ROTATIONAL STUDIES OF ASTEROIDS WITH SMALL TELESCOPES. V. Reddy[1], R.R. Dyvig[2], B.D. Heathcote[3], P. Pravec[4], [1]Department of Space Studies, P.O. Box 9008, University of North Dakota, Grand Forks, North Dakota 58202. vishnu.kanupuru@und.nodak.edu. [2]Badlands Observatory, Quinn, South Dakota. dyvigron@gwtc.net. [3]Barfold Observatory, Glenhope, Victoria, Australia. bd-heath@bigpond.net.au. [4]Ondrejov Observatory, Astronomical Institute AV CR, Ondrejov, Czech Republic. ppravec@asu.cas.cz.

Introduction: Today, there are ~100,000 numbered asteroids with more continually being discovered, but only ~2,000 of them have accurate rotational periods [1]. Rotational periods of asteroids, especially near-earth asteroids (NEA), are important for understanding their collisional evolution [2]. Rotational periods are also very useful for radar and near-IR spectroscopic observations. Asteroid lightcurves, taken over several apparitions, help in determining the orientation of rotation axes, and even their shapes [3]. While there has been increasing interest in rotational studies over the last decade, the rate at which rotation periods are determined is light years behind the discovery rate of new asteroids. The availability of small telescopes (< 1.0 m), affordable CCD cameras and user-friendly telescope automation and data reduction software provide a unique opportunity for small universities and amateur astronomy groups to pursue original asteroid research.

In this work, we present the results of rotational studies of main belt Asteroid 1459 Magnya, and Apollo-type potentially hazardous asteroid (PHA) 2004 VW14 [4] as examples of research that can be conducted using small telescopes. Details of observational and data reduction methods are presented with the goal of encouraging other small telescope users to pursue similar work.

Observational Techniques: Observations were performed at Badlands Observatory (MPC 918), a privately-owned facility located on the northern edge of Badlands National Park, South Dakota, and from Barfold Observatory, also a private facility in Glenhope, Victoria, Australia. Observations from Badlands were taken in R band using a 0.66m F/4.8 Newtonian telescope and Apogee AP8 CCD camera using a 1024 x 1024 SITe back-illuminated sensor with a 26.6' x 26.6' field of view at 1.56"/pixel [5]. Barfold Observatory employed a 0.35m F/5.2 SCT and SBIG ST-8XE CCD camera with a Kodak 1530 x 1020 KAF-1602E front-illuminated sensor with R filter yielding a field of view of ~25' x 17'. The selection of the target is made based on its V magnitude, motion, air mass range, and number of hours the asteroid could be observed. The exposure time for an asteroid is calculated using the simple formula:

Exposure time (min) = FWHM (arc secs)/rate of motion of asteroid ("/min)

For a main belt object like 1459 Magnya (0.5"/min), the exposure time is typically ~180 seconds, taking image saturation, drive errors, and seeing into account and much shorter (~60-120 seconds) for fast-moving NEAs. The selected asteroids were observed only above an air mass range of 2.0 (or 30º above local horizon) to avoid extinction issues. Based on the above-mentioned factors, exposure times were adjusted to get a minimum signal-to-noise-ratio (SNR) of at least 50 or ~0.02 mag error [3]. In order to avoid an ambiguous period solution, two consecutive nights of data are needed for an object with unknown period.

All observations from Badlands were made remotely using the Share Your Sky web-interface from DC-3 Dreams [6]. A simple script operated the telescope, CCD camera, and the dome all night while the observer remotely monitored the system. The images collected were automatically compressed and transferred to an ftp site where they could be downloaded following an observing run.

Data Reduction Methods: Calibration is done automatically using Maxim DL software. The master dark is created using a median combine of 5-10 darks and the master flat is an average of 10 twilight flats taken through a uniform diffusion screen which eliminates star images in the flats. Each flat is taken using the same filter as the images and is dark subtracted before the final combine. Since the primary goal is to determine the rotational period, differential photometry techniques are employed, where the difference between the asteroid's brightness and at least two comparison stars is measured. These measurements and the period determination are done using Windows-based software MPO Canopus from Bdw Publishing [7]. A "session" is created for each night's data which uses the same set of comparison stars and filter. Light time correction for the observations is calculated and applied based on the Sun, Earth and asteroid distances. Size of the measuring aperture is usually set based on the FWHM of the stars in the image and is typically 4-5 times the FWHM. Due to the asteroid's motion, it is difficult to find standard stars that can be used as comparison stars. Stars that are of the same brightness as the asteroid, and remain in the field of view throughout the night, are typically used as comparison stars. It is important to verify, after the reduction, in order to determine whether the comparison stars used are variable stars themselves. The measured data can be plotted in Canopus with differential magnitude in the *y*-axis and Julian Date on the *x*-axis. The period analysis in Canopus is based on the Fourier analysis method developed by Alan Harris [3].

Rotational Period of PHA 2004 VW14: 2004 VW14 was discovered by the LONEOS search program based at the Lowell Observatory in November 2004 [1]. Classified as an Apollo-type PHA, 2004 VW14 made a close approach on December 24, 2004, at a distance of 0.0127 A.U. Based on its absolute magnitude, the asteroid has an estimated diameter between 340 m - 760 m [4]. During the observing period, spanning five nights (Dec. 10-18, 2004), the asteroid's *V* magnitude changed from 16.2 to 14.4 and sky motion from 0.97"/min to 5.70"/min. Exposure time was changed to compensate for these effects. Initial observations were made from Badlands observatory on three nights, but period analysis by P. Pravec lead to an ambiguous solution due to lack of coverage on consecutive nights. Further observations of the object resolved the issue and led to a period of 2.5009 hrs (± 0.0002 hrs) with an amplitude of 0.14. The lightcurve of 2004 VW14 is presented in Fig. 1.

Rotational Period of 1459 Magnya: Main-belt Asteroid 1459 Magnya was discovered by G. N. Neujmin from Simeis (MPC 94) in Crimea in 1937 [1]. Lazzaro et al. (2000) suggested that 1459 Magnya has a basaltic surface, which was later confirmed by Hardersen et al. (2004). The asteroid was observed for three nights from Barfold Observatory and two nights from Badlands. Analysis of combined five nights of data by P. Pravec shows that the rotational period of the asteroid is 4.67869 hours (±0.00009 hrs) with an amplitude of 0.68 as shown in Fig. 2. The period determined here confirms and refines the 4.68 hours period published by [8], which was based on incomplete coverage of the rotational phase.

Conclusion: Rotational studies of minor planets is an important but often overlooked area of asteroid research. While there has been renewed interest in recent years, there are ample opportunities for small telescopes to contribute. Commercial telescope automation software and user-friendly Window-based data reduction tools also help in the process. The examples shown here are proof of what can be accomplished with limited resources and international collaboration. We have determined the period of PHA 2004 VW14 to be 2.5009 hrs (±0.0002 hrs) and confirmed and refined the previously derived period of 4.68 hours (±0.1 hrs) period for 1459 Magnya.

References: [1] Minor Planet Center, http://cfa-www.harvard.edu/iau/mpc.html. [2] Binzel R.P. et al. (1989) *Asteroids II,* 416. [3] Warner, B. D. (2003) *A Practical Guide to Lightcurve Photometry and Analysis.* [4] JPL NEO Page http://neo.jpl.nasa.gov/ [5] http://www.sdsmt.edu/space/bo.htm [6] DC-3 Dreams Software http://shareyoursky.com/ [7] Bdw Publishing http://www.minorplanetobserver.com/htms/mpocanopus.htm [8] Almeida, R. et al. (2004) *Astron. Astrophy. 415,* 403-406.

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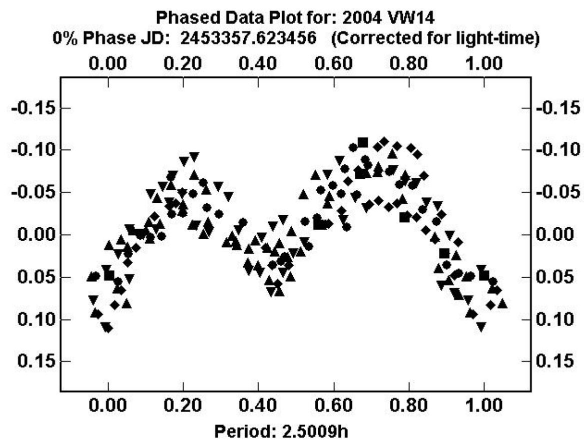

Fig. 1: Composite lightcurve of PHA 2004 VW14.

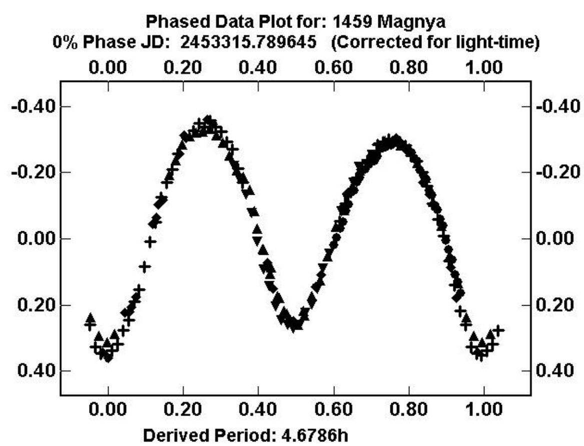

Fig. 2: Composite lightcurve of 1459 Magnya.