm$ 0.001 hours (Figure 4), in excellent agreement with the period determined by (Odden *et al.*, 2013), (Warner, 2013) and (Polishook, 2013), and in close agreement with (Carbognani, 2014).

5. CONCLUSIONS

The very small minor planet 2012 TC4 was observed during two nights from the Astronomical Institute of the Romanian Academy, using a (0.38 m) RC telescope.

The solution for the rotational period was secured from observations made in the second observing run. The other set of data could not be used because of the relatively few data points per rotation period. Nevertheless, this set of data also exhibited the fast rotation and the large brightness variations of the object. We determined a synodical period of 0.204 ± 0.001 hours and that the asteroid has a non-principal axis rotation. The changes of the asteroid lightcurve due to the evolution of the geometry between asteroid-Earth-Sun are negligible in the data span of our observing run (the phase angle changed between 34° and 44°).

The short rotational period of 2012 TC4 is consistent with a rocky monolithic object; indeed, the spin of this object reflects strong cohesion forces which are not compatible with high porosity and/or a rubble pile structure (Pravec and Harris, 2007).

Based on lightcurve amplitude we also found the ratio of 1.7 between its axis in the assumption of an oblate ellipsoid. (Polishook, 2013) estimated a minimal 2.3 $\pm$ 0.2 axial ratios while (Ryan and Ryan, 2017) gives a ratio greater of 2. Being such a fast rotator and a tumbling asteroid, 2012 TC4 axial ratios estimates could vary because of the ever-changing view angle of its large axis.

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