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PHOTOMETRIC OBSERVATION AND LIGHTCURVE ANALYSIS OF (24445) 2000 PM8

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Photometric observations of NEO (24445) 2000 PM8 were made over three nights in September 2013. A synodic period $P = (6.81 \pm 0.03)$ h was derived from these data.

ROTAT (Remote Observatory Theoretical Astrophysics Tübingen) is a 60 cm remotely operated telescope, located on the OHP site (Observatoire de Haute-Provence) at Haute-Provence (France), about 100 km north-east of Marseille. ROTAT was formerly located and operated in Tübingen, Dept. for Theoretical Astrophysics, University of Tübingen.

Image acquisition was made with a SBIG STL-1100M CCD camera attached to the f/3.2 Newtonian focus of the ROTAT telescope, resulting in a pixelscale of 1.94 arcs/px (with 2x2 binning). No filters were used. Exposure times were 50, 45 and 35 seconds for the three nights: 2013 Sept. 19, 20 and 25. It should be noted that during the last night the nearby moon was interfering the observation and that the SNR in that night was about half of the SNR of the two previous nights.

All images were measured using *Astrometrica*, i.e. PSF-based all-sky photometry. Dark images obtained in the same night and a masterflat image were applied. The UCAC4 star catalog was used for the reduction.

Near-Earth Asteroid (24445) 2000 PM8 belongs to the Amor orbital class with an Earth MOID of 0.08173 AU. Given an absolute magnitude $H = 14.6$ and an assumed albedo for a C or S type asteroid, 0.04 and 0.20 respectively, a diameter range of 3.6 – 8.1 km is derived. The object was also observed on 2013 Sept. 25 with the Arecibo radar telescope (*http://www.naic.edu/~pradar/*).

Lightcurve analysis

The lightcurve analysis was carried out with *Peranso*. Originally intended for variable stars, *Peranso* also supports the FALC method by A.W. Harris (Harris et al., 1989). This method was used, though a second analysis was also performed using the ANOVA period analysis method, which confirmed the result obtained with the FALC algorithm. The three observation sets were aligned (zero-point-adjustment) by subtracting the average magnitude of each set from the observations of that night. A period $P = 6.81\text{h} \pm 0.03\text{h}$ was found for (24445) 2000 PM8, which is in agreement with a value of $P = 6.811\text{h}$ found by Warner (2013).

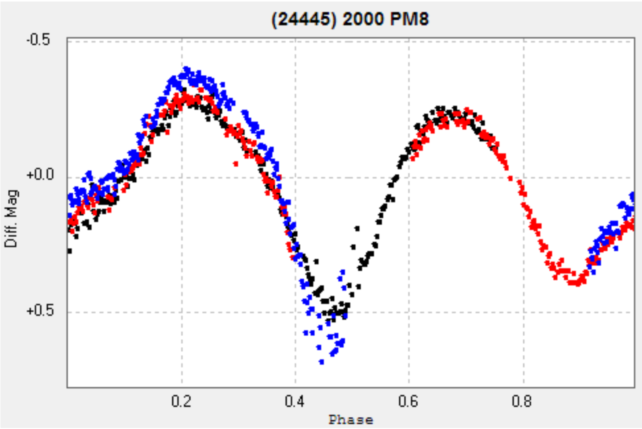

Fig. 1: Phased plot: 2013 Sept. 19 (black), 20 (red), 25 (blue)

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THE LIGHTCURVE OF 3753 CRUITHNE

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A calibrated lightcurve was obtained for 3753 Cruithne during an observing campaign at the Spacewatch 1.8 meter telescope between August and October of 2012. Analysis indicates a rotation period of 27.30990 ± 0.00015 hours and an amplitude of 0.67 ± 0.01 magnitudes. Insufficient small angle phase coverage was observed for spin axis orientation.

An Aten of some note, 3753 Cruithne's interesting horseshoe orbit is in a 1:1 orbital resonance with Earth, making for an easily accessible spacecraft target. It also has an appreciable size for a near-Earth asteroid, having an absolute magnitude of H=15.6. The albedo and diameter have been determined by NEOWISE (Mainzer *et al.* 2012). The Asteroid Lightcurve Database (Warner et al. 2013) indicates that Cruithne has a period of 27.4 hours, which is based on 1995 observations presented in Erikson *et al.* (2000). Given the incomplete coverage of those observations over a whole rotational cycle, that value was estimated to be uncertain by 30% in the JPL Small-Body Database Browser (2013).

Observations. The Spacewatch Project performed an observing campaign to obtain a better value for this rotation period over 29 nights between 2012 August 10 and 2012 October 23, observing Cruithne low in the east each morning. During the campaign, Cruithne's distance from the Earth varied from 1.127 AU to 0.461 AU. The phase angle was quite high and varied substantially, from 44.6° to 76.3°. This led to a brightening from V=18.4 to 16.6 over the course of the campaign. The rate of motion varied by more than a factor of three which caused some later exposures to be trailed. Additionally the motion of the asteroid carried it into the galactic plane. Despite the short observing windows at low elevation, effort was made to observe as long a series as possible during every sitting so that the measured slope of the lightcurve would help constrain the solution.

All observations were made with the f/2.7 Spacewatch 1.8 meter telescope. The camera was a Finger Lakes Instruments ProLine Model PL3041-LC with a 2Kx2K Fairchild 3041 thinned, back illuminated, broad band antireflection coated CCD. The system is filtered with a Schott OG-515, yielding an effective bandpass of 515-950 nm (approximately V+R+I). MaximDL was used to perform basic image calibration with dark, flat-field and fringe frames. In all cases, high signal-to-noise measurements were made with the exposure time being 120 seconds for most observations before October 6 and decreasing to 60 seconds for most images thereafter as the asteroid became brighter. Time calibration for each session was performed by using ntp at the telescopes.

Data Reduction. Object catalogs were created for each image using the most recent version SExtractor package of Bertin and Arnouts (1996) while astrometry was performed using Bertin's SCAMP program (Bertin 2010). A custom set of analysis tasks were written to allow images displayed in the SAOImage ds9 to access the object catalogs so that measurements of both astrometric position and magnitude could be collected by clicking on the objects as they were identified by blinking.

As Cruithne was not in regions covered by SDSS directly, observations suited for formal absolute photometric calibration were also performed each night using the deep catalogs of Osmer *et al.* (1998), which itself has been supplemented with additional magnitudes from SDSS DR7 (Abazajian, *et al.* 2009). The photometry was stable, the night to night variations of the zero point varied by only 0.04 magnitudes in the worst case. As Cruithne was rather low in the east each night, the airmasses remained relatively high: between 1.43 and 2.32. Due to a lack of a second bandpass, only a generic reddening term could be used. Additionally, the asteroid moved deeper into the galactic plane, so the increasing star densities caused a growing fraction of observations to be lost to crowding.

On each night, Cruithne was measured in all images along with two check stars that were used for internal photometric consistency measurements. Relatively stringent criteria were placed on each measurement. In general, if another star of appreciable magnitude was visible within 10 arcseconds of Cruithne's position, the observation was rejected. This did not help in all cases, however, because fainter stars and the wings of occasionally brighter stars are still present. Each night's photometry was examined and if the check stars varied by more than 0.05 magnitudes over the duration of the observations observations observations were removed from consideration. In practice, this resulted in the full removal of August 13 and truncation of the observing sessions on August 10 and October 6. In all cases, the observing logs had also made note about degraded weather conditions.

Light travel time corrections were manually calculated before the fit using an ephemeris generated by the Minor Planet Center on August 3. Weather conditions were variable at times.

In the end, 718 observations passed the quality control measures.

Analysis: Lightcurve analysis was primarily performed using Harris's original FALC code from Harris *et al.* (1989) as well as an independent check determination (and JD of zero phase determination) using Peranso Version 2.50 (Husar 2006). Given the numerous effects on the photometry, the original FALC program was preferred because it kept each night to night zero point as a free parameter.

The primary result of the period determination is presented in Figure 1. While FALC used independent zero point determinations, Peranso did not and instead used the photometry calibration directly. Persanso returned a very similar period (to within seconds but we adopt the FALC period preferentially because of the possibility of photometric calibration, distance and phase errors in the raw magnitudes over the wide duration of the campaign. The photometric errors relative to the final lightcurve are presented in Figure 2.

We conclude that Cruithne has a 27.30990 ± 0.00015 hour period and an amplitude of 0.67 ± 0.01 magnitudes. Our results are in good agreement with that of Erikson *et al.* (2000) but sample the asteroid lightcurve over the entire cycle.