Threat Assessment of Small Near-Earth Objects

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ABSTRACT

Researchers at the Magdalena Ridge Observatory's (MRO) 2.4-meter telescope facility are in their third year of a program to derive physical characterization information on some of the smallest (less than 200 meters in diameter) objects in the Near-Earth Object (NEO) population. Tiny comets and asteroids are being discovered by survey programs on a routine basis, so targets available for study have been abundant. Our primary objective is to derive rotation rates for these objects, and to place the results in context with previous data to enhance our understanding of asteroid impact physics and better address the threat from NEOs having Earth-crossing orbits. Rotation rate can be used to infer internal structure, which is a physical property important to assessing the energy needed for object disruption or other forms of hazard mitigation. Since the existing database of rotational data derived from lightcurves of objects in this small size regime is sparse, collection of additional observational data is beneficial. Acquiring more knowledge about the physical nature of NEOs not only contributes to general scientific pursuits, but is important to planetary defense.

1. INTRODUCTION

Asteroids typically are irregularly shaped, so that as they rotate, their effective cross sectional area changes as viewed from the Earth. That means that the light reflected back to an observer also changes, and that light variation over time is called a "lightcurve". By observing the light curve as the asteroid rotates, its rotational period (or how fast it's spinning on its axis) can be determined. A full lightcurve will typically have 2 peaks and 2 troughs, and the rotation period is simply the elapsed time for this to occur. The peaks and troughs in the light occur because as the asteroid rotates, usually about its shortest axis, an observer sees reflected sunlight from the surface defined by its longest axis (twice) and its other short axis (twice). The spin rate of an object can imply important information about an asteroid's internal composition (via deduction of strength boundary limits) and degree of fracture, and thereby its collisional history. Typical rotational periods for asteroids in the main asteroid belt between Mars and Jupiter are 5 - 15 hours, but near-Earth objects have been observed to rotate with spin rates on the order of minutes or seconds.

To best assess and plan for mitigation of a potential asteroid impact with the Earth, a better understanding of the physical parameters (impact strength, size, spin rate, shape) that characterize the near-Earth population of objects is required. As a result of our characterization study, we have determined rotation rates for asteroids from 150 meters to as small as 8 meters in diameter. Objects of this size were traditionally not considered to be a significant threat. However, a recent impact in Carancas, Peru (see Fig. 1) which occurred on September 15, 2007, was likely produced by a 3 meter diameter chondritic meteorite (i.e., asteroid fragment). The impactor caused significant ground damage resulting in a crater approximately 13.5 meters in diameter. Further, researchers have been modeling low-altitude airbursts of hypervelocity impacts from NEOs that are less than 100 meters in diameter, finding an increased damage potential on Earth's surface relative to earlier models that did not factor in the downward momentum of the exploding bolide. Additional computer simulations have analyzed the effects of ocean impacts of NEOs less than 500 meters in diameter, and concluded that the overriding danger is within 100 km of the impact site, and results from the formation of non-linear breaking waves that have the potential to ravage coastal areas. Since these recent studies have implied that objects in this size range can be dangerous, a better understanding of their structure and physical characteristics is required.

Fig. 1. Impact crater (~40 feet in diameter) formed by ~3 meter object impacting in Carancas, Peru in 2007. (From Tancredi, et al. 2008, ACM proceedings.)

2. NEAR-EARTH OBJECT THREAT AND CHARACTERIZATION STUDIES

The lower limit of NEO sizes that could cause significant damage is not well known and may vary by object type. Motivated by the recent work that assigns a higher hazard level to small potential Earth-impactors, we present new rotational data derived from lightcurves of small NEOs, and suggest connections to internal structure (a parameter important to threat mitigation strategies that require an estimate of object strength). Rotation rates collected thus far have indicated that these bodies can exhibit a range of spin rates, and can also be tumbling, suggesting a recent collisional event.

Very small asteroids (< 200 meters) are rotating so fast (some with rotation periods on the order of seconds) that they would not be able to stay together in a rubble pile via self gravity, suggesting that they must be monolithic or coherent bodies if they are rotating faster than 2.2 hours [1]. Holsapple [2] suggests refinements to the 2.2 hour rotation monolithic/rubble pile limit, such that rubble piles may be able to spin that fast or faster without breaking apart if cohesive forces are considered. Not only spin rate, but also amplitude (i.e., the extent of the peak-to-peak variations) can be an indicator of strength. Even NEOs that are rotating more slowly (greater than a 5 hour spin period) can display large amplitude variations that imply very elongated ellipsoidal shapes. Therefore, these bodies may not be strengthless rubble piles, but coherent monoliths. The objective of inferring bulk material strength from rotation dynamics requires a robust data set before definitive conclusions can be made, however.

In the following we discuss a sample of small NEA lightcurves recently obtained (2008 - 2010) from which we have derived rotation rates. The most notable recent discovery from our observational program was the acquisition of a lightcurve for a small, faint NEO that resulted in a period determination for the fastest known natural rotator in the Solar System. Fig. 2 shows the lightcurve for 2010 JL_{88} with a spin rate of 24.5 sec.

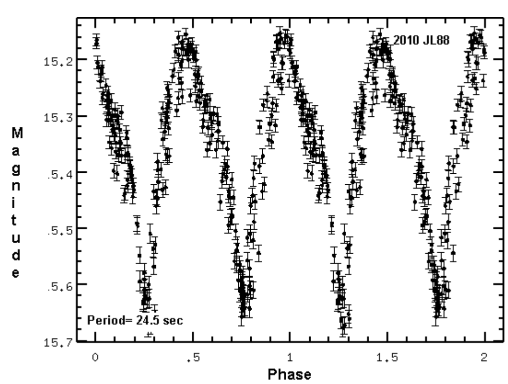

Fig 2. Lightcurve of NEO 2010 JL88 (estimated to be 18 meters in diameter) taken on May 17, 2010, having a rotation period of 24.5 seconds, the fastest natural rotator discovered to date.

Lightcurve data collected on one of our target asteroids revealed it to be tumbling, possibly as a result of a recent collision. The rotation behavior of NEO 2009 WV_{25} is shown in Fig. 3. The fundamental rotation rate of this asteroid is still under analysis.

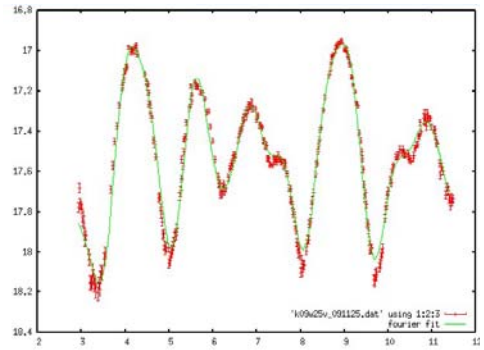

Fig. 3. Lightcurve of radar target 2009 WV_{25} exhibiting non-principle axis rotation (tumbling). The data were taken in November, 2009, and the asteroid's diameter is estimated to be 68 meters.

To give these results context, Fig. 4 represents a summary of rotational data from the compilations by Warner et al. [3] and Birtwistle [4], with the results of our program (through May 2010) superimposed as green squares [5]. The data we have collected thus far (24 new asteroids) adds significantly to the existing database in the small size regime, and as we continue to increase the number of objects under study, a clear pattern of spin rate as a function of asteroid size should emerge.

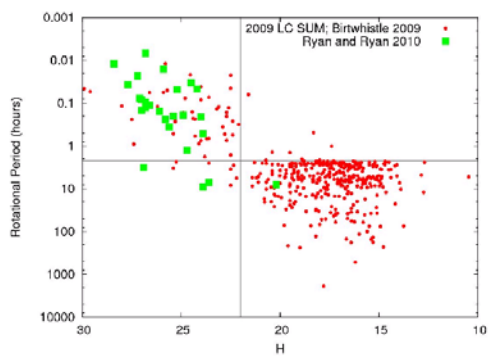

Fig. 4. A plot of rotation period *vs.* absolute magnitude (H) where the filled (red) circles are all NEOs from Warner [3] and Birtwistle [4], and the filled (green) squares are the new data acquired via this current work. The horizontal line corresponds to a rotation period of P~2.2 hours, which is the hypothesized rubble pile rotational barrier. The vertical line denotes absolute magnitude H=22.

3. CONCLUSIONS

Motivated by findings that smaller objects can pose a significant threat to the Earth upon impact, we have acquired new rotational data derived from lightcurves of small NEOs. Rotation rates have indicated that these bodies exhibit a range of spin rates, and can also be tumbling, suggesting a recent collisional event. Improved knowledge of the physical nature of NEOs not only contributes to general scientific pursuits, but is important to planetary defense.

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4. REFERENCES

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