Observational Study of the Rotation Rates of Very Small Near-Earth Asteroids

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Introduction

An observational program implemented at the Magdalena Ridge Observatory's (MRO) 2.4-meter telescope (Figure 1) has as its objective to contribute to the study of Near-Earth Asteroids (NEAs) by working in partnership with survey programs to provide astrometric follow up and physical characterization data (lightcurves) on the faintest objects being discovered. The lightcurves we have collected on asteroids primarily smaller than 200 meters have allowed the determination of rotation rates, adding to our physical knowledge of the small end of the NEA size distribution. The rotation rate of an object can imply essential information about its material properties (via deduction of strength-spin boundary limits) and more data can help validate current theories of the relationship between spin limits and overall strength. Previously, extensive work had been done to acquire rotation rates for asteroids greater than 200 meters; however the data are still lacking for objects in the less than 200 meter size-range.

Figure 1. The Magdalena Ridge Observatory 2.4-meter fast-tracking telescope (right) and support facility (left) located outside of Socorro, NM on Magdalena Ridge at 10,612 feet. The observatory became operational in September 2008, and performs target-of-opportunity scientific research as well as work in the area of space situational awareness.

Near-Earth Object Photometric Survey

To best interpret the current data base of rotation rates as a function of size, our strategy has been to obtain more observational data in the regime separating strength-dominated from gravity dominated asteroids. We have paid specific attention to trying to establish whether or not there are monolithic fast-rotating asteroids larger than 200 meter in diameter, as well as discerning what percentage of asteroids with absolute magnitude H > 22 rotate more slowly than the critical threshold for strengthless bodies. With a larger observational database and better statistics, more definitive conclusions regarding the observed distribution of small asteroid spin rates can be made.

In our program, lightcurve observations are obtained for target-of-opportunity objects with limited observing windows (i.e., those which have been recently discovered). This naturally leads us to examine the smaller objects (< 200 meters) that have brighter apparent magnitudes as they make a close approach and pass the Earth. Figure 2 shows that the recently discovered objects most likely to possess material strength are truly targets-of-opportunity. We can generally expect to be capable of ~5% photometry of asteroids with V~19 with 10 second exposures. Recognizing that typical NEA speeds are 5 - 20 km/sec, traveling ~ 0.003-0.011 A.U./day, we discern that the observing window for the H=27 objects is one to a few days. For the brighter H=23.5 targets, this extends to a few weeks. However, it is important to note that, in practice, these times are shortened since discovery does not always occur immediately and the full observable window can not always be utilized.

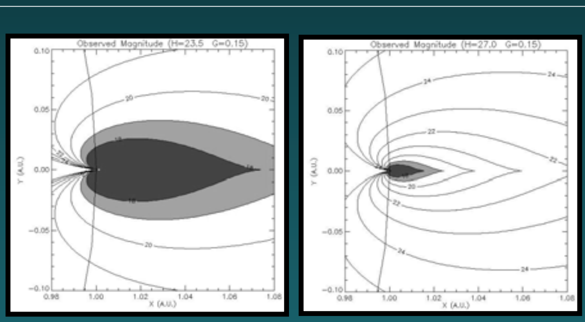

Figure 2. Contour plots showing the apparent visual magnitude of an H=23.5 (diameter ~50-120m) and an H=27.0 (diameter ~10-25m) NEA as a function of position in the near-Earth vicinity. The Earth's location is at (1, 0) and the partial circle represents the Earth's orbit. The shadings represent the regions where V<18 (darker interior) and V < 19 (lighter shade).

NEA Lightcurves

In the following we describe a sample of small NEA lightcurves recently obtained (September 2008 - 2009) from which we have derived rotation rates. Figure 3 shows lightcurve and color data (see Table 1) obtained on asteroid 2008 RQ_{24}. The asteroid was observed during multiple nights that were scheduled with characterization as a primary task.

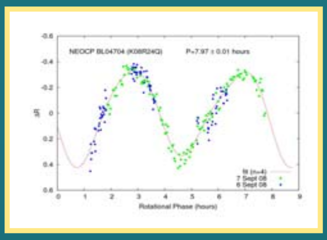

Figure 3. Lightcurve data obtained for asteroid 2008 RQ_{24} is shown. Its visual magnitude was V~19.5 when observed, and it was moving at ~1.25"/minute. The derived rotation rate (P_{rot}) is 7.97 hours.

B-V:	0.76 ± 0.08
V-R:	0.51 ± 0.05
V-I:	0.93 ± 0.05
H_R:	20.7
H_V:	20.2
P_{rot}:	7.97 ± 0.01 hr

Table 1. Detailed characterization data on asteroid 2008 RQ24: colors B-V, V-R, and V-I, as well as absolute magnitudes H (in R and V) are shown. The color data imply that this asteroid is a higher albedo S-type, with a diameter of about 270 m.

Figure 4a, b shows lightcurves for near-Earth asteroids 2008 TY_{09} and 2009 BF_2. NEA 2008 TY_{09}, which has a diameter of 25 - 75 meters, had a visual magnitude of V~19.5 when observed and was moving at 10.42"/min. Its rotation period was ~11.5 minutes. 2009 BF_2, with a diameter of 20-50m, displayed a period of only 57 seconds. Both asteroids were imaged with 10 second integrations while tracking on the asteroid. These objects follow the general trend that asteroids with diameters less than 200 meters have rotation periods which indicate that they possess material strength. Figure 5 shows 2008 UP_{100} with a much slower rotation period and an amplitude that implies a non-negligible strength.

This research is funded through NASA's NEOO program.

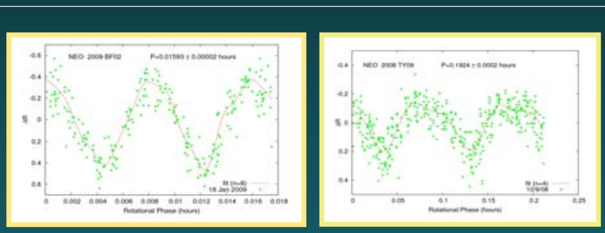

Figure 4 a, b. The lightcurve for NEA 2009 BF_2 is shown on the left. It's 57 second rotational period is the second fastest observed to date (see the Asteroid Lightcurve Database maintained by Warner et al. 2008) and is indicative of a monolithic body. On the right is the lightcurve for NEA 2008 TY_{09}, which has a period of 11.5 min.

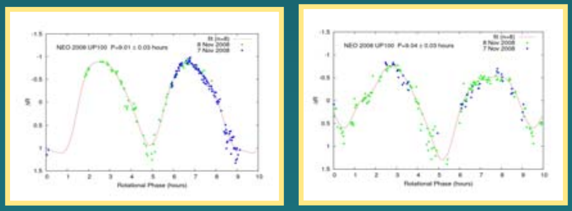

Figure 5. NEO 2008 UP_{100} (H=23.9; diameter ~50 – 100 m) during 4 nights in Nov. 2008. The large magnitude variation was initially noticed while performing follow-up astrometry. Solar phase angle was 29 - 39° for Nov. 1-4 and 21 - 23° degrees for Nov. 7-8. A large amplitude of ~2 magnitudes is still evident at the lower phase angle. Recent modeling of rubble pile structures by Harris et al. (2009) indicates that this amplitude borders on or exceeds the elongation limit of a slowly rotating strengthless object, implying that this asteroid may have a non-negligible material strength.

Using the data collated by Warner, Harris, and Pravec from the Asteroid Lightcurve Database (2009), as well as that collected by Birtwhistle (2009), we plot rotation periods for asteroids in the near-Earth zone in Fig. 6. The 17 new asteroids (one asteroid is larger than the 200 meter diameter) for which we have acquired enough lightcurve data to definitively solve for a rotation rate are also shown in Fig. 6. Three of the 16 small asteroids (H~22 and greater) that we studied show spin rate periods longer than the expected 2.2 hours (or shorter) rotational barrier domain.

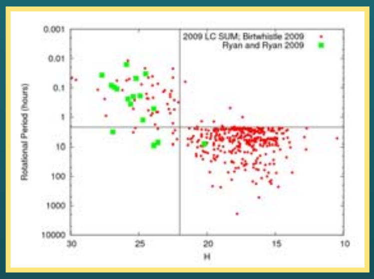

Figure 6. A plot of rotation period *vs.* absolute magnitude (H) where the filled (red) circles are all NEAs from (Warner et al. 2009) and Birtwhistle (2009), and the filled (green) squares are the new data acquired via this current work. The horizontal line corresponds to a rotation period of P~2.2 hours, which is the hypothesized rubble pile rotational barrier. The vertical line denotes absolute magnitude H=22.

Summary

Rotation rates derived from the lightcurves of newly discovered NEOs indicate that the asteroids in this small size regime exhibit both slow (hours) and fast (minutes) rotation periods.

References:

Birtwhistle, P. (2009), *Minor Planet Bulletin* 36, 186-187 (2009); Harris, et al. (2009), *Icarus* 199, 310-318;; Warner, et al. (2009), http://www.minorplanetobserver.com/astlc/LightcurveParameters.htm